Meteor science

Four Meteor Showers from the SonotaCo Network Japan

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The SonotaCo Network Japan meteor orbit database is examined using D-criterion methods to both cross match it against comet orbits and itself revealing four possible showers.

Received 2011 July 16

1 Introduction

The existence of the SonotaCo Network Simultaneously Observed Meteor Data Sets[a] was first noted in Vereš and Tóth (2010). The dataset was obtained and orbital elements were analysed according to the Jopek (1993) modification of Southworth & Hawkins' (1963) D-criterion formulation.

The entirety of the orbital elements was tested against a database of comet orbits[b] (for details see the example of Greaves (2000), when a similar analysis was conducted using the meteor orbits database of the Dutch Meteor Society for the period 1991 to 1999). A small subset was tested against themselves. In order to reduce confusion generated by the major meteor showers and also to reduce computational overhead, one to two week time periods centered upon the maxima of showers such as the Geminids, Perseids, Leonids and others were removed prior to the testing of the SonotaCo orbits against themselves. This substantially reduced the number of orbits to be checked against themselves and the number of radiants to be plotted. The number of orbits to be tested was greatly reduced from over 65000 to around 5000.

Instead of the typical D-criterion threshold of 0.15, a threshold of 0.10 was used for testing against the known comet orbits as a seed and 0.06 was used for the mutual meteor cross matching to ensure that only the best candidates were retained. Also only orbits identified as sporadic in the SonotaCo catalogues (SonotaCo, 2009) were used in the tested subset.

For the comets, each comet orbit was used as a seed against which the meteor orbits could be tested one by one. For the self-test of the meteor orbits against themselves, every orbit is tested against every other orbit. Multiple pairings can occur, such that if orbit a matched to orbit b and orbit b is matched to orbit c, not only will the match of orbits b to a and orbits c to b occur, but matches between orbits a to c and orbits c to a are also likely. However, in fact only orbits a, b and c (i.e., three individual results), were returned in the final data. This was achieved by importing the D-criterion matched orbital pairs into a relational database management package and indexing upon the local time log of each event, and then cross indexing this against a copy of itself such that only unique matches would be returned via the package's indexing function. This could then be linked back to all the data of interest for each resulting object and stored in a full database imported version of the SonotaCo dataset with the local time parameter as indices.

Objects had their observed Right Ascension and Declination, Solar Longitude, Geocentric Velocity, Perihelion Distance, Eccentricity, Inclination, Argument of Perihelion, Ascending Node, Magnitude and "local-time" logged. Some of these details were used to plot orbit diagrams whilst others were used for radiant chart plots. In the analysis each object's local time as per the SonotaCo catalogue was utilised as the object identifier.

It is reiterated that relatively more stringent criteria than usual were utilised in the analysis in order to reduce false alarms and coincidences as much as possible while still leaving a reasonable chance of not missing a weak shower. Thus it is possible that the objects listed here represent a subset of the total number of objects for each shower that can be found in the full SonotaCo database.

An attempt at assessing Zenithal Hourly Rates was initially made but abandoned since using the canonical figure of $r = 2.5$ when dealing with an unknown population index gave very large numbers. This was likely because the limiting magnitude for SonotaCo is around 2[c] with many meteors being zero magnitude and brighter. The number of bright meteors for known weak showers as well as candidate showers within the database was something of a concern but there were no means with which to assess the data for magnitude calibration accuracy.

D-criterion analyses upon orbital elements enabled an objective assessment of meteor relationships. Plotting of orbits also added an extra dimension to the space and time plotting of radiant positions upon the sky, allowing comparative assessments.

2 Results

Four showers were sufficiently well defined to likely be real. These do not appear in the full list of the International Astronomical Union AU Meteor Data Centre[d] (IAU MDC) and are summarised below. Of the many

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IMO bibcode WGN-401-greaves-newshowers
NASA-ADS bibcode 2012JIMO...40...16G

[a]http://sonotaco.jp/doc/SNM/

[b]Guide 8.0 CDROM (www.projectpluto.com) from a public data file of Jost Jahn

[c]http://sonotaco.com/soft/UO2/UO21Manual_EN.pdf

[d]http://www.astro.amu.edu.pl/~jopek/MDC2007/Roje/roje_lista.php?corobic_roje=0&sort_roje=0

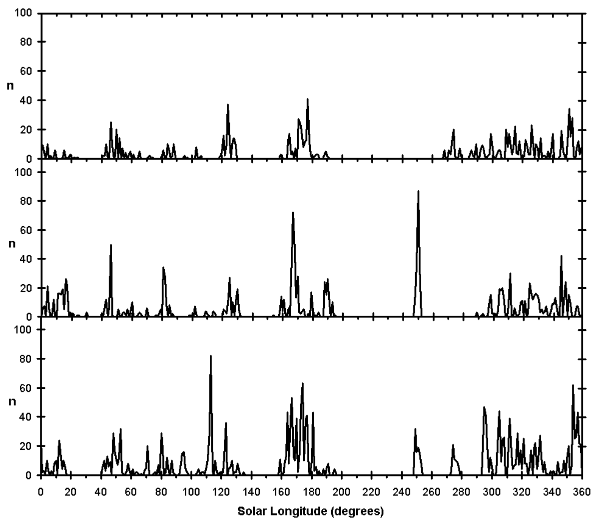

Figure 1 – For each of the years 2007, 2008, and 2009 the count per one degree bin of Solar Longitude is given with respect to the dataset of near 5000 objects analysed. In this way some idea can be gained as to whether showers absent some years yet not others were simply missed due to lack of observations.

successful cross matches against comet orbits only one appeared to be unknown previously as well as supported by a number of meteor orbits. Two further showers were of sufficient number to appear real and possessed candidates spanning more than one year. One final shower at first sight seemed real but as the number of objects was lower and only one of the three years (2007 to 2009) worth of data gave meteors it was a somewhat more tentative candidate shower.

There is also the possibility that some of the showers were only observed during a single year simply because there were no observations taken on that date for other years, whether due to no observing being done, clouds or equipment problems. Accordingly Figure 1 presents a plot for each of the individual years derived by doing a count per one degree bin of Solar Longitude. The actual count value is retained despite not being necessarily meaningful. The attempt is to demonstrate the times during each year that actually had some data and to allow some assessment of whether any of the candidate showers noted could merely have been absent just because no observations were being taken at those times.

One common feature of all four showers was their retrograde orbits, reflected in their geocentric velocities being around the 60 to 70 km/s region. Most orbits for the following showers also had aphelia extending into the outer Solar System.

The details for each particular shower are given below, complete with shower names, acronyms and number as provided by the International Astronomical Union Meteor Data Centre's Nomenclature Committee (Jenniskens, 2008). Orbit diagrams are given for each shower. The associated meteor radiants for the showers are also charted showing the local constellations, and in some cases the radiant position of any nearby IAU list meteor shower is also plotted, labelled with its IAU identity code and Solar Longitude value.

For each shower a table giving their "localtime" identifier listing the Japanese Local Time of the meteor in YYYYMMDD_hhmmss format, observed radiant Right Ascension (α) and Declination (δ) in degrees, Solar Longitude ($\lambda_{\odot}$) in degrees, Geocentric Velocity (V_g) in kilometres per second and magnitude (mag.) from SonotaCo is presented, with the D-criterion value (D_0) of the meteor shower relative to C/1846 J1 also included for the first noted shower (Table 2). Also given is a table showing their "localtime" identifier and orbital elements in the order of q (perihelion), e (eccentricity), i (inclination), ω (argument of perihelion) and Ω (ascending node) for each shower.

The mean Right Ascension, Declination and Solar Longitude are given for each shower, and the mean of each orbital element for the orbits (Tables 1 to 8). In the case of the σ-Virginids the value of D_0 given is that for the mean orbit of the meteors in comparison to that of the comet, and not a mean of the other D_0 values.

3 December σ-Virginids and C/1846 J1

The only comet orbit found to have a strong match to those of the meteor orbits while also being an unpublished association and unknown shower as far as the IAU MDC was concerned was C/1846 J1 (Brorsen) (1846 VII old style). SonotaCo also classified all the meteor orbits as being sporadic meteors. All three years of 2007 to 2009 provided several meteors in roughly equal amounts.

Their radiant generally drifts from the region of σ Virginis to τ Virginis and the main concentration of meteors appears to occur between December 20 to 22 between Solar Longitudes 267 to nearly 270 degrees (Figure 3 and Tables 1–2). The IAU MDC number is 428 and the code is DSV.

4 α-Coronae Borealids

Appearing in late January examples from all three years were found for this shower, however the predominant year by far was 2009. Examination of Figure 1 suggests that it was possible that the time period was under-observed in the previous years. A higher rate in 2009 could not be ruled out especially as roughly a quarter of the total meteors (four) appeared within two hours of each other on the 2009 January 29, with each being around zero magnitude or brighter (Table 3). The IAU MDC number is 429 and the IAU MDC code is ACB.

5 September π-Orionids

Appearing around the time of the Northern Autumnal Equinox this shower is reasonably well represented in all three years of data, despite Figure 1 suggesting that 2009 was the better observed year of the three around the time of Solar Longitude 177 to 178 degrees.

The radiants lie just east of the arc of π^1 to π^4 Orionis (Figure 7), which form part of the asterism of Orion's Bow. For simplicity the shower is name the π-Orionids. The IAU MDC number and code are 430 and

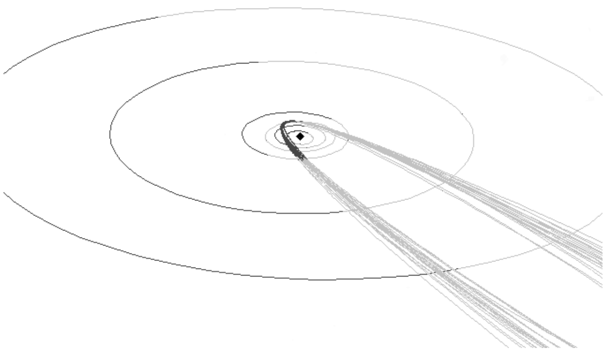

Figure 2 – Orbit Plots for the SonotaCo meteor orbits having D-criterion threshold of less than 0.10 relative to the orbit of C/1846 J1. The orbits of the planets out to that of Saturn are also shown.

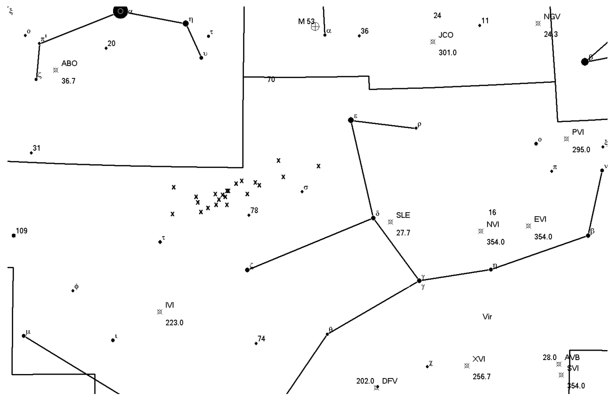

Figure 3 – Radiant Plots for the SonotaCo meteor orbits having D-criterion threshold of less than 0.10 relative to the orbit of C/1846 J1. Plots for radiants from the IAU meteor database are also given labelled with their identifying acronyms. Numerical labels for all radiants are for their Solar Longitude in degrees.

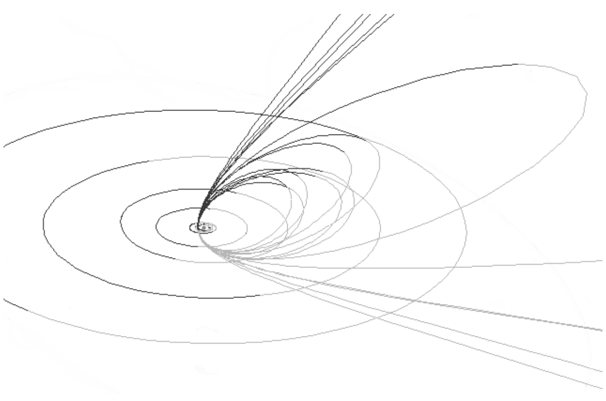

Figure 4 – Orbit Plots from SonotaCo for the α-Coronae Borealid shower. Planetary orbits out to that of Neptune are also shown.

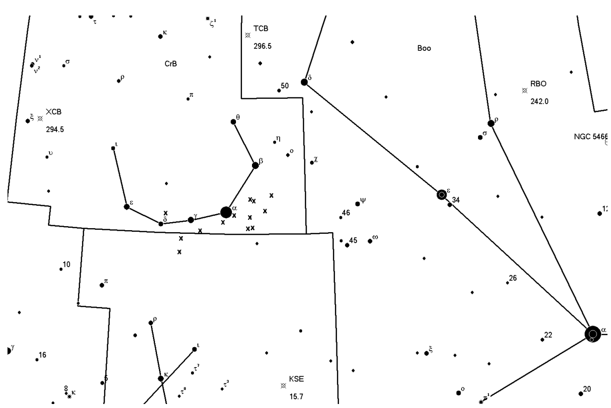

Figure 5 – Radiant Plots from SonotaCo for the α-Coronae Borealid shower.

Table 1 – SonotaCo Radiant Particulars for the December σ-Virginids.

LOCALTIME	α	δ	$\lambda_\odot$	V_g (km/s)	mag.
20071215_043648	200°.8668	+6°.6662	262°.322	65	+0.45
20071216_032750	201°.2448	+7°.9325	263°.291	66	+0.05
20071218_042126	203°.0490	+6°.2146	265°.364	66	−3.08
20071218_045352	202°.7508	+6°.0379	265°.387	67	−2.15
20071220_044915	204°.5392	+6°.1428	267°.419	67	−0.73
20071220_055029	205°.2622	+4°.4902	267°.462	66	−0.45
20071221_031950	205°.3700	+5°.1169	268°.374	67	−1.40
20071225_055049	209°.4751	+3°.7297	272°.553	67	−1.66
20081218_032735	203°.6642	+5°.3570	266°.076	67	−2.17
20081219_050334	205°.2103	+5°.5762	267°.161	66	+1.60
20081221_030959	206°.1672	+5°.3158	269°.117	67	−0.10
20081221_040655	206°.0988	+4°.5003	269°.158	67	−0.10
20081221_060310	207°.2677	+3°.9291	269°.240	67	+2.85
20091212_053613	198°.1051	+7°.4794	259°.804	66	−1.45
20091219_031553	204°.1017	+6°.3322	266°.828	67	−0.53
20091220_051934	205°.1753	+5°.5644	267°.933	66	−0.18
20091220_054225	205°.5557	+5°.2424	267°.949	66	+0.11
20091220_055507	205°.8649	+4°.9221	267°.958	67	+0.39
20091222_022025	209°.3800	+5°.8432	269°.843	65	+0.73
20091222_031839	206°.7428	+4°.2686	269°.885	66	+1.40
20091222_053907	207°.6411	+5°.1027	269°.984	66	+0.23
20091222_060659	207°.4771	+4°.6865	270°.004	67	+0.70
Mean Position	205°.0459	+5°.4750	267°.414	66	

Table 2 – SonotaCo Orbital Elements for the December σ-Virginids.

LOCALTIME	q (AU)	e	i	ω	Ω	D_0
C/1846 J1	0.633760	0.990414	150°.6809	99°.7253	263°.9889	—
20071215_043648	0.569595	0.925616	149°.8195	97°.0931	262°.3219	0.089
20071216_032750	0.615408	0.959967	147°.8727	103°.5874	263°.2906	0.097
20071218_042126	0.603168	0.955856	149°.6777	102°.0085	265°.3638	0.051
20071218_045352	0.616221	0.975933	150°.5729	104°.0784	265°.3867	0.059
20071220_044915	0.631587	0.984977	149°.3022	106°.1687	267°.4191	0.071
20071220_055029	0.587831	0.964208	151°.1529	100°.3720	267°.4624	0.069
20071221_031950	0.614889	0.985264	150°.1863	104°.1505	268°.3738	0.043
20071225_055049	0.616414	0.979218	150°.0181	104°.2168	272°.5531	0.092
20081218_032735	0.591726	0.961941	150°.6023	100°.7763	266°.0755	0.050
20081219_050334	0.598744	0.975734	149°.1823	101°.9685	267°.1611	0.051
20081221_030959	0.620437	0.992027	149°.2860	104°.9754	269°.1171	0.054
20081221_040655	0.617605	1.000196	150°.9822	104°.8145	269°.1573	0.048
20081221_060310	0.590461	1.000594	150°.7995	101°.5765	269°.2395	0.075
20091212_053613	0.588135	0.937879	150°.9218	99°.6682	259°.8037	0.095
20091219_031553	0.624445	0.989298	149°.0031	105°.3824	266°.8276	0.068
20091220_051934	0.617171	0.964782	149°.6200	103°.9418	267°.9334	0.050
20091220_054225	0.603088	0.959101	149°.7052	102°.0878	267°.9496	0.058
20091220_055507	0.600122	0.985918	150°.0675	102°.3753	267°.9585	0.047
20091222_022025	0.566372	0.979757	144°.4203	98°.2028	269°.8436	0.079
20091222_031839	0.603187	0.963410	150°.5586	102°.2162	269°.8848	0.077
20091222_053907	0.611157	0.974057	148°.5237	103°.4395	269°.9841	0.074
20091222_060659	0.621133	1.012775	149°.7951	105°.5119	270°.0039	0.060
Mean Orbit	0.604950	0.974023	149°.6395	102°.6642	267°.4141	0.045

Table 3 – SonotaCo Radiant Particulars for the α-Coronae Borealids.

LOCALTIME	α	δ	$\lambda_\odot$	V_g (km/s)	mag.
20070202_032122	236°.3113	+24°.6946	312°.414	58	−0.60
20080128_053145	232°.2706	+27°.3945	307°.169	57	−0.70
20080201_042137	236°.2217	+25°.3734	311°.183	58	−0.22
20090128_023106	231°.0367	+27°.5904	307°.796	58	+2.50
20090128_032120	231°.4365	+26°.7880	307°.831	58	+2.25
20090128_041708	232°.0668	+27°.3007	307°.871	60	+0.27
20090129_030621	232°.1539	+25°.9364	308°.837	60	−2.00
20090129_033629	232°.4114	+25°.8759	308°.858	59	−0.15
20090129_043731	232°.2919	+26°.4847	308°.901	59	−1.85
20090129_045857	233°.8488	+26°.2206	308°.917	60	+0.10
20090129_054619	233°.2042	+26°.5809	308°.950	57	+1.40
20090201_031653	237°.1444	+26°.6725	311°.892	57	+1.60
20090201_053410	235°.1486	+25°.7880	311°.989	59	+0.95
20090202_022615	231°.5717	+30°.3649	312°.871	57	+0.45
20090202_022742	232°.1111	+32°.0430	312°.872	57	+0.90
Mean Position	233°.2820	+27°.0072	309°.890	58	

Table 4 – SonotaCo Orbital Elements for the α-Coronae Borealids.

LOCALTIME	q (AU)	e	i	ω	Ω
20070202_032122	0.978857	0.885206	106°.5682	170°.3874	312°.4142
20080128_053145	0.981480	0.900618	104°.6787	173°.2873	307°.1693
20080201_042137	0.977128	0.924561	105°.8402	169°.3990	311°.1830
20090128_023106	0.983853	0.928833	105°.0627	176°.3786	307°.7958
20090128_032120	0.983096	0.939804	106°.2043	175°.1497	307°.8313
20090128_041708	0.983023	1.096985	106°.4249	175°.2282	307°.8707
20090129_030621	0.982994	1.062162	108°.1207	175°.0002	308°.8371
20090129_033629	0.982492	0.971101	107°.3783	174°.2578	308°.8584
20090129_043731	0.983668	1.022560	107°.0764	175°.9180	308°.9015
20090129_045857	0.980414	1.083236	107°.0651	172°.3826	308°.9166
20090129_054619	0.982272	0.879612	105°.3129	173°.8347	308°.9500
20090201_031653	0.977163	0.917551	103°.1936	169°.3342	311°.8919
20090201_053410	0.983505	1.057291	107°.1335	175°.1460	311°.9887
20090202_022615	0.981311	1.067447	101°.7078	187°.3032	312°.8713
20090202_022742	0.981323	1.105569	99°.2949	187°.2318	312°.8724
Mean Orbit	0.981505	0.989502	105°.4041	175°.3493	309°.8901

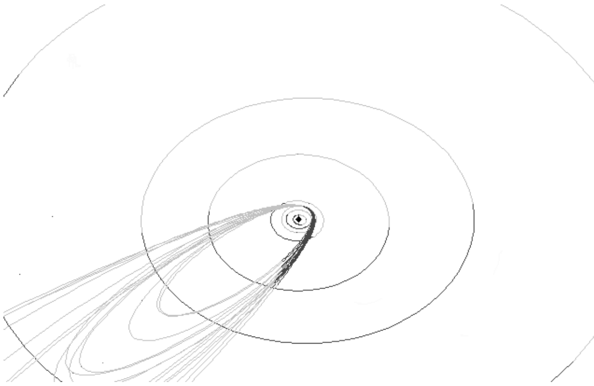

Figure 6 – Orbit Plots from SonotaCo for the September π-Orionid shower. Planetary orbits out to that of Uranus are also shown.

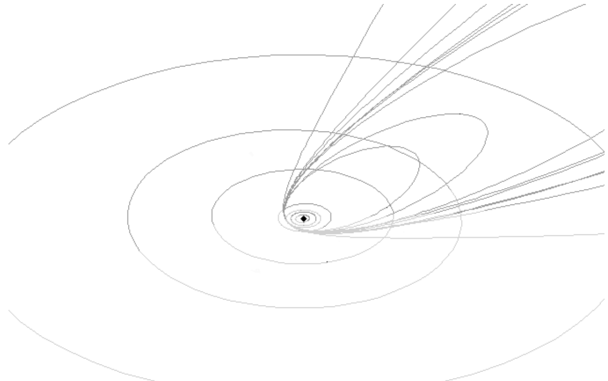

Figure 8 – Orbit Plots from SonotaCo for the June ι-Pegasid shower. Planetary orbits out to that of Uranus are also shown.

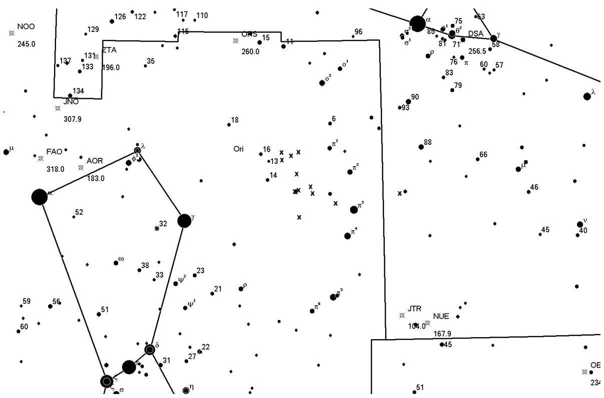

Figure 7 – Radiant Plots from SonotaCo for the September π-Orionid shower.

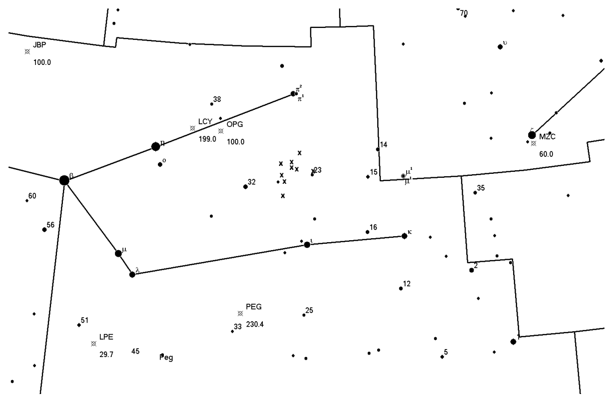

Figure 9 – Radiant Plots from SonotaCo for the June ι-Pegasid shower. Nearby IAU shower radiants and their Solar Longitudes are also shown.

POR respectively. Given its location this is a shower for both Hemispheres,and an Equinoctial shower too, providing all observers a similar night length.

6 June ι-Pegasids

The radiants lie near 23 Pegasi and are concentrated around 2009 June 26, Solar Longitude 94.15 degrees, and barely lasted two hours in total at that time (Figure 9 and Tables 7–8). This shower was not present in the other years, nor much outside the roughly two hour window in 2009. However, Figure 1 shows that other meteors were detected around this time in 2007 and 2008 suggesting the lack of June ι-Pegasids is real. The IAU MDC number is 431 and the IAU MDC code given is JIP.

7 Conclusion

Multiple station meteor orbit observations allow the examination of Earth impacting objects and their orbital evolution from a ready supply of impinging objects, i.e. meteors. Despite the New Zealand AMOR radar experiment (Galligan & Baggaley, 2005) and the more recent Canadian CMOR orbit research (Brown et al., 2008), itself radar based, little recent work has occurred of this nature.

SonotaCo is a welcome exception, and in tandem with D-criterion tests can be seen to give tangible results. In this analysis four new candidate showers, one with a previous unsuspected parent comet to a meteor shower, were presented based on that data. Other papers (e.g. Vereš and Tóth, 2010) have revealed that not only traditional showers can be examined with the data, but also new things can be revealed about those showers.

The D-criterion test upon meteoroids enables a somewhat independent test of relationship between groups of meteoroids, and although not totally independent (orbits are derived from radiant positions and time of event for instance) can give information on meteors which were only classified as being sporadic by radiant clustering techniques.

Future work that can be applied to this data includes examining the data around the times of major showers for showers contemporaneous yet independent of them, often lost in the flood of the major shower meteors. Also possible is the confirmation of IAU Working List showers (for instance, in the same D-criterion analysis, evidence of meteors associated with the γ-Ursae Minorids, the x-Herculids, possibly the β-Hydrids (or an adjacent new shower), and with less certainty the ζ-Serpentids exist, although still pending a refined anal-

Table 5 – SonotaCo Radiant Particulars for the September π-Orionids.

LOCALTIME	α	δ	$\lambda_{\odot}$	V_g (km/s)	mag.
20070920_032502	75°.7316	+9°.7597	176°.335	68	−0.15
20070921_024714	75°.5239	+7°.9531	177°.286	68	−0.40
20070921_032641	73°.4067	+7°.3376	177°.313	68	+0.85
20070921_035613	75°.3657	+7°.9869	177°.333	67	+0.33
20080923_011605	75°.3477	+9°.9596	179°.902	68	−0.35
20080923_012837	75°.4521	+8°.8274	179°.911	69	+2.50
20080923_023333	75°.5113	+7°.9363	179°.955	67	+1.50
20090920_040504	74°.7151	+8°.1846	176°.841	67	−0.57
20090921_015837	74°.6176	+7°.8420	177°.732	67	+0.77
20090921_030907	76°.2522	+9°.9570	177°.780	68	+1.73
20090921_034052	75°.2998	+6°.5990	177°.805	67	+1.05
20090921_034534	70°.0620	+7°.8133	180°.599	70	+0.45
20090924_031013	76°.2157	+9°.5464	180°.717	68	−0.40
Mean Position	74°.8847	+8°.4387	178°.424	68	

Table 6 – SonotaCo Orbital Elements for the September π-Orionids.

LOCALTIME	q (AU)	e	i	ω	Ω
20070920_032502	0.895048	0.894718	156°.4287	39°.7200	356°.3349
20070921_024714	0.877189	0.936818	153°.1094	42°.4054	357°.2860
20070921_032641	0.841588	1.022539	152°.2060	47°.1868	357°.3128
20070921_035613	0.862318	0.862551	152°.8796	45°.9879	357°.3328
20080923_011605	0.827017	0.962532	156°.2198	50°.1052	359°.9014
20080923_012837	0.836615	1.023459	154°.3926	47°.8425	359°.9099
20080923_023333	0.823756	0.944396	152°.4241	50°.8610	359°.9541
20090920_040504	0.855242	0.835985	153°.1694	47°.6363	356°.8408
20090921_015837	0.847250	0.893393	152°.5250	48°.0225	357°.7325
20090921_030907	0.878830	0.901675	156°.5474	42°.5407	357°.7803
20090921_034052	0.867757	0.896079	157°.8022	44°.5522	357°.8019
20090921_034534	0.861128	0.938155	150°.4784	45°.1079	357°.8051
20090924_031013	0.827247	0.995914	155°.4485	49°.5835	0°.7165
Mean Orbit	0.853922	0.931401	154°.1255	46°.2732	358°.2084

Table 7 – SonotaCo Radiant Particulars for the June ι-Pegasids.

LOCALTIME	α	δ	$\lambda_{\odot}$	V_g (km/s)	mag.
20090626_015125	331°.2860	+29°.1779	94°.128	62	−0.70
20090626_023635	333°.2110	+28°.9767	94°.158	60	+0.55
20090626_024721	333°.1318	+27°.9278	94°.165	60	+0.60
20090626_025341	332°.3210	+29°.2853	94°.169	59	−1.45
20090626_031852	332°.6257	+29°.3893	94°.186	57	−0.85
20090626_034154	332°.1428	+30°.1221	94°.201	59	−1.50
20090626_234937	332°.6141	+29°.6467	95°.001	59	−2.17
20090627_005602	333°.2585	+29°.6033	95°.045	58	−0.44
20090627_010714	333°.0444	+28°.6408	95°.053	60	+1.20
Mean Position	332°.6261	+29°.1967	94°.456	59	

Table 8 – SonotaCo Orbital Elements for the June ι-Pegasids.

LOCALTIME	q (AU)	e	i	ω	Ω
20090626_015125	0.908359	1.241787	114°.1918	216°.1069	94°.1281
20090626_023635	0.909513	1.000905	114°.4773	217°.8550	94°.1580
20090626_024721	0.894732	0.978189	115°.4206	220°.7365	94°.1651
20090626_025341	0.899465	0.946350	112°.6234	220°.2552	94°.1693
20090626_031852	0.889735	0.807746	111°.3804	223°.8736	94°.1860
20090626_034154	0.909202	1.007885	111°.9390	217°.8442	94°.2013
20090626_234937	0.903890	0.980183	113°.0068	219°.0942	95°.0014
20090627_005602	0.899195	0.871049	112°.4808	221°.2342	95°.0454
20090627_010714	0.899458	1.058645	114°.9742	219°.1034	95°.0528
Mean Orbit	0.901505	0.988082	113°.3883	219°.5670	94°.4564

ysis). In such cases, the finding of a shower via D-criterion methods from SonotaCo that coincides with a shower found from an independent survey and one not necessarily using orbital data is strong evidence for the reality of such a shower, as it is repeatability via an independent team using independent equipment.

Whilst preparing this paper a new shower (the February η-Draconids) was found using the upcoming and developing CAMS system (Jenniskens & Gural, 2011), showing that something of an outburst in this area of observation may well be underway. Certainly confirmation of showers will be easier with a multil-ongitude approach, not just because weather may be better in one place than another, but also there is some suggestion from the SonotaCo data that some showers have very short lived and tight presences, making observer location even more crucial than usual in the detection of shower outbursts, or "mini-outbursts".

This does not necessarily mean the passing of more traditional or even other modern methods of meteor observing. Targets need confirming, and other methods may well be more suited to determination of shower display nature and Zenithal Hourly Rates and population indices, and more able to go down to fainter magnitudes. As well as also providing more showers spread around the year for visual observers to enjoy, because decent skies, suitable moon phase and predicted meteoric events rarely have the good grace to all three coincide.

There is also some circumstantial evidence, given the nature of these showers, and from data in SonotaCo for showers like the η-Lyrids (associated with comet IRAS-Araki-Alcock), that a number of discrete retrograde orbits of some inclination may mean a number of long lived Earth crossing showers where no necessarily recognisable parent may exist, and that they may be common. Examination of databases like SonotaCo and the future CAMS data will lead to an accumulation of information and nature of such showers should they be shown to be common. Such objects would have implications in terms of Earth impact studies, for if they exist in any number they will reveal that material on the orbits of retrograde comets are likely minimally affected by perturbations. As a result the material can take a very long time to be dispersed.

Taking this analysis as an example, the December σ-Virginids seem to repeat from year to year, as do the September π-Orionids, with the latter being a target for both Northern and Southern Hemispheres and presenting itself at a time of year when meteor showers are normally at a minimum.

All four showers had orbits inclined and retrograde which if not purely a selection effect (i.e., such showers may be the easiest to detect) is at least suggestive of some background of fossil orbit showers from comets long gone from our neighbourhood.

Acknowledgement

This paper would not have been possible if it was not for the SonotaCo Network Japan making their data available in the public domain, for which the author is greatly appreciative.

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Handling Editors: Wayne Hally and Javor Kac