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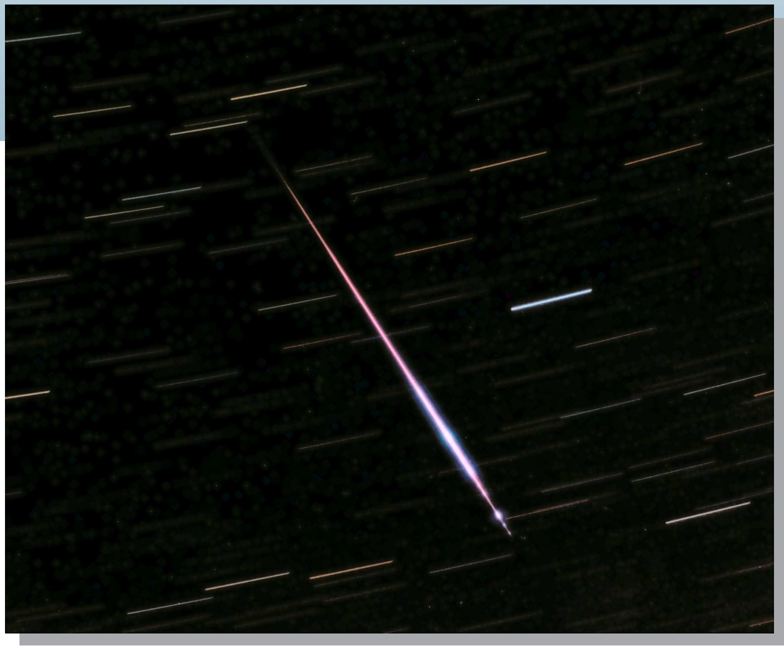

Video meteors
Radio meteors
Perseids

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WGN Vol. 37, No. 2, April 2009, pp. 51 – 76

Administrative

Ongoing Meteor Work

Preliminary results

Front cover photo

This Perseid was photographed on 1999 August 9 at $8^{\mathrm{h}}54^{\mathrm{m}}$ UT from Ottawa, Illinois, USA. The equipment used was an Olympus OM-1 camera with 28-mm f/2.8 Rokinon lens and Fuji 800 film. Photo by Ken Hodonsky.

Writing for WGN This Journal welcomes papers submitted for publication. All papers are reviewed for scientific content, and edited for English and style. Instructions for authors can be found in WGN **31:4**, 124–128, and at `http://www.imo.net/articles/writingforwgn.pdf` .

Cover design Rainer Arlt

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Editorial — waiting for the meteor Spring to come

Javor Kac

Since early January, the meteor activity has been low. With the exception of occasional fireballs, little was happening in the sky and only a handful of meteors could be seen. Also, the weather has been bad in most of Europe. However, as the Winter recedes, the temperatures become more comfortable and nights get shorter, the meteors activity also picks up again. The April Lyrids are the first sign of the meteor Spring and we are all looking forward to see what they will offer this year.

Not unlike the meteor rates, WGN article submissions have also slowed down during past couple of months. As every journal, WGN depends strongly on the material submitted. If you are doing some interesting meteor-related work, make shower analyses, or have new ideas, do share them with WGN readers. Similarly, if you know someone else who is doing such work, encourage him/her to write an article for WGN. I am confident all readers will appreciate it!

IMO bibcode WGN-372-editorial NASA-ADS bibcode 2009JIMO...37...51K

IMC 2009 in Poreč, Croatia

IMC Local Organizing Committee

Location and period

The 2009 International Meteor Conference (IMC) will take place from September 24 to 27 in the town of Poreč. Poreč borders the the Adriatic Sea and is situated on the Istrian Peninsula, about 70 km south of the Italian city of Trieste. It is a historic town almost 2000 years old, that still preserves some Roman remains. Currently, the population of Poreč is approximately 12 000 people.

During the period of the IMC, you may expect maximum temperatures in the order of 20–24° C and minimum temperatures in the order of 10–15° C.

The Local Organization is in the hands of the Višnjan Observatory.

Venue

The conference will take place in the *Pical Hotel*. For more information in English, please visit the web page `http://www.valamar.com/pical-hotel-porec`. There are double rooms and double rooms with an extra bed. Each room has toilet, shower, and TV.

How to get there

Fromt the conference location, the nearest major cities are Venice and Trieste (Italy), Pula, Rijeka and Zagreb (Croatia), and Ljubljana (Slovenia), all of which have airports. For those intending to fly, Trieste is perhaps the most convenient destination. There are regular bus services from Trieste to Poreč. Train travelers can choose Trieste, Rijeka, Zagreb, or Ljubljana, and take a bus from there. Poreč itself has no railroad connections. There are also ferries from Venice. Finally, Poreč can also be reached by car very easily.

Registration

To register, please visit `http://www.imo.net/imc2009` and fill out the registration form that you will find there by following the appropriate link. Alternatively, you can fill out the paper registration form printed on page 7 in *WGN* **37:1**. The registration fee amounts to 160 EUR. If you book no later than 2009 June 30, however, you get a 10 EUR deduction, and you pay only 150 EUR. In this amount is included:

- a parking place for those coming by car;
- general conference materials and a 2009 IMC T-shirt;
- accommodation for 3 nights;
- all meals (from dinner of Thursday, September 24, up to lunch on Sunday, September 27);
- refreshments during coffee breaks;

- the conference excursion and dinner;
- the proceedings.

Single rooms will require a supplement of 40 EUR.

We also encourage you to give a presentation of your results or the results of your group. Make sure your registration as well as the abstract of the talk(s) you intend to give reaches us before 2009 August 31. However, we strongly advise you not to wait that long and register at your earliest convenience.

As during previous years, the IMO will provide limited support to dedicated meteor workers who need it in order to be able to attend. We are fortunate that the local organizers have also dormitory facilities available near the Višnjan Observatory, which considerably increases our possibilities to provide support. For more details, please see page 8 in *WGN* **37:1**.

IMO bibcode WGN-372-imcann2 NASA-ADS bibcode 2009JIMO...37...51L

I had a dream

Marc Gyssens [1]

Some time ago, Paul Roggemans wrote a historic account of WGN (Roggemans, 2008). While this account covered the entire existence of the Journal, it was, quite naturally of course, focused on the period in which Paul was most intimately connected with it. Therefore, I felt that the picture would remain incomplete if I were not to add to it my own perspective on the fifteen-odd years that I have been WGN's Editor-in-Chief. Rather than giving a chronological account, which would inevitably repeat much of what Paul already wrote, I prefer to share with the readers in a somewhat more chaotic way some remeniscensens of that period: the ambitions that drove me, the hopes I sherished, the successes achieved, but also my frustrations, the problems and setbacks encountered, on how they were dealt with. In short, I want to share with you the story of a dream that came true.

Indeed, I once had a dream, back in the eighties. For a meteor worker, these were particularly exciting times. The scene was becoming increasingly international – an evolution in which the extensive network established by Paul Roggemans was pivotal. The East was – first slowly and then rapidly – opening up towards the West, and means of communication were dramatically improving on the verge of the personal computing and internet revolutions. The observing method we are essentially still using today was becoming the standard, allowing for the combination of data gathered throughout the globe with the aim of making comprehensive analyses.

I had a dream. In this exciting context, it had to be possible to establish an international amateur journal about meteors – no, not some Working Group News of a Belgian meteor group, however prominent its international content, but a truly international journal.

Driven by this dream, which I had often discussed with Paul, we agreed that I would take over the editing of WGN, starting with the February 1987 issue. Part of my dream was a completely new layout for the journal, to make it more comparable with professional journals. The new layout was an immediate success. Initially, a fancy IBM typewriter was used for this purpose, but, eventually, I switched to word processing using TEX– the program on which later LATEXwas built – first for titles and abstracts, and finally for the entire journal.

Producing WGN in those days should not be measured by today's standards. It was not just producing a PDF-file and sending this to a printing shop. Figures were often still drawn by hand, and sometimes had to be redrawn if the quality was too poor, and subsequently had to be reduced or enlarged to fit the article and glued in into the manuscript, which in this way became considerably thicker than the number of pages may have suggested.

Oh, yes, and before I forget. To save on costs, we had WGN printed by an amateur-printer who was sympathetic to our cause. The downside of this, however, is that we literally had to assemble and staple all the copies by hand. As has been the case for many IMO-related issues over time, I was lucky to be able to count on the support of many people of the Urania Public Observatory to do this tedious job. Of course, when a large group of people try to complete a tedious task as quickly as possible, mistakes may happen. Therefore, each copy was

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weighed on letter weighing scales before it was stapled. In this way, we could easily find out if a copy contained a particular page twice, or, worse, lacked a page.

When the old printing machine was so worn down that it was no longer possible to print WGN on it with reasonable quality, we used the services of a printing shop in Mechelen, which offered very good quality at incredibly low princes, as a consequence of which the assembling and stapling was now done for us.

But quite soon, another problem arose. While printing could nowhere be done even nearly as cheaply as in Belgium, mailing could nowhere be done even nearly as cheaply as in Germany. And with postage in Belgium continually on the rise, we had to resort to this awkward combination. Elaborate schemes were set up. Sometimes I went to Aachen or Dusseldorf as the first leg of a relay race which finally brought WGN to Berlin or Potsdam. Sometimes, I was lucky and Sirko Molau was able to pick up WGN at my university, which is not too far from Aachen, but many times, I had to meet Ina Rendtel or Rainer Arlt along the *Autobahn Raststätte* in Herford, more or less half way between Antwerp and Berlin. These meetings were often combined with lunch, giving us the opportunity to exchange the latest news and discuss some ongoing IMO affairs. If wish to emphasize here that nobody charged his or her fuel expenses for these travels, which were luckily not yet as high as they would be now.

'Form follows function' was a phrase made famous by the great Chicago-based architect, Louis Sullivan. The efforts invested in giving WGN a more professional look indeed paid off.

Meteor workers from another national 'working group', the *Arbeitskreis Meteore*, this time Potsdam-based, became very succesful in integrating observing methods with meteor physics, and communicated their results to the meteor community via WGN. Yes, I am talking about people like Jürgen Rainer and Rainer Arlt. Also, more and more professional meteor workers deamed WGN worthy to publish some of their articles, either for the purpose of rapid dissemination of results, or because they wanted to reach the amateur meteor community, or just as a service to this community.

Two years along the road of my editorship, the IMO was finally founded, and WGN became its journal. It was no longer a regional publication but a truly international journal in every sense of the word. My dream had come true...

This is not to say, of course, that there have been no obstacles during the nearly 15 years that I edited WGN.

Yes, there have been more delays than I would have liked, sometimes resulting in double issues to catch up. Yes, unfortunate mistakes both in the editing and production of WGN have occurred, but these have resulted in firm procedures to avoid them and that turned out to be very effective (think of the letter weighing scales!).

During my editorship, there were also significant shifts in the contents of WGN.

On the one hand, there was a growing number of articles at the level of professional journals on observing methods and tools, global analyses of meteor showers, and results from professional meteor work.

On the other hand, the number of reports with raw observational data declined. Generally spreaking, meteor workers lost their motivation to write such reports, because e-mail and mailing lists allowed for a much more efficient dissemination of such data, and because more and more observers started to realize that only global analyses could yield meaningful conclusions on meteor shower activity.

In a sense, this evolution has been a mixed blessing, because the professionalization of WGN alienated many meteor workers from the Journal, some of which lost interest all together. For a while, I introduced a refereed section in WGN to separate articles by professionals or professional amateurs from less prestigious but therefore not less important articles from local groups, but this measure turned out to be not very successful and was abandoned again. Striking a balance between publishing high-level contributions and keeping in touch with the amateur meteor worker at large has remained one of the greatest challenges up to the present day.

It should also be remembered that WGN used to be not only the Bimonthly Journal. For many years, we have also edited a Report Series, in which mainly the visual meteor data were summarized. (At one occasion, we also published an electrophonic fireball catalogue in this series.) With the Visual Meteor Data Base becoming increasingly accessible for analyzing purposes and with growing confidence in the robustness of electronic data, this publication was eventually discontinued.

There was also an increasing awareness that paper journals were no longer able to compete with electronic tools as far as rapid dissemination of first results was concerned. This led to the introduction of the 'IMO Rapid Communication Network' during the golden years for the Leonids, and which I have coordinated many times. This mode of operation has been used several times since, mainly by the Visual Commission Director.

When a job is done too long, however, the dream is dreamt, and drive makes way for routine. If other, mainly professional, commitments or health concerns put additional pressures on available time, delays tend to accumulate to a point where it is no longer acceptable. If there is one thing I regret, it is that I did not see this happen earlier and instead – out of a false sense of duty – forced myself to continue to the point where I had no more energy left at all for the job. I was a very lucky guy at that point to have such a good friend as Rainer who held a proverbial mirror in front of me and confronted me with the impossible situation in which I found myself. I felt actually relieved that he was willing to take over, assuming that it was temporarily, until my burn-out was over. Eventually, a much better solution came up: a new editor in the person of Chris Trayner, with new dreams.

He made new changes to the Journal, some of which I liked more than others, but that is besides the point: new ideas are needed and, therefore, old ideas sometimes have to be put aside, even if these are your own.

Even though I have not ended my editorship in beauty, I have an overall feeling of satisfaction about my achievement of almost 15 years. Of course, part of the credit for this goes to the authors and the readers without whom every effort would have been futile, and to the many people, such as Paul, Jürgen, Rainer, Ina, Sirko, André, Alastair, and Cis, to name just a few of them, who have helped me in this task.

I had a dream. Despite all my imperfections and shortcomings, that dream came true. It came true because I believed in it and therefore invested a lot of myself in it, and because of the efforts of many others whom I was fortunate to make part of this dream, and who became very good friends along the way. For having been able to achieve this, I feel very grateful and, yes, proud.

Of course, dreaming cannot be an excuse for not facing the problems we are confronted with and which threaten our very existence. These challenges need to be addressed, and, if necessary, we should not shy away from drastic solutions. But, even so, today's problems may just be the opportunity we need to make changes for the better, as, indeed, changes are not made when everything runs smoothly. When Chris's succession became an issue – and I invite him to share with us also his perspective on editing WGN! – we had to rethink entirely the way in which WGN was produced, leading to the current solution with Javor Kac as Editor-in-Chief. However, such solutions require creativity. And creativity requires vision. And vision requires idealism. And idealism requires..., yes, dreams!

And, precisely therefore, we should never, never stop dreaming!!!

References

Roggemans P. (2008). "WGN volume 36, 2008 or could it have been IMO Journal, volume 21, 2008?". *WGN*, **36**, 25–26.

Correction — IMO Video Meteor Network results, April 2008

Sirko Molau

We regret that Figure 2 of (Molau, 2008) was misprinted. The figure as printed was a copy of the top part of Figure 1. The correct Figure 2 is printed here.

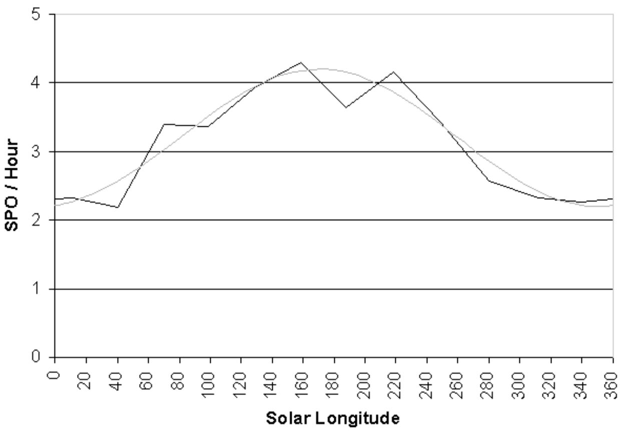

Figure 2 – Annual variation of the average number of sporadic meteors per hour (black jagged curve — original values; gray smooth curve — sine fit).

References

Molau S. (2008). "Results of the IMO Video Meteor Network — April 2008". *WGN*, **36:3**, 65–66.

IMO bibcode WGN-372-molau-correction NASA-ADS bibcode 2009JIMO...37...54M

Ongoing Meteor Work

A meteor shower catalog based on video observations in 2007–2008

SonotaCo [1]

A new meteor shower catalog was established from two years of continuous video observations based on almost 240,000 single-station observations by more than 100 video cameras operated at 25 stations in Japan. 39 208 meteor orbits were computed from them as qualified multi-station observations. From this sample, 38 meteor showers were obtained as the result of applying a uniformized method of clustering in the four-dimensional space of appearance in Solar longitude, radiant position, and geocentric velocity. The full set of showers in the new catalog covered 37% of all meteors. No other concentration was confirmed from the remaining 63%. The catalog is the first one based on long term, wide area, multi-station video observations, and shows the recent real activity for all major meteor showers that are optically observable from northern hemisphere. Eleven showers have been added to the list of meteor showers of the IAU Meteor Data Center (MDC).

Received 2009 January 29

1 Introduction

Automated multi-station video meteor observations present a very good detection ability, fair accuracy of orbit computation, and the capability for long term continuous observations necessary to creating a shower catalog.

UFOCapture (SonotaCo, 2005) is a motion detection software which allows video recording from a few seconds before the trigger. Written by SonotaCo in 2003, it has been used by scientific observers chronicling rare events such as meteors or TLEs (transient luminous events caused by lightning discharge). By the end of 2006, the meteor measurement software UFOAnalyzerV2 (SonotaCo, 2007), and the orbit computation software UFOOrbitV2 (SonotaCo, 2007) had been published, and the environment for multi-station meteor observation had been established. Results of the system have already been used for the detection of the τ-Ursae Majorids (Uehara, et al., 2006; now October Ursae Majorids) and the analysis of meteor altitudes (Molau & SonotaCo, 2008).

Having started as an online user forum for UFOCapture, SonotaCo Network has been working since 2004. The members of the network are amateur astronomers, staffs of public observatories, and a few professional researchers. The network itself had grown to more than 30 stations by 2007. These stations are observing the night sky above Japan every night, even when it is raining.

In this paper, we describe a set of meteor showers which are a result of two years of observations by the SonotaCo Network.

2 Outline of observation

For this study we used the SonotaCo Network's published observational results for the period 2007 January 1 to 2009 January 1 (731 nights). This data was compiled by 25 stations using more than 100 cameras. The totals are listed in Table 1, and the contributing stations are listed in Table 2. Figure 1 shows the distribution of the observed trajectories. Many stations use multiple cameras with standard lenses to inprove the accuracy and to cover larger area. The typical equipment is as follows:

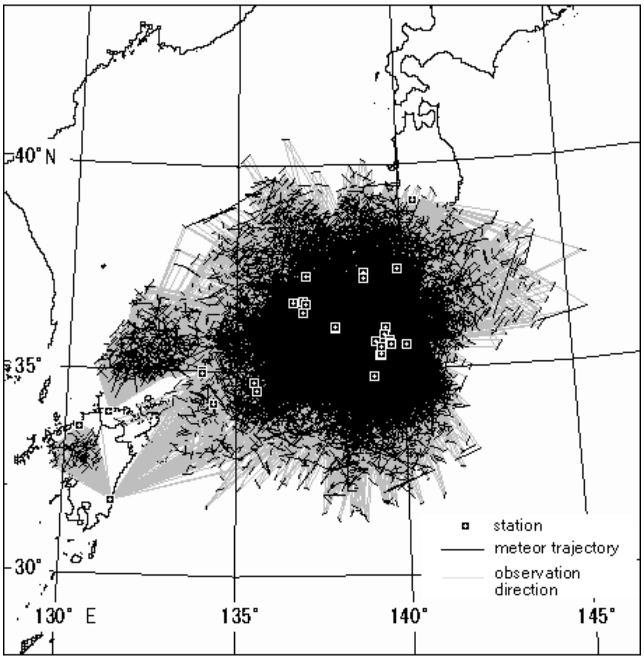

Figure 1 – Observation area and the stations.

- **Camera:** Hi-sensitivity monochrome CCD video camera, WATEC-100N or WATEC-902H2U.
- **Lens:** CS-mount lens, $f/0.8, f = 3.8 - 12$ mm (FOV: $90 - 30°$).
- **Video format:** 720×480 or 640×480 AVI digitized from analog NTSC signal (29.97fps, interlaced).
- **Software:** UFOCaptureV2, UFOAnalyzerV2, UFOOrbitV2.

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IMO bibcode WGN-372-sonotaco-catalog
NASA-ADS bibcode 2009JIMO...37...55S

Table 1 – Totals of the observations in 2007–2008.

Number of single-station meteors:	293 702
Number of qualified single-station meteors:	244 247
Number of single-station observations composing simultaneous observations:	114 026
Number of meteors qualified for multi-station observation:	39 208 (see Figure 2)
Average number of simultaneous observations per meteor:	2.93 camera/meteor
Average number of qualified meteors per night:	53.6 meteors/night
Number of nights with > 100 qualified meteors:	120 nights / 2 years
Number of nights with no meteor observed:	133 nights / 2 years
Top 6 nights which had most meteors (UT)	2007/12/14 (1051 meteors)
	2007/08/12 (845 meteors)
	2007/12/13 (796 meteors)
	2007/08/13 (700 meteors)
	2007/10/20 (655 meteors)
	2008/12/14 (603 meteors)

Table 2 – Number of single-station observations and the observers. (The location ID includes the prefecture name in Japan.)

Location ID	Observations	Observer
Akita1	3304	Izumi
Chiba2	18843	Ada
Fukuoka1	720	Shigetaka Shiraishi
Fukushima1	687	Hiromichi Horigane
Ishikawa1	4169	Hideaki Muroishi
Ishikawa2	13078	Hiroshi Yamakawa
Kanagawa1	19744	Hiroyuki Inoue
Miyazaki1	11457	Kouji Maeda
Okayama1	4749	Junichi Yokomichi
Okayama4	297	Junichi Yokomichi
Nagano1	56576	T. Masuzawa
Niigata1	138	PURU
Niigata2	19113	Toshio Kamimura
Osaka01	17063	Satoshi Uehara
Osaka03	12011	Masayoshi Ueda
Saitama1	37531	Takashi Sekiguchi
Saitama2	604	NOMOTO Satoko
Sizuoka3	99	SonotaCo
Tokyo1	34232	SonotaCo
Tokyo2	536	Koji Ito
Tokyo4	6338	Hiroshi Yamakawa
Tokyo5	20914	Junichi Nakai
Tokyo6	7281	Naoya Saito
Toyama1	4460	Toyama Astronomical Observatory
Toyama2	204	T. Komai
Others	52	–

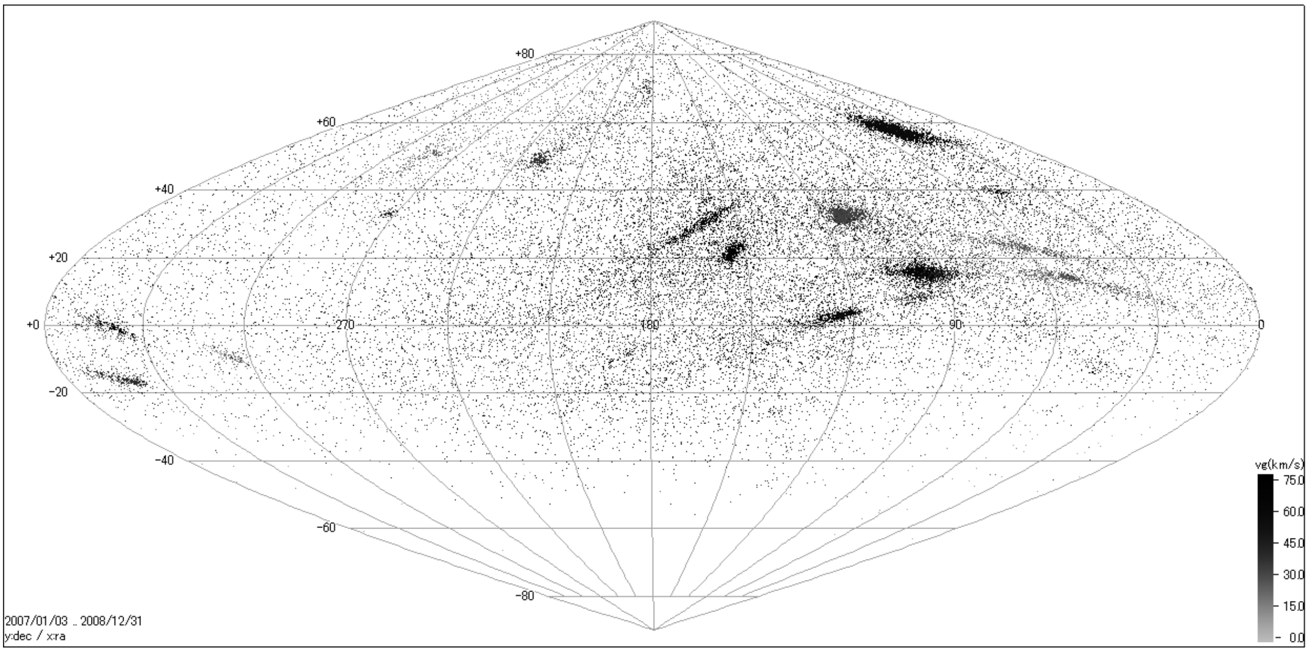

Figure 2 – Radiant of 39 208 meteors observed over two years, in a sinusoidal projection with x the right ascension α and y the declination δ (J2000.0). The original graph with the colour coded geocentric velocity is printed on the outer back cover.

3 Observation accuracy

The typical accuracy of single-station observation measurement is 0°.03 for the direction and 0.5 s for the absolute timing. This level of accuracy is achieved from UFOAnalyzerV2 plate adjustment using fixed stars and time synchronization obtained from Network Time Protocol on the Internet. The time resolution is 0.017 s, and it is very accurate for timing of NTSC video. This accuracy can be used as basic measurement accuracy for most of the meteors which show a narrow trajectory and no burst or explosion.

The accuracy of the radiant position and the velocity depend on the geometric conditions of simultaneous observations, such as distance from station to the meteor or the cross angle of the observed planes. Although UFOOrbitV2 improves the accuracy by calculating all (more than two) simultaneous observations by the least square method (unified radiant mode), the effectiveness of this method also depends on the number of simultaneous observations and their geometric situations. Therefore, the accuracy is different for each meteor. In this study, the lowest quality check of UFOOrbitV2 (mode Q1) was used for all data. It checks the intersection angle, duration time, height, velocity, and matching of the trajectory. It rejects results which have obvious large errors. As a statistical result, the radiant of compact showers, such as the Quadrantids, show a concentration within a radius of a 3° circle, and 20% deviation of the velocity if data from one night are used.

The commixture of non-meteoric objects such as air planes, satellites, or cosmic ray noise was negligible, because all single-station observations have been checked manually by the observer and UFOOrbitV2 checked it again. But because the post-process was fully automated, the data set possibly includes a small number of the following cases:

- Records that have big errors caused by an explosion, asymmetrical brightness, or background noise.
- Mis-combined data from multiple meteors which happened almost simultaneously, close to each other, and along a very similar vector.
- Mis-combined data caused by time adjustment failure.

4 Statistical bias of the data set

The analysis involves a number of different biases which are discussed here.

Magnitude: Figure 3 shows the distribution of magnitudes. The average visual magnitude was 0.84 for single-station observations, and 0.20 for simultaneous observations. The average absolute magnitude was

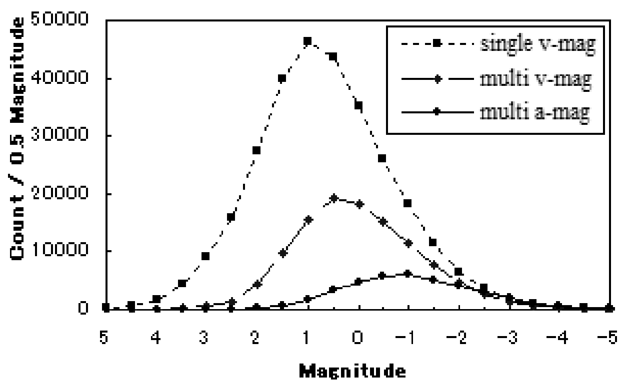

Figure 3 – Distribution of meteor magnitudes. Single v-mag is the visual magnitude of single-station observations, multi v-mag the visual magnitude of simultaneous observations, and multi a-mag absolute magnitude of qualified meteors.

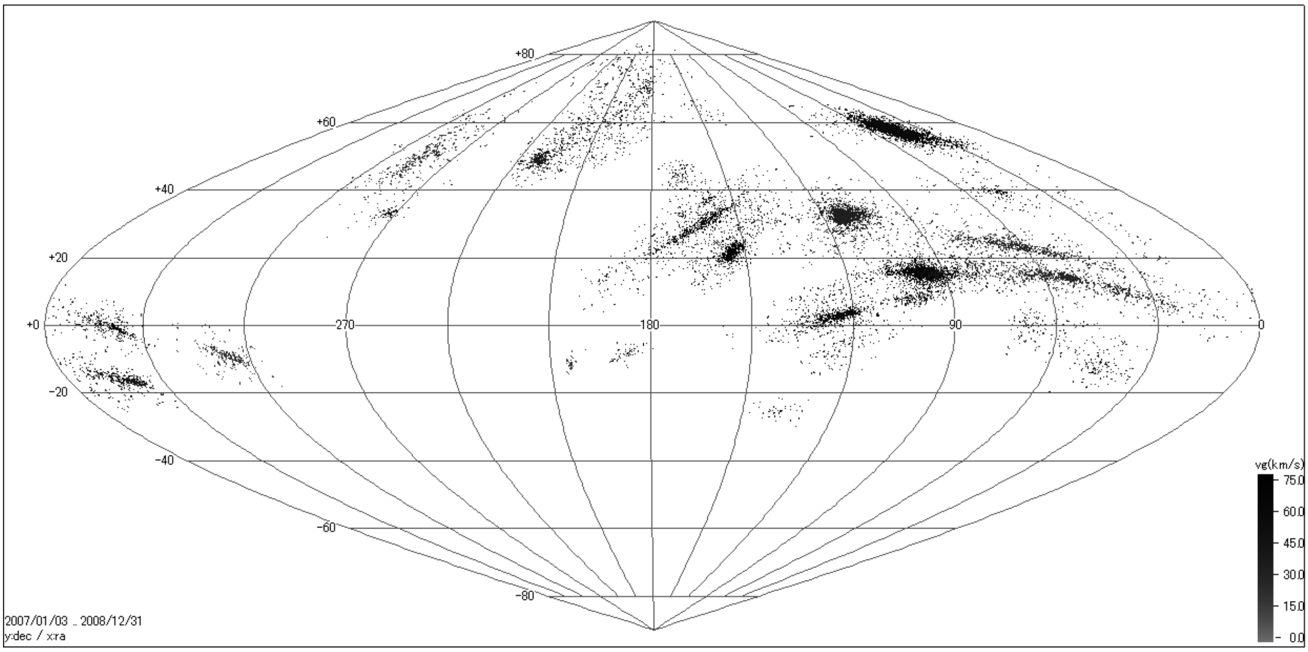

Figure 4 – Radiant areas of 38 meteor showers obtained from the clustering.

−0.87. Meteors fainter than absolute magnitude 2.0 are very rare in the set.

Length: meteors which had less than 1° trajectory length were rejected.

Geographical condition: all observations were made in the latitude range between 32° and 40° N. Therefore, many of the southern hemisphere radiants are out of range.

Weather: the dependency on the weather over Japan in 2007 and 2008 was not small. The effect of clouds, reduced transparency, or Moon light could not be omitted even by combining data collected over two years.

5 Clustering method

The purpose of clustering is to determine the set of the minimum number of meteor showers which covers all obvious concentrations and does not include too many sporadic meteors. Correcting for clustering also means that we obtain a smooth distribution of sporadic meteors.

This clustering was done in a four-dimensional space. The axes are the time of the meteor appearance in Solar ecliptic longitude ($\lambda_\odot$), the radiant's right ascension (α_p) and declination (δ_p), and the geocentric velocity (V_g). The radiant positions α_p, δ_p and the velocity V_g are corrected for the effect of zenith attraction due to the Earth's gravity. As is well known, the observed radiant position and observed velocity varies with the radiant elevation angle in the sky, while α_p, δ_p and V_g do not depend on the time of night.

In this study, one shower is expressed by 10 parameters as summarized in Table 3. The clustering involved the following steps.

1. Initialization: combine a meteor data set from all observations.
2. Reference making: select one meteor which is near the center of the largest concentration in the set and select it as the reference. (A dominant orbit of a known shower can be used as the reference for the confirmation of shower's existence.)
3. Clustering: select meteors which are close to the reference in the four-dimensional space from the set. Consider the radiant drift if it has already been computed. Then, the ranges of $\lambda_\odot$, R and ΔV are tuned, depending on the characteristics of the shower, to cover the whole concentration and not to include too many surrounding sporadic meteors.
4. Reference update: compute the shower parameters from the selected meteors, and update the reference as the center of selected meteors.
5. Iteration: repeat steps 3 and 4 until the association of the selected meteors does not change, or an association to another shower occurs.
6. Set update: once a cluster is found, its parameters are recorded and the clustered meteors are deleted from the set. Then the procedure is repeated from step 2 until all concentration disappears.

After this process, parameters of other known showers were checked to find out whether there was any concentration among the remaining meteors. If the concentration was confirmed and compared with the sporadic meteors surrounding it, then it was added to the catalog even if the number of observations was small The checked known radiants were those in the established IAU list (IAU, 2008) which contains 56 showers, and the UFOAnalyzerV2 current stream list (145 showers).

Table 3 – Observed parameters of 38 meteor showers. IAU code: number and code of the IAU Meteor Data Center list. $\lambda_{\odot 1}$, $\lambda_{\odot 2}$: Solar longitude of the shower activity start and end. $\lambda_{\odot p}$: Solar longitude of the shower peak date in 2008. α_p, δ_p: Right ascension and declination of the radiant at its peak. $\Delta\alpha, \Delta\delta$: radiant drift in right ascension and declination measured at its peak. The motion of the shower radiant is assumed as a motion along a great circle of the celestial sphere. The $\Delta\alpha, \Delta\delta$ compose one vector which shows the direction and velocity of the motion at its peak. Therefore the computation of a radiant position on a specified day becomes rather complex, but it can express the motion in the higher declination region by only one vector. V_g: geocentric velocity. R: radius of the radiant distribution circle that was allowed for the shower association. ΔV: difference of V_g that was allowed for the shower. SN2006 is the code which is used by the current UFOOrbitV2.

IAU Code	Name	$\lambda_{\odot 1}$ [°]	$\lambda_{\odot 2}$ [°]	$\lambda_{\odot p}$ [°]	Date (2008)	α_p [°]	δ_p. [°].	$\Delta\alpha$ [°]	$\Delta\delta$ [°]	V_g [km/s]	R [°]	ΔV [km/s]	Number of meteors	SN2006
334 DAD	December α-Draconids	236.4	278.3	256.5	12/08	207.9	60.6	0.40	−0.14	41.0	9.0	4.0	145	–
331 AHY	α-Hydrids	266.3	290.8	279.0	12/30	124.9	−7.7	0.45	−0.10	44.2	5.0	3.0	38	J1_aHy
018 AND	Andromedids	212.6	241.9	228.6	11/10	22.5	29.7	0.12	0.30	17.0	5.0	5.0	18	J1_tPs
343 HVI	h-Virginids	27.8	43.6	39.0	04/29	204.2	−11.6	0.11	−0.27	18.7	3.0	3.0	16	–
342 BPI	August β-Piscids	128.8	151.2	140.0	08/12	346.4	1.4	0.74	0.22	38.3	6.0	4.0	71	J1_bPs
001 CAP	α-Capricornids	114.3	138.4	126.1	07/28	305.7	−9.4	0.50	0.26	22.4	6.0	3.0	122	J1_Cap
020 COM	December Comae Berenicids	244.0	311.2	265.7	12/17	159.7	31.6	0.79	−0.32	63.0	6.0	4.0	652	J1_Com
335 XVI	December χ-Virginids	246.1	266.4	256.7	12/08	186.8	−7.9	0.20	−0.14	67.8	3.0	7.0	31	–
221 DSX	Daytime Sexantids	187.8	190.9	189.2	10/02	156.3	−2.9	−0.76	−0.86	31.2	3.0	3.0	4	J3_Sex
191 ERI	η-Eridanids	124.1	147.4	137.6	08/09	44.5	−11.7	0.49	0.03	64.0	6.0	6.0	86	–
145 ELY	η-Lyrids	42.5	54.2	49.8	05/10	291.7	43.8	0.20	0.02	44.3	4.0	3.0	14	J1_eLy
031 ETA	η-Aquariids	34.7	68.7	46.3	05/05	338.3	−0.8	0.62	0.29	65.4	5.0	5.0	220	J1_etA
344 JUG	July γ-Draconids	121.8	128.8	125.3	07/28	280.1	51.1	1.17	1.45	27.4	4.0	3.0	22	–
004 GEM	Geminids	245.6	279.4	261.4	12/13	112.8	32.3	0.90	−0.19	33.5	7.0	12.0	2510	J1_Gem
016 HYD	σ-Hydrids	227.9	280.6	252.9	12/04	123.2	3.0	0.49	−0.12	59.0	7.0	5.0	699	J1_Hyd
012 KCG	κ-Cygnids	123.7	155.5	140.7	08/13	285.0	50.1	0.45	0.45	21.9	10	5.0	213	J1_kCg,gDr
336 KDR	December κ-Draconids	239.7	259.7	250.2	12/02	186.0	70.1	0.05	−0.09	43.4	4.0	3.0	61	J1_aDr
013 LEO	Leonids	220.9	247.1	235.4	11/17	153.9	21.9	0.56	−0.39	70.0	4.0	7.0	713	J1_Leo
022 LMI	Leonis Minorids	203.7	220.9	208.9	10/22	158.8	37.1	0.44	−0.08	61.9	4.0	6.0	39	J1_Lmi
006 LYR	April Lyrids	24.3	41.6	32.5	04/22	272.6	33.2	0.82	−0.29	46.7	5.0	5.0	73	J1_Lyr
019 MON	December Monocerotids	245.6	269.9	257.6	12/09	100.1	8.2	0.52	−0.11	41.2	3.0	3.0	161	J1_Mon
337 NUE	ν-Eridanids	156.8	174.5	167.9	09/10	68.7	1.1	0.14	−0.13	65.9	3.0	3.0	29	–
250 NOO	Nov. Orionids	228.7	260.2	249.2	12/01	92.6	15.4	0.53	−0.04	42.0	4.0	5.0	210	J1_nOr
017 NTA	Northern Taurids	202.9	258.0	234.4	11/16	62.0	24.0	0.65	0.12	26.7	5.5	4.0	475	J1_nTa
281 OCT	October Camelopardalids	188.8	199.9	197.1	10/10	163.3	76.7	−0.93	−0.13	45.3	5.0	5.0	10	–
338 OER	o-Eridanids	227.9	245.0	234.7	11/16	60.7	−1.5	0.65	−0.03	26.9	5.0	4.0	26	J1_bEr
008 ORI	Orionids	178.9	234.0	207.9	10/21	95.5	15.5	0.61	0.01	66.2	4.0	8.0	2733	J1_Ori
183 PAU	Piscis Austrinids	124.0	140.6	133.2	08/05	352.8	−20.4	0.27	−0.03	42.8	4.0	3.0	10	J1_oAq
007 PER	Perseids	119.0	160.5	139.2	08/11	47.2	57.7	1.17	0.19	58.7	5.0	20.0	3524	J1_Per
339 PSU	ψ-Ursae Majorids	240.0	265.1	252.9	12/04	167.8	44.5	0.20	−0.01	60.7	3.0	3.0	33	–
010 QUA	Quadrantids	276.4	291.1	283.1	01/04	230.0	49.0	0.15	0.17	40.0	5.0	6.0	243	J1_Qua
208 SPE	September-Perseids	154.8	181.2	167.1	09/09	47.3	39.3	0.77	0.06	63.9	5.0	4.0	109	J1_gAn
005 SDA	Southern δ-Aquariids	118.0	145.4	129.7	08/01	341.9	−16.2	0.62	0.26	39.4	4.0	4.0	324	J1_sdA
002 STA	Southern Taurids	178.0	275.3	219.7	11/01	50.1	13.4	0.73	0.16	27.2	6.0	5.0	707	J1_sTa,gTa
340 TPY	θ-Pyxids	239.9	256.2	249.4	12/01	139.0	−25.5	0.43	0.04	60.1	3.0	3.0	23	–
333 OCU	October Ursae Majorids	194.6	214.6	204.7	10/17	147.6	64.0	0.13	0.09	54.4	4.0	3.0	15	J1_tUm
015 URS	Ursids	257.0	282.7	265.5	12/17	215.1	76.2	0.94	0.04	33.2	5.0	5.0	28	J1_Urs
341 XUM	ξ-Ursae Majorids	296.8	306.3	300.6	01/21	169.0	33.0	−0.13	0.01	40.2	5.0	3.0	12	J1_xUm

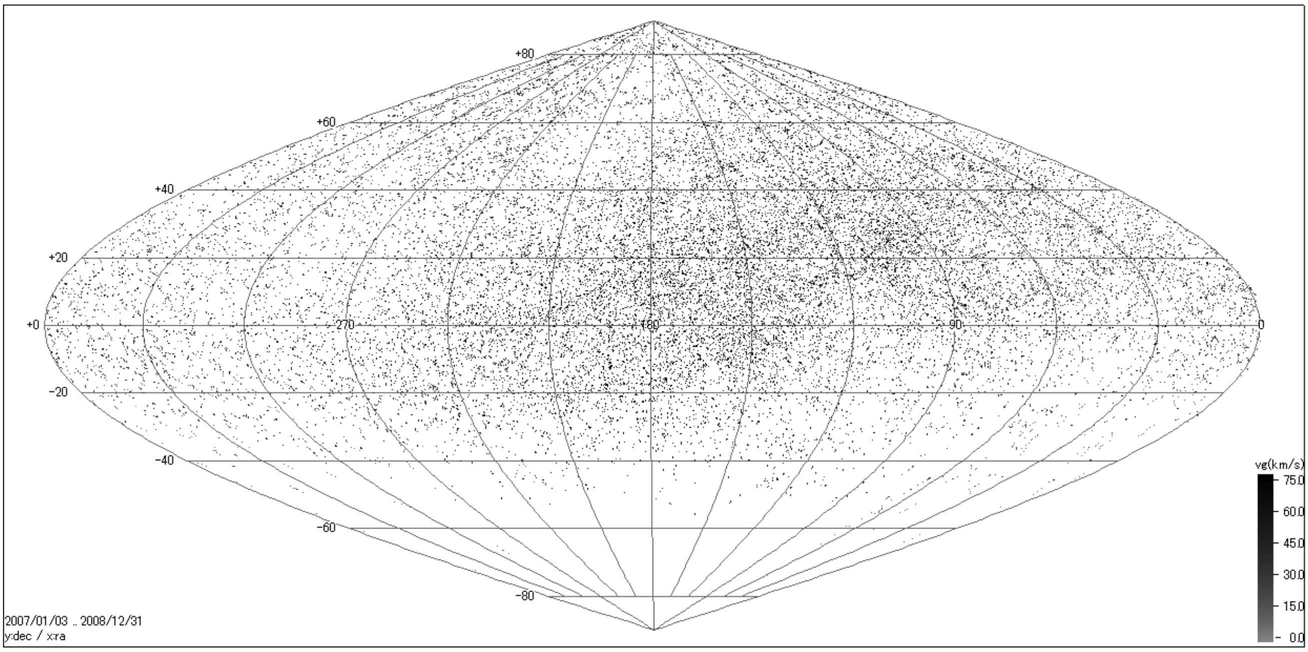

Figure 5 – Radiants of 24 837 non shower meteors in right ascension and declination.

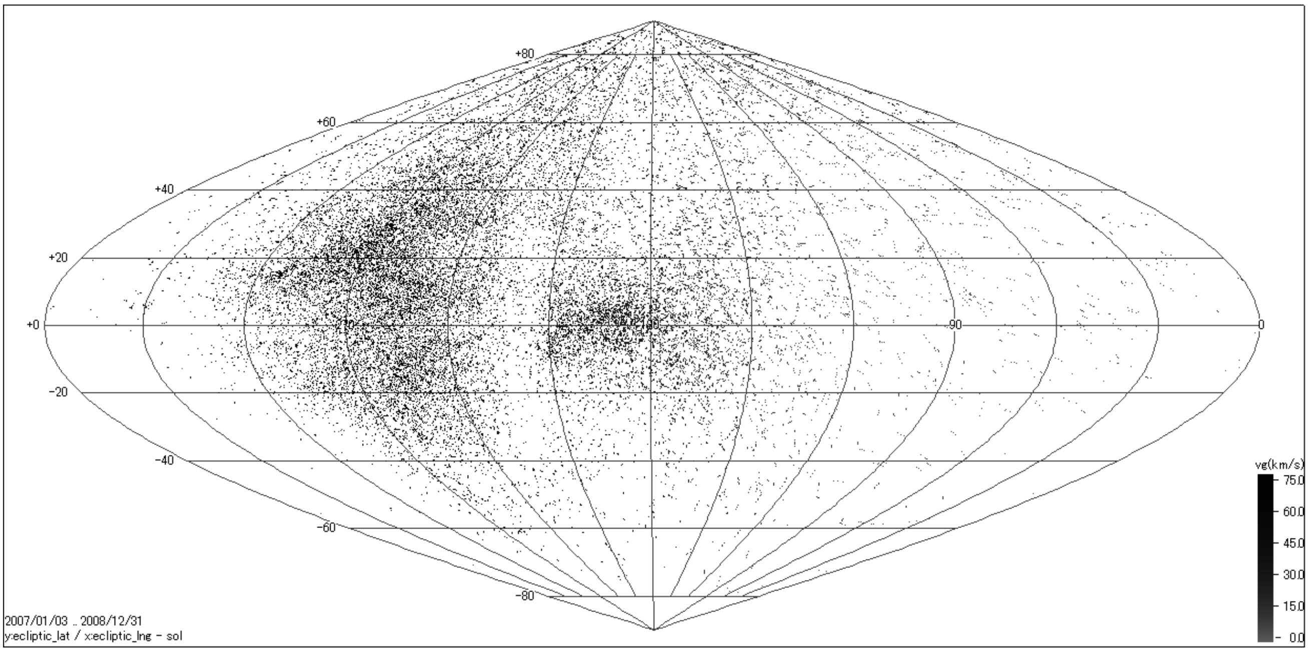

Figure 6 – Radiants of 24 837 non-shower meteors in coordinates of x-axis: ecliptic longitude λ – solar ecliptic longitude $\lambda_\odot(\lambda - \lambda_\odot)$, y-axis: ecliptic latitude. This projection shows the (season independent) solar direction from the Earth (0, 0), the apex direction (270, 0), and the antihelion direction (180, 0). Most of the radiants occur in the range of $\lambda - \lambda_\odot = 90$ to 270°. This almost corresponds to the zenith direction at 18^{h} and 06^{h} local time. The high density area around the apex is the maximum of geocentric velocity and it gradually decreases towards (90, 0). It means that the velocity of the Earth's orbital motion dominates the meteor velocity. We find a low-density area around (220, 0). This is the region of Sun-grazing meteors, which are not on stable orbits. The colour version of this Figure can be found on the back cover.

Table 4 – IAU showers unified to one shower because they appear as one source in the four-dimensional space.

020 COM, 032 DLM, 090 JCO	J4_Com (020 COM)
016 HYD, 246 AMO	J4_Hyd (016 HYD)
017 NTA, 256 ORN	J4_nTa (017 NTA)
002 STA, 257 ORS	J4_sTa (002 STA)
005 SDA, 003 SIA	J4_sdA (005 SDA)

6 Clustering result

Table 3 and Figure 4 show the result of the clustering. 38 showers were confirmed and their parameters were obtained. They covered 14 381 meteors and were 37% of all meteors. It was also confirmed that no concentration existed on the remaining 63% of meteors on the condition of more than 10 meteors in the range of $\lambda_\odot \pm 5°$, $R < 3.0$ degree, and $\Delta V \pm 30\%$, except the image of the major showers (Per, Gem, Qua, Ori, Tau) caused by the observation errors. Figures 5 and 6 show the remaining 24 827 meteors.

The comparison with the 56 showers in the IAU list of established showers, shows 24 showers obtained from this study correspond to 30 showers in the IAU list. Another 14 showers found from our analysis are not in the IAU list, while 26 showers listed in the IAU compilation have not been recognized as concentration in our data. A consultation with the IAU MDC yielded eleven new entries in the working list (numbers 334–344; see Table 3).

In our catalog, the IAU showers listed in Table 4 were unified to one source because the parameters in the four-dimensional space gave no reason to divide them.

The Antihelion source as well as the North and South Apex, and the Southern Toroidal source were not confirmed as concentrations. Their borders were too diffuse to distinguish them from the sporadic background.

It should be noted that there were fuzzy concentrations around the Quadrantids, during November to January. This area overlaps the so called Northern Toroidal source. In the new catalog, they are divided into three showers shown in Figure 7. One is the Quadrantids (010 QUA) which is compact and shows a short activity period. The second cluster which has a slightly higher velocity and obviously a short activity period was now included in the working list as number 336 KDR. The other activity center occurring over a long term was listed as 334 DAD.

Close to the κ-Cygnids, one early sharp cluster was extracted and listed as 344 JUG, while others were clustered to one fuzzy shower 012 KCG shown in Figure 8. The cluster 344 JUG, however, shows an unusual radiant drift and requires further investigation.

7 Conclusions

The determination of a meteor shower is difficult because it requires large numbers of accurate observations.

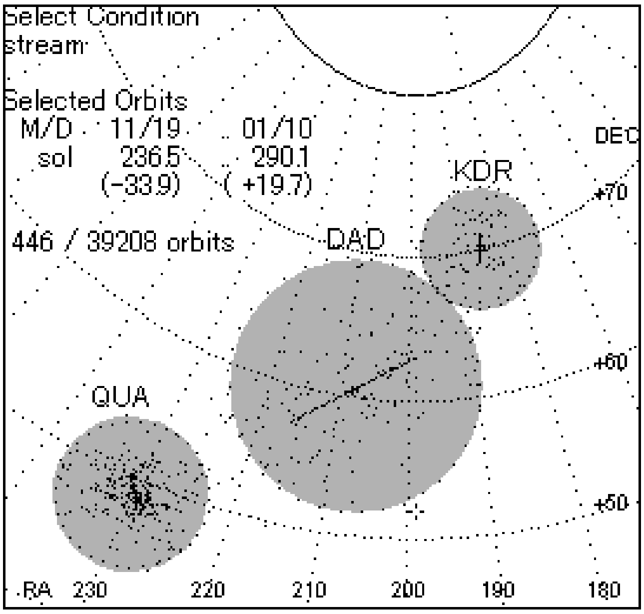

Figure 7 – Three showers in the region of the Northern Toroidal source.

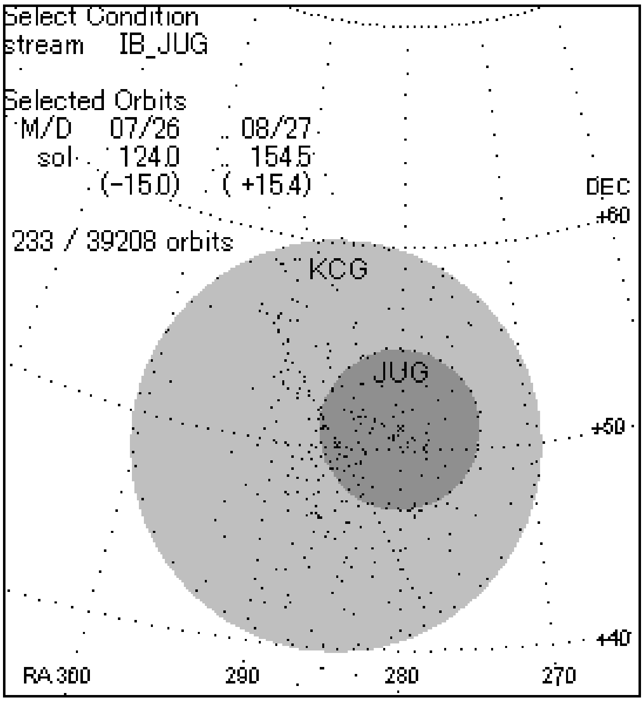

Figure 8 – Clusters of κ-Cygnids.

Sporadic meteors can easily be identified as parts of showers if the number of observations is not sufficient and a calibration with the surrounding sporadic meteors has not been done. Showers which have a long activity period like the Comae Berenicids can easily be (artificially) divided into multiple showers. Applying an automated clustering on a large data set with too sensitive clustering conditions may yield hundreds of meaningless showers. Therefore, a clustering criterion is needed to produce a reliable shower list.

In this study, only clear concentrations in the four-dimensional space that can be thought to maintain a relation to their parent objects were considered to be showers.

The 38 showers in the new catalog were obtained from a uniform procedure based on a larger sample of recent observations than ever previously recorded. Therefore, these data can be assumed to show the recent real activity of major meteor showers that are optically observable from the northern hemisphere.

The difference between this result and the established IAU list is not small. Further research needs to be done for 14 new showers which are not in the IAU list. Ten showers have been included as new entries in the working list of the IAU MDC. For those 26 showers in the IAU list which were not confirmed by this study, a careful study of the activity in recent and future years should be done.

One of the results of this study, the almost smooth distribution of sporadic meteors, suggests the possibility of finding further minor showers or discovering a mechanism responsible for changing sporadic meteor orbits. Since sporadic meteors can only be obtained by subtraction of the meteors of known showers, however, we need to know more details about the distribution of shower meteors.

The current study's results are limited by the detection ability, resolution and accuracy of current video observation. Wider-ranging and longer observations will reduce the effects of weather and moonlight and enable more precise clustering. Continued observation and additional research from many regions on the Earth can be expected to clarify which meteors are associated with showers, and to more sharply distinguish shower-associated meteors from sporadic meteors.

Acknowledgements

This study was made possible by the continuous efforts and contributions of the observers in the SonotaCo Network. I sincerely express my great thanks to the people listed in Table 2, who observe every night and make their results available. Much respect and thanks is also due to Sirko Molau, the pioneer of video meteor observation who brought me into contact with the IMO.

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Calculation of the incident flux density of meteors by numerical integration. II

Galina O. Ryabova [1]

A method for calculation of the flux density of meteors from backscatter radar observations is proposed. The method is a modification of the Kaiser-Belkovich method, aimed at performing direct numerical calculations instead of approximations. It allows one to work with physical models of a user's choice.

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Introduction

This is the second part of the paper, describing a method for calculation of the incident flux density of meteors from backscatter radar observations. In the first part (Ryabova, 2008) we have introduced the main definitions of the proposed method and derived a formula for the flux calculation. Now we shall continue and describe calculation of radar sensitivity, i.e. minimal detectable mass (Section 6) and the mean meteor layer thickness (Section 7) in any given direction of the echo-plane. Also we shall consider calculation of mass index s (Section 8).

The paper was divided into two parts for technical reasons. These parts are not independent, so for convenience of the Reader, numeration of the Sections and Equations will be kept through. Below, unless otherwise specified, we shall use SI units without prefixes.

6 Calculation of m_0 and m_θ

To calculate the incident flux density of meteoroids we need to know the minimal detectable mass of meteoroids m_0. This value can be calculated, if we know electron line density in the maximum of ionization of the weakest trail α_0. Another important parameter is characteristic height h_0, i.e., height of the maximum of ionization for this trail.

The main idea of the method is the following. It is obvious that the weakest trail can be observed in the direction of the maximum of sensitivity of the radar antenna lobe. It is also obvious that the minimal electron line density corresponds to the threshold level of the radar receiver. These two points allow us to calculate the sensitivity profile, i.e., to obtain α_0 as function of height (characteristic height, to be more precise) for the direction of the maximal radar sensitivity. This profile gives a totality of trails (having maximal ionizations α_0 at heights h_0) that the radar in question can register. From the other side, meteor physics gives us the ablation profile $h_{max}(m)$ showing height of the maximal ionization point h_{max} on the trail for a meteoroid with the mass m. This profile gives the totality of trails that can exist. Intersection of the profiles gives us one point $\alpha_0(h_0)$ for the trail that can exist and can be registered.

A radar does not register the line density, but the amplitude, so for the weakest observable echo its amplitude will be equal to the threshold value U. It is clear that for the point on the trail, where $\alpha = \alpha_{max}$, the inequality $A < U$ is true[1], nevertheless this trail will be registered. This is the starting position for obtaining the sensitivity profile for a radar, i.e., the function $\alpha_0 = \alpha_0(h)$.

6.1 Sensitivity profile

In what direction do we observe the trail with the lowest ionization? The most obvious answer is: in the direction of the maximal sensitivity of the radar antenna lobe. So to find the minimal electron line density corresponding to the receiver threshold level we should take such a trail which has a *maximal* echo amplitude equal to U, and the reflection point giving this maximal amplitude will be on the line of maximum radar sensitivity. The maximal electron line density α_{max} for this trail will be the required α_0. Let this be the first definition for α_0.

In (Belkovich & Verbeeck 2006b, p.40) α_0 is defined as 'the minimum detectable electron line density *in the direction of maximal sensitivity of the antenna.*' Let it be the second definition. In the first version of the method Belkovich (1971) used the first definition.

To find out what should be used is essential, because flux is calculated by integration over directions in the echo plane, and we use α_0 and α_θ (minimal detectable electron line density in the direction θ in the echo plane) for that. Here we consider calculations for the first definition. A difference exists, but it is not dramatic, as it will be shown.

An algorithm for calculation of a radar sensitivity profile is the following:

- We assign an arbitrary reasonable value for h_0, i.e., a trail with maximum ionization at height h_0 is considered.
- We neglect the difference in the antenna gain on the distance of the trail between the points of maximal ionization and maximal amplitude. So we take $G_T(\delta,\varphi) = G_T(\delta_m, 0)$, and $G_R(\delta,\varphi) = G_R(\delta_m, 0)$, where φ is the azimuth of the reflection point with respect to the direction of maximum antenna gain, δ is the elevation angle of the reflection point, and δ_m is the elevation angle for maximal sensitivity.
- The distance d to the point of maximal amplitude

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NASA-ADS bibcode 2009JIMO...37...63R

[1] See Figure 1 in the first part of the paper

can be calculated as:

$$d = \frac{h}{\sin\delta_m}, \qquad (28)$$

where δ_m is the elevation angle for the maximal radar sensitivity, $h = h_A$, the height of the maximal amplitude. We know that the point of the maximal ionization for this trail is above the maximum of amplitude by several kilometers, so the elevation angle δ is a bit larger, but we again neglect this difference, and for all reflection points on this trail use elevation angle δ_m, and equation (28). That leads to some error in the calculation of h_0.

- To obtain h_A, the height of the maximal amplitude, we just 'step down' the trail, and calculate the amplitude using equation (17). We do not know $\alpha_{max} = \alpha_0$ in this equation, but it is not important, we may use *any* reasonable value, for example, the one calculated by the Lovell-Clegg formula used for theoretical determination of radar sensitivity (Belkovich 1971, (5.31)):

$$\alpha^* = 6.3\times10^{15}\frac{U}{\sqrt{R_i P_T G_R G_T}}\left(\frac{d}{\lambda}\right)^{3/2} \mathrm{m}^{-1}. \quad (29)$$

- We know that this maximal amplitude is equal to U, so using (17) we can calculate α_A:

$$\alpha_A = \frac{U}{\sqrt{R_i} F d^{-3/2} g_{01}\exp\{-(kr_0)^2\}\varphi_w}. \qquad (30)$$

Knowing that $\alpha_A = \alpha_0 z(t_A)$, it is easy to calculate α_0.

- So we obtained $\alpha_0(h_0)$. Repeating calculations for $h_0 \in [h_{beg}, h_{end}]$, where $[h_{beg}, h_{end}]$ is the range of meteor altitudes, we obtain the sensitivity profile. An example is shown in Figure 1.

- Taking into account that τ_f, D_a, and r are functions of V, we have a sensitivity profile for a given V. To calculate $r_0(h)$ and $D_a(h)$ equations (12) and (13) from (Belkovich & Verbeeck 2006a) were used:

$$r_0 = 1.65\cdot\sqrt{\frac{V}{4\times10^4}}\cdot\exp\left(\frac{h-9.5\times10^4}{2H}\right), \quad (31)$$

$$D_a = 13.2\cdot\exp\left(\frac{h-9.5\times10^4}{H}\right). \qquad (32)$$

Here r_0 is in m, D_a in m^2 s^{-1}, h in m, V in m s^{-1}, H in m.

Another physical model could be found in Kostylev (1970):

$$r_0 = 24\cdot V\cdot\exp\left(\frac{h-95}{6.23}\right), \qquad (33)$$

$$D_a = 5\cdot\exp\left(\frac{h-92}{6.23}\right). \qquad (34)$$

Here dimensions are as in (31)–(32), only h is in km.

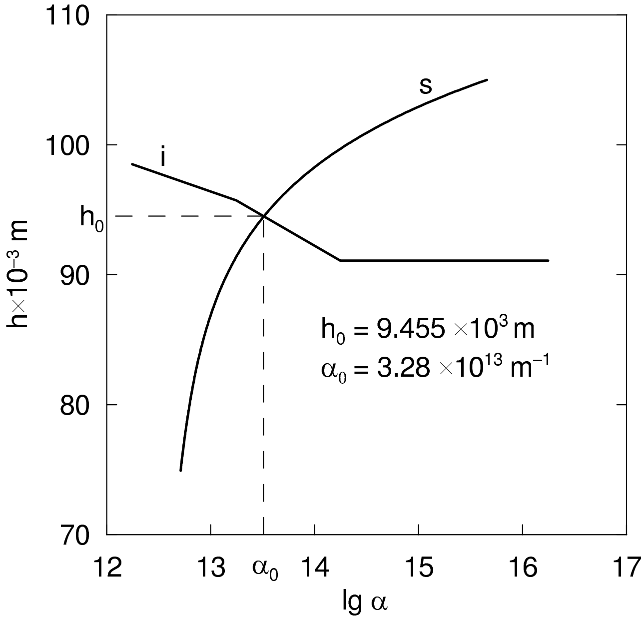

Figure 1 – A sensitivity profile (s), and an ionization profile (i). For the ionization profile $\chi = \delta_m$ was used.

The algorithm described above is intended mainly for the explanation. Certainly, it can be improved. Its main idea could be formulated very concisely. Let us rewrite equation (17) as

$$A = A'(t)\cdot\alpha_{max}. \qquad (35)$$

Then for any given h_0 we can evaluate α_0, solving

$$\alpha_0 = \frac{U}{max(A'(t))}. \qquad (36)$$

A comment. I did not experiment with antenna gain, taking into account that theoretical formulae for antenna gain, and real antenna gain differs, and, probably, several kilometers is nothing to pay attention at. But I experimented with d. If we calculate α_0 and h_0 using the second definition, we should calculate d_0 taking elevation δ_m for h_0, and later use $d = [h^2 + (d_0\cos\delta_m)^2]^{1/2}$. The difference between profiles obtained for the first and second definitions is within thickness of the plot line, i.e., negligibly small.

We know that for backscatter radar observations of a meteor shower the reflection points of meteors from that shower will all lie in the echo plane normal to direction on radiant (Belkovich & Verbeeck 2006, p.38). A sensitivity profile is calculated for a definite direction in the echo plane. So the different heights of the profile are related to different distances. It is evident from the equation (28), though.

6.2 Profile of maximum ionization

The sensitivity profile accounts just for *possibility* of a radar to register a meteor with the given velocity V, having maximal ionization α_0 at height h_0. But this does not mean that a meteor can have α_0 at height h_0. Now we shall consider the profile of maximum ionization, i.e. the function showing at what height a meteor with given velocity, density ρ, mass m, and zenith angle of the radiant (for the local zenith in the reflecting point) χ has maximum of ionization.

An example of an ionization profile is given in (Belkovich & Verbeeck 2006a, (16), Fig.3).

$$h_{max}(m) = \begin{cases} h^* & \text{if} \quad 10^{-11}\text{kg} \le m \le m_k, \\ h^* - \frac{H}{3} \cdot \ln \frac{\alpha_{max}(m)}{\alpha_{max}(m_k)} & \text{if} \quad m \ge m_k. \end{cases} \tag{37}$$

The formula is given in a general form, concrete values for h^* or m_r are not given. The reference on (Belkovich et al. 1999) was not very helpful, because the case is much the same: specific values are given only for a specific example. Taking into account that our main purpose is to explain the method, the ionization profile was taken more or less voluntary (see Figure 1).

Another physical model for the ionization profile was published by Kostylev (1970):

$$p_m = 4.67 \cdot 10^3 (V)^{-2.15} [m \left(\frac{\rho}{3.4}\right)^2]^{0.28} (\cos\chi)^\gamma, \tag{38}$$

$$\gamma = 0.40 + 0.037 \ln[m \left(\frac{\rho}{3.4}\right)^2] + 0.112 \ln V. \tag{39}$$

In this formula p_m (in Pa) is the atmospheric pressure at the point of maximal ionization (ablation), ρ (in g cm^{-3}) is the meteoroid density, mass m in g, and V in km s^{-1}. The physical model of Kostylev is cited here only as an example. One should realize that 40 years old physical model obtained at the time, when there were no optical observations of faint meteors having masses close to the masses of radar meteors, should not be used. To calculate $h(p_m)$ we may use equation:

$$\ln \frac{p_0}{p} = \frac{h_0 - h}{H}, \tag{40}$$

but only as a first approximation. For $h_0 = 95$ km $p_0 = 0.0752834$ Pa, and $H = 5.63$ km according to the Standard Atmosphere GOST 4401-81. For more precise calculations we should use one of the reference atmospheric models instead of (40). In reality the relationship between p, H and h has diurnal, seasonal variations, and variations depending on solar activity.

Intersection of the sensitivity and ionization profiles gives a single point with coordinates $\alpha_0(m_0)$ and h_0, which are the required values (Figure 1). For the considered example we obtained, that minimal detectable electron line density for our radar turned out to be $\alpha_0 = 3.3 \times 10^{13}$ m^{-1} and characteristic height is $h_0 = 9.46 \times 10^4$ m.

Some notes about term 'characteristic height'. In the first version of the Kaiser-Belkovich method, description of the meaning of the term 'characteristic height' is 'the height of the maximum ionization of the trail having a minimal detectable electron line density α_0' (Bel'kovich & Tokhtas'ev 1974), or, 'Let for the most weak meteor trail $\alpha_{max} = \alpha_0$. Let us name the value α_0 — the minimal detectable electron line density in a trail, and the height h_0, corresponding to the height of the maximum of ionization for the trail with $\alpha_{max} = \alpha_0$ — characteristic height' [2] (Bel'kovich 1971). In other words, $\alpha_0 - h_0$ depends of a radar sensitivity and, in a sense, is a measure of the radar sensitivity. In Lectures, term 'characteristic height' was used in the same meaning (e.g. p. 36 in Lectures), *and*, unfortunately, also in the other one. According to Belkovich-Tokhtas'ev physical model, meteoroids in the atmosphere will break into fragments that all have nearly the same size, and as a consequence will all evaporate at the same height (the same for a given meteor shower, i.e., with velocity V, density ρ and zenith angle χ fixed). In other words, all these meteors will have maximum of ionization on the same height. In Lectures, this height is *also* defined as characteristic height (p.25 in Lectures). *This* characteristic height does not depend on a radar, it is related to the ionization profile. In my opinion, different conceptions should not be mixed, and it is advisable to find another term for the 'characteristic height' related to the ionization profile to avoid confusion.

[2]Translation is mine.-*RGO.*

6.3 Conversion from α to m

The following equation helps us to make a conversion from α_{max} to m (Belkovich, 1971):

$$m = \frac{0.62 \mu H \alpha_{max}}{\beta \cos\chi}. \tag{41}$$

Here μ is the mass of one meteoroid atom, β is the ionization coefficient (the number of free electrons generated by one evaporated atom), and χ is the zenith angle for the meteor, i.e. for the local zenith in the reflecting point. The theory can be found in books of McKinley (1961, Ch.7) or (mainly) Bronshten (1983, Ch.V).

According to Tokhtasev–Belkovich ionization model: $\mu = 6.68 \times 10^{-26}$ kg, $\beta = 3.9 \times 10^{-15} (V - 8.15 \times 10^3)^3$.

Using these parameters, we find $m_0 = 1.78 \times 10^{-7}$ kg corresponding to our $\alpha_0 = 3.2 \times 10^{13}$ m^{-1} (for $\chi = \delta_m$). This is the minimal observed mass of a meteoroid for our radar.

According to Kostylev model $\mu = 3.82 \times 10^{-26}$ kg (Kostylev 1970), $\beta = 1.26 \times 10^{-16} (V - 6.14 \times 10^3)^{3.5}$ (Kostylev & Svetashkova 1977).

Several words about χ (for the local zenith in the reflecting point) and χ' (with respect to the zenith of the radar).

$$\frac{\cos\chi'}{\cos\chi} = 1 + \frac{h}{R_E} \approx 1,$$
$$\sin^2\chi \approx \sin^2\chi' + \frac{2h}{R_E}, \tag{42}$$

where R_E is the Earth's radius. The detailed derivation of the formulae can be found in (Kaiser 1960).

6.4 Calculation of α_θ and m_θ

We considered a method for calculation of minimal detectable electron line density (in maximum of ionization), i.e., for calculation of the minimal detectable mass of meteoroids, and the corresponding characteristic height. It is obvious that the same approach may be used for calculation of α_θ (minimum detectable electron line density in the direction θ in the echo plane).

The principle is the same. The difference is that the trail, giving α_θ, can be an overdense trail.

Let us assume that the trails with $\alpha_{max} < \alpha_c$ are underdense trails, and those with $\alpha_{max} > \alpha_c$ are overdense trails. The value α_c can be obtained from the continuity of the amplitudes (we should equate right-hand member of (17) to right-hand member of (18):

$$\alpha_c = \left(\frac{g_{02}}{g_{01}}\right)^{4/3} \left[\exp{(kr_0)^2}\frac{1}{\varphi_w}\right]^{4/3}. \quad (43)$$

Then we may operate as follows. We determine α_θ assuming the trail is underdense, i.e. using formula (17), but if $\alpha_\theta > \alpha_c$ we recalculate α_θ using formula (18).

This is a simplification. In the Lectures it is shown that the situation is slightly more complicated, and a transition region exists. Let us reserve it for the future.

7 Calculation of $I'(\theta)$

1. Let us consider meteoroids of a fixed mass m (more precisely with masses between m and $m + dm$). All these meteoroids have the same maximum of ionization α_m, and the height of this point on the trail is h_m. Knowing m we calculate h_m from an ionization profile (see Subsection 6.2), and for conversion to α_m we use the formula (41).

2. The trails of these meteoroids can be at different distances from the radar, so the reflection point can sit at any part of the trail: the further the trail, the higher the reflection point (because the reflection points all are situated in the echo plane). The meteor is recorded by the radar if the amplitude A for the echo exceeds or equal the threshold level U.

3. To calculate $I'(\theta)$ we consider meteoroids with masses $m > m_\theta$ (see the integral limits in (15), so for our meteor[3] (with the mass m) $A \geq U$ at least in the point of maximal ionization, i.e. on the height h_m. Let us walk up and down from this point and find the upper (h_{1m}) and the lower (h_{2m}) points, that still can be registered.

4. The process of 'walking' is realized in the following way. The variation of the electron line density α along a meteor trail could be described by the equations (8–10). To walk up the trail, we put $h = h_m + \Delta h$, and calculate α for this height. Then we should calculate the amplitude of the signal A, using the equation (17), if the trail is underdense, and the equation (18), if the trail is overdense. If $A > U$, we perform the next step. If $A \leq U$, we found h_{1m}. In the similar way we go down the trail and find h_{2m}.

5. *An example.* The parameters for the radar and for meteors we use are the same as above (see Section 3). We consider the direction $\theta = 0$, i.e. the direction of maximal sensitivity. For that direction $\alpha_\theta = \alpha_0 = 3.28 \times 10^{12}$ m^{-1}, $h_\theta = h_0 = 9.455 \times 10^4$ m (see Figure 1). Let $m = 10^{-6}$ kg, then from the equation (41) $\alpha_m = 1.76 \times 10^{14}$ m^{-1} for $\chi = \delta_m$, and $h_m = 9.11 \times 10^4$ m from the equation (37). Figure 2 shows the sensitivity curve and the ionization (or ablation) curve for the example in question (the same as in the Figure 1). Their intersection gives the point α_θ, h_θ as explained above in Subsection 6.2. The point α_m, h_m lays on the ionization curve. Plot 1 in Figure 2 shows all points, where $A > U$. In such a way we found for $h_{1m} = 9.62 \times 10^4$ m and $h_{2m} = 8.51 \times 10^4$ m for $m = 10^{-6}$ kg. This trail is the underdense trail because for our example $\alpha_c = 2.48 \times 10^{14}$ m^{-1} (remind that α_c is the transitional electron line density between the underdense and overdense reflections), and $\alpha_\theta < \alpha_c$.

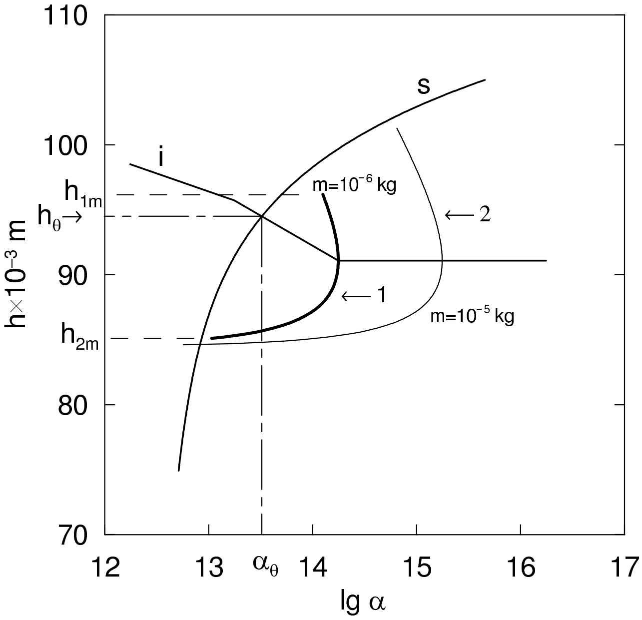

Figure 2 – The sensitivity profile (s), and the ionization profile (t) for an example (see text). 1 – all possible points on a trail of a meteoroid with the mass 10^{-6} kg, where $A > U$. 2 – the same for a meteoroid with the mass 10^{-5} kg.

6. *Another mass.* Let us now consider another mass for the same example, namely $m = 10^{-5}$ kg. Here $h_m = 9.11 \times 10^4$ m, and $\alpha_m = 1.76 \times 10^{15}$ m^{-1}, so this is the overdense trail. For this mass we have $h_{1m} = 1.013 \times 10^5$ m and $h_{2m} = 8.45 \times 10^4$ m. Plot 2 in Figure 1 shows all points, where $A > U$.

7. Calculating h_{1m} and h_{2m} we were talking about walking up and down a trail, as if it is one trail, but it is not so. They are all possible trails that could be produced by meteors of mass m, having reflection points in the direction θ of the *echo plane.* Let us come back to our example. For $m = 10^{-6}$ kg we have $h_m = 9.11 \times 10^4$ km and distance from the radar to the reflection point is $d = h/(\sin\chi\cos\theta) = 2.116 \times 10^5$ m. But for $h_{1m} = 9.62 \times 10^4$ m distance is 2.235×10^4 m. Trails are perpendicular to the echo plane, so these reflection points belong to different trails.

Now we can calculate the integral in (25), and consequently $I'(\theta)$.

8 Calculation of the mass index s

Nothing can be added to the algorithm expounded in the Lectures (Belkovich et al. 2006). The main idea of the algorithm is that we use two values of the flux density to ajust s. Namely, flux $Q(m_0)$, that is the flux density for the all registered meteors, and $Q(m_T)$

[3]It is difficult to follow strictly the convention: meteoroids are bodies, meteors are trails. So, in principle, when we talk about 'mass', we should use 'meteoroid'. But in reality it is not a meteoroid, it is already a meteor!

that is the flux density for the meteors with duration $T > 1$ second. We begin calculation from a reasonable starting value for s (say, $s = 2$). Then we vary s and recalculate $Q(m_0)$ and $Q(m_T)$ iteratively until their coincidence.

Finding m_T is not a simple problem (see the Lectures). But s can be found also from the distribution of the echo amplitudes (Belkovich 1971, or Lectures p.37), or from the distribution of the echo durations (Belkovich 1971). This problem goes beyond the scope of the paper.

9 Conclusions

In this paper, the approach to numerical calculation of the incident flux density of meteors by the Kaiser-Belkovich method is outlined. To make integration using the basic formula (27), we need to know how to calculate the minimal detectable meteoroid mass m_θ (Section 6) and the mean meteor layer thickness $I'(\theta)$ (Section 7) in any direction of the echo plane, also we should know the mass index s (Section 8).

The method presented is a very model-oriented one. We can play with various physical models, but we should keep in mind that in reality the transmitter power, for example, is not stable, and many other parameters also. So, using the *observed* echo amplitude distribution to get the antenna sensibility seems to be more correct. Nevertheless I believe that the method described above is good to obtain preliminary results very fast. Also it can be useful when we have lack of information, for example, when we process data from old observations.

Acknowledgements

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Erratum

In the first part of this paper (Ryabova, 2008) two misprints were found. The classical electron radius is $r_e = 2.81 \times 10^{-15}$ meters, not centimeters. Also in the equations (17) and (18) the maximal electron line density was designated by α_m, and should be α_{max}.

The D-criterion for the Perseid stream

M. G. Ishmukhametova [1,2,3], *E. D. Kondrat'eva* [1] *and V. S. Usanin* [1]

An analysis of the upper limit value of the D-criterion of family association of meteoroid bodies in the Perseid stream is presented. On the basis of modeling of ejections of meteoroids in the stream out of the parent comet at different points of the comet it is shown that D value for the Perseids is not higher than 0.1 over the whole most probable range of ejection speeds.

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1 Introduction

Criteria of family association of the orbits of celestial bodies are widely used in astronomy. For example, they are used for identifying small bodies of the solar system with possible parent bodies, discovering family connections with asteroid groups, meteor associations, and designation of the elements of mean orbits of meteoroid streams.

Similarity of the Keplerian elements of their orbits is considered to be a criterion for family association of two bodies. This question, which is based on the solution of a limited three-body problem, was considered for the first time by F. Tisserand in 1889. It was concluded that a necessary condition for the family association of two comets is the proximity of their invariants:

$$C = a^{-1} + 0.16860 p^{1/2} \cos(i) \qquad (1)$$

where a, p, and i are the orbit parameters of comet. The value C was called the Tisserand constant or Tisserand criterion. As for the small meteoroid streams the distribution according to the value of the Tisserand constant mostly corresponds to the short-period comet distribution. The maximum of both distributions coincide when $C = +0.55$, besides about 40% of the small streams have Tisserand constants in the interval from +0.45 to +0.60, which corresponds to the Jupiter group of short-period comets. The result of studying the value of the Tisserand criterion statistically can show connections between some asteroids, comets and small meteoroid streams.

Later the D-criterion, in which the proximity of orbital parameters between bodies in the 5-dimensional phase space (Southworth & Hawkins, 1963; Drummond, 1981; Klačka, 1999) and others is taken as a measure of the family association, was suggested to research the evolution of meteoroid streams. The most widespread criterion was suggested by R.B. Southworth & G.S. Hawkins (1963). For the two bodies being considered the D-criterion is represented by the formula:

$$\begin{aligned} D^2 &= (e_2 - e_1)^2 (q_2 - q_1)^2 \qquad (2) \\ &+ (2\sin(I/2))^2 + ((e_2 - e_1)/2)^2 (2\sin(W/2))^2 \end{aligned}$$

where

$$\begin{aligned} \left[2\sin\left(\frac{I}{2}\right)\right]^2 &= \left[2\sin\left(\frac{i_2 - i_1}{2}\right)\right]^2 \\ &+ \sin(i_1)\sin(i_2)\left[2\sin\left(\frac{\Omega_2 - \Omega_1}{2}\right)\right]^2 \end{aligned}$$

and

$$\begin{aligned} W &= \omega_2 - \omega_1 \\ &\pm 2\arcsin\left(\cos\left(\frac{i_2 + i_1}{2}\right)\right. \\ &\left.\sin\left(\frac{\Omega_2 - \Omega_1}{2}\right)\sec\left(\frac{I}{2}\right)\right) \end{aligned}$$

and I is the reciprocal angle of orbits, W is the angle between directions towards perihelion, and e, a, q, i, w, ω and Ω are orbital elements. The $\pm$ is negative when $|\Omega_2 - \Omega_1| > 180°$. It is noted that the two bodies will have the same origin if the distance between their orbits in the given area will appear to be less than some given value of D. The method assumes the measurement errors in the orbital elements to be considerably smaller than the real dispersion of the orbits in the stream.

The basic problem of using the D-criterion is in the choice of the value of D as the measure of the common origin of two bodies. The upper limits of D are from 0.115 to 0.30 in different sources. While researching the meteor association or finding mean stream orbit for the Perseid, Geminid, Orionid and other meteor showers, D is taken equal to 0.2. But the studies show that for example showers slightly inclined to the ecliptic (such as the Taurids) cannot be clearly distinguished from the background by using this value. In conclusion, we can assume that using the same upper limit for all showers can be used just as a first approach. For a better identification of meteor bodies the upper limit of D has to be defined for every meteor complex individually. Most probably the definition of the D-criterion for meteor complexes is different and serves to be as some evolutionary characteristic of a given meteoroid stream.

2 Results

This particular work considers various D-criterion values for the Perseid meteoroid stream. Following the disintegration of the comet nucleus, the orbits of ejected fragments are connected with the parent body, so the D-criterion value will depend on the particle ejection speed and the point of its ejection round the orbit. That is why the limit of the D value can be found from the

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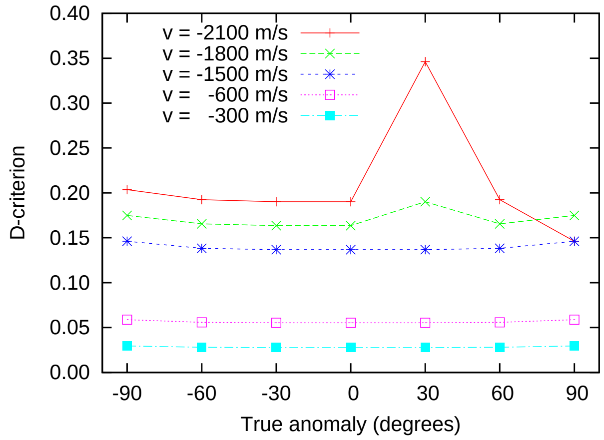

Figure 1 – The D-criterion at the moment of ejection in 1348 depending on the ejection speed and the location of the ejection point in the comet orbit.

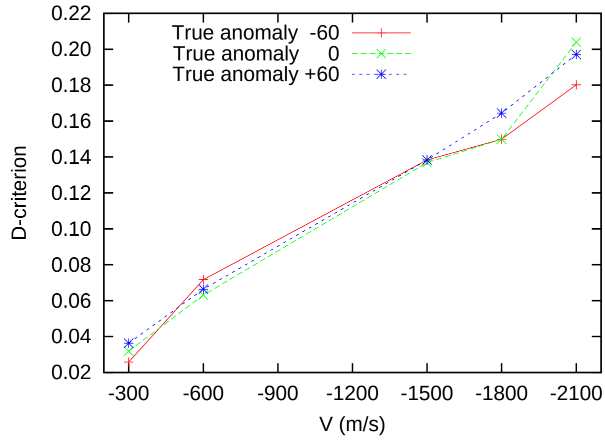

Figure 2 – The D-criterion at the moment of ejection in 1348 depending on the ejection speed.

physically possible speeds of particles from the nucleus of a comet.

The process of modeling the formation of a Perseid meteoroid stream made by the authors earlier is described in detail in their works (Ishmukhametova & Kondrat'eva, 2004; Ishmukhametova & Kondrat'eva, 2006). The elements of a parent comet 109P/Swift-Tuttle are taken from the catalogue of B. Marsden (1995). Using the results of modeling the ejection of Perseids from their parent comet in 1348, we analyze the D-criterion value for different ejection speeds of model particles in different points of the comet orbit.

As an example, we will consider only the ejection perpendicularly to the radius vector and in the opposite direction to the comet movement (type III, vector T, $V < 0$). The values of the D-criterion for two orbits of a comet-meteor, which are found through (eqn. 2), for a range of ejections speeds from 300 – 2100 m/s before and after the comet's perihelion are shown in Figure 1.

In Figure 2 there is a dependence of the D-criterion on the ejection speed of particles in 1348 at the points of the comet orbit with true anomalies of $-60°$, $0°$ and $+60°$. The D-criterion practically does not change for particles ejected with the same speed at different points in the orbit. According to the present day understanding of physical and chemical model of disintegration of the comet nucleus while approaching the Sun, the ejection speeds are not higher than 600 m/s. We can conclude that for the model Perseid stream particles just ejected, the value of the D-criterion is not higher than 0.075 and stays practically equal for the particles ejected before and after perihelion.

The D-criterion does not take into account gravitational and non-gravitational orbit perturbations. But because of planetary perturbations orbits of meteoroids in the steam can be very different from each other. That is why it is interesting to trace the dynamics of the D-criterion values depending on the evolution of the stream. The orbital elements of model particles ejected in 1348 were integrated before 1862 taking into account perturbations from all the planets. The D-criterion

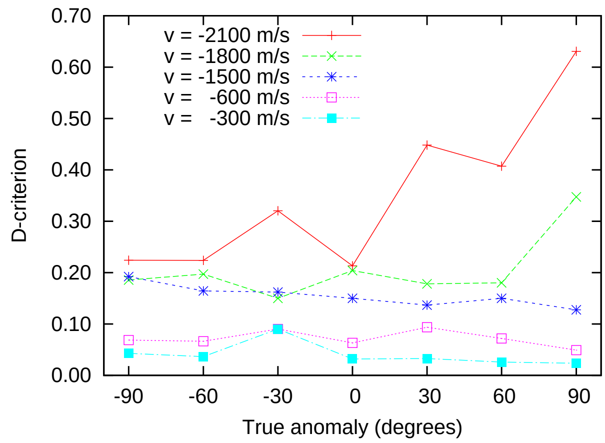

Figure 3 – The D-criterion 500 years after the particle ejection as a function of true anomaly of the ejection point.

value for two orbits of a comet particle, obtained from (eqn. 2) for particle perturbation, are presented in Figure 3.

As we see from Figure 3, for Perseids the D-criterion value of 0.2 is reached only for particles which were both perturbed by planets and were ejected with very high speeds — higher than 1000 m/s. A D-criterion higher than 0.22 is given by a model particle ejected with a speed of 2100 m/s at the point of the orbit with true anomaly $+30°$.

This is connected with the approaches of the particle to Jupiter: one of them is close (the distance between them is 0.27 A.U.) and two of them are on the border of its sphere of influence. With the same ejection speed V_{ej} at the point in the orbit with true anomaly of $-30°$ the main disturbance in the orbit of the particle is caused by the Earth. The number of close approaches to the Earth is rather large — 1469, 1497, 1525, 1590, 1730, 1758, 1786 and 1842; moreover, in these approaches the minimum mutual distance is 0.093 A.U. and the maximum is 0.16 A.U. Such perturbations lead to significant changes of the orbital elements of model meteoroids during 500 years (Table 1).

Let us look at the range of the most probable ejec-

Table 1 – Perturbation of orbital elements of model particles during 500 years.

Orbital element	Comet 109P/ Swift-Tuttle	Model particle orbital elements, V_{ej}=2100 m/s True anomaly: $-30°$	$+30°$
ω	152° (2000.0)	157°	143°
Ω	139°	141°	141°
i	113°	112°	108°
e	0.963	0.790	0.711
a	25.851 A.U.	4.436 A.U.	4.529 A.U.

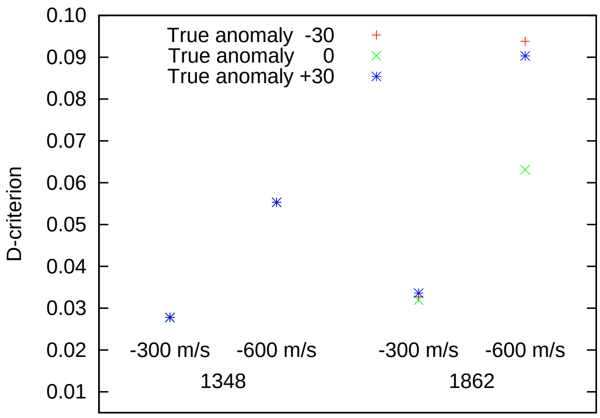

Figure 4 – Variations of the D-criterion values while selecting model particles during the period 1348 – 1862.

tion speeds of Perseid meteoroids out of their parental comet — about 600 m/s. In Figure 4 there are the D-criterion values for model particles ejected in 1348 with a speed of 300–600 m/s in the most probable points of the comet orbit with true anomalies of $-30°$, $0°$ and $+30°$ and D-criterion values of the same particles in four orbits around the Sun. The D-criterion values even for perturbed Perseid orbits are not higher than 0.1.

3 Conclusions

The D-criteria are used by many researchers for studying the evolution of meteoroid streams though the upper limit of 0.2–0.3, found empirically for asteroids, has been used for the comet-meteor complex unquestioningly. In his work K.V. Kholshevnikov pointed to the unreliable character of the existing criteria. When identifying two comet orbits or comet and meteor orbits it is suggested that the decision should be based on a comparison of the orbit elements themselves taking into account their possible perturbations, but not their artificial union in some criterion (Kholshevnikov & Besmertny, 2003).

While identifying meteor showers we assume that the most reliable criterion remains the traditional one based on proximity of radiants. Radiant coordinates are found more precisely than the meanings of semimajor axes and perihelion distances included in the different formulas of D-criteria.

It is enough to take any catalogue of meteor orbits and we will see that the spread along the semimajor axes for Perseids is from 3 A.U. to about 40 A.U. This spread is far higher than the real dispersion of orbits in the stream. This is the requirement for the reliability of D-criteria, as the main condition on their usage is that the mistakes of measurements of orbit elements must be a lot smaller than the real dispersion of orbits in the stream.

Only for young meteoroid streams can the D-criterion serve as a reliable instrument for discovering family connections. But at the same time it is necessary to find the individual upper value of D for every meteoroid stream under observation.

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Preliminary results

Results of the IMO Video Meteor Network — January 2009

Sirko Molau [1] *and Javor Kac* [2]

The cameras of the IMO Video Meteor Network covered all 31 nights in 2009 January. Almost 9 500 meteors were observed in over 2 500 hours of effective observing time. The Quadrantids activity was well covered – the preliminary analysis is presented and compared to visual data. The presence of the Alpha Hydrids, a minor shower active from December 31 to January 11, is confirmed by the video data.

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1 Introduction

The new year started as successful as the old one ended. At least in the first half, January surprised the observers at many sites with unusually good weather. For the Quadrantid maximum, which was Moon-free and fell almost entirely into the European night-time hours, the weather was particularly co-operative. In total, 21 video systems were in operation on January 2/3 and collected together 2 400 meteors in 177 hours of effective observing time. The second half of the month was mediocre, but the January total of more than 2 500 observing hours and 9 400 meteors was still amazing (Figure 1 and Table 1), since it more than doubled the figures of the best previous January.

Two outstanding recordings should be mentioned at the outset. On January 3 at 01^h47^m UT, Klaas Jobse managed to record a rare double meteor – in this case a double Quadrantid – with his image-intensified camera BETSY2 (Figure 2). The angular separation of both meteors was nearly one degree. At an height of 100 km and an altitude of roughly 45 degrees, this translates into a spatial distance of 2 to 3 km between the two meteoroids burning up in the atmosphere.

A few days later, on January 13 at 00^h02^m UT, Flavio Castellani captured a bright fireball with BMH2 (Figure 3). The meteor could not be recorded in a single image, because MetRec is not designed for such bright objects. Still, the brightness curve of the bolide, which reached roughly full Moon brightness at maximum, is clearly visible.

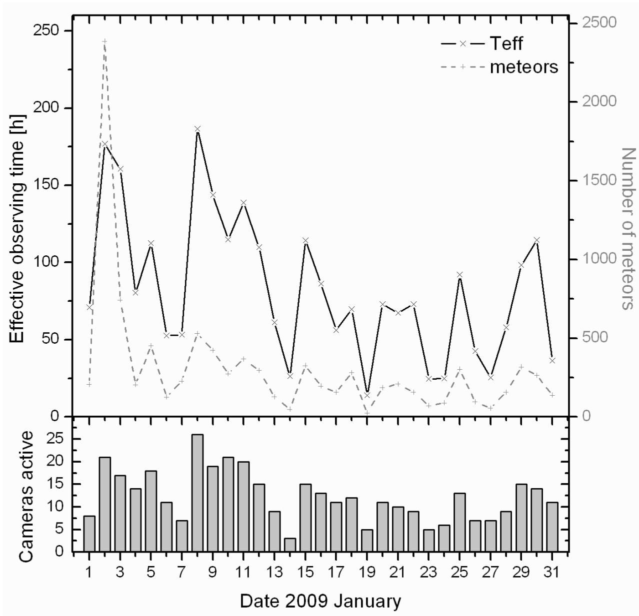

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2009 January.

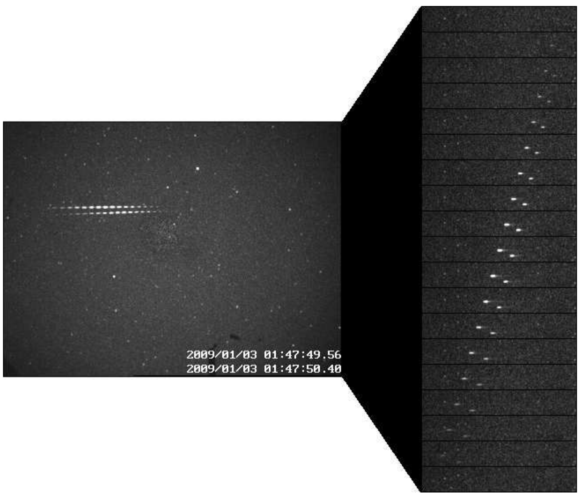

Figure 2 – Double-Quadrantid, recorded by Klaas Jobse on 2009 January 3 at 01^h47^m UT. Individual frames are shown on the right.

2 Quadrantids

With respect to meteor showers, there is just one significant source in January. As mentioned before, the Quadrantids could be well observed this year. The maximum was predicted for 13 UT on January 3. Since the Quadrantid maximum is extremely short, we expected only some rise in activity in the European morning hours, whereas the American observers were placed best. The visual observations proved, however, that the maximum was early by about two to three hours, such that also the European observers witnessed zenithal hourly rates up to 100 at dawn. The increase in activity by about a factor of three between midnight and dawn was further enhanced by the rising radiant, which made the increased activity even more dramatic. This is also well

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NASA-ADS bibcode 2009JIMO...37...71M

Figure 3 – Bright fireball on 2009 January 13, $00^{h}02^{m}$ UT, recorded by Flavio Castellani.

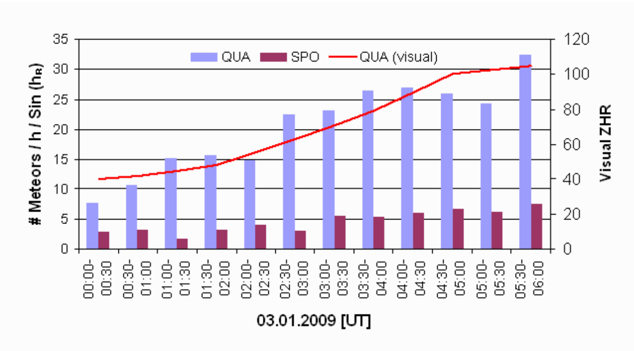

Figure 4 – Activity profile of the Quadrantids on the morning of 2009 January 3. For comparison, the visual ZHR profile is shown as a line.

documented in the video data: the number of Quadrantids in the last half hour before dawn was about ten times as high as in the first half hour after midnight.

The analysis of the 2009 video data was based on 978 Quadrantids and 303 sporadic meteors, recorded by 13 video cameras between 0 and 6 UT on January 3. The Quadrantids were grouped in 30-minute intervals, corrected for the radiant altitude as usual, and averaged over all cameras. For comparison, the number of sporadic meteors per hour was also plotted. The activity graph (Figure 4) shows an almost linear rise in activity in the morning hours of January 3. The live ZHR graph from visual data of IMO (2009), which is plotted as a line, shows the same trend.

Unfortunately, the graph could not be continued until the maximum, because there was just one active video camera in the US. Therefore, the individual measurements from that time show significant scatter. On the other hand, the European observers recorded a few nice long-lasting Quadrantids at the first evening hour of January 3. Later that night, the rates went down below a ZHR of ten again.

What do we learn about the Quadrantids from the complete video data analysis of 2008? According to the IMO handbook for meteor observers (Rendtel & Arlt, 2008), this shower is active between January 1 and 10. The majority of 1330 video Quadrantids was recorded within one solar longitude interval, which is

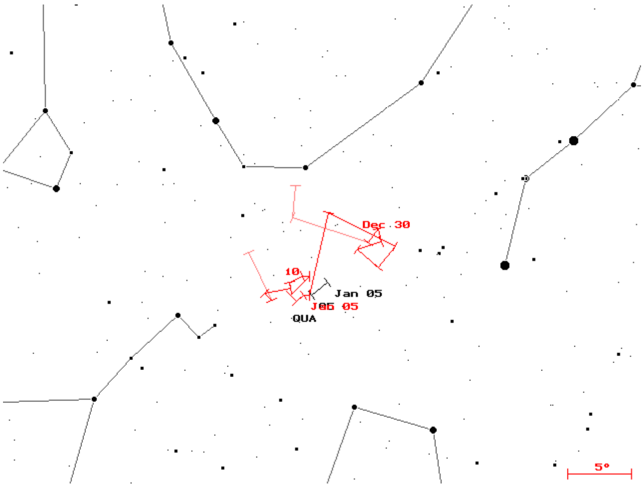

Figure 5 – Radiant position of the Quadrantids from data of the IMO Video Meteor Database. Black line denotes the radiant drift of the Quadrantids as given in the IMO Handbook.

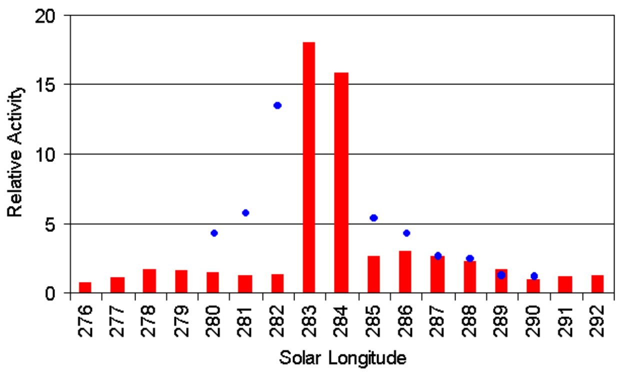

Figure 6 – Long-term activity profile of the Quadrantids. Dots represent the visual activity profile.

why the radiant position before and after the maximum is not well-defined (Figure 5). Still, the activity starts probably at December 28 and lasts until January 12.

Figure 6 presents the long-term activity profile of the Quadrantids. It shows that the activity away from the maximum (which is smeared out over two values because of the sliding intervals) is very low. For comparison, the blue dots show the visual activity profile

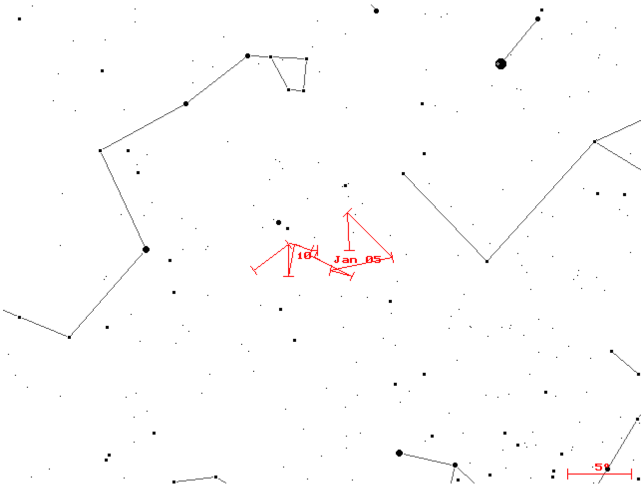

Figure 7 – Radiant position of the Alpha Hydrids.

between 1988 and 2008, taken from the IMO handbook (Rendtel & Arlt, 2008). Interestingly, the rates right before and after the peak are much higher in the visual data, i.e. the rise and fall of activity is less steep there.

3 Alpha Hydrids

Since there are no other major showers beside the Quadrantids, and the sporadic activity remains low, January is a good time to detect weak meteor showers. The analysis from Fall 2008 (Molau, 2009) revealed a possible shower between December 31 and January 11. Its radiant, which was derived from 160 shower members, is located in the southern part of Hydra (Figure 7).

At maximum on January 7 ($\lambda_\odot = 287°$), the radiant lies at $\alpha = 129°$, $\delta = -9$, based on 28 shower meteors. The velocity of the shower is 45 km/s, but this value shows some scatter because of the low meteor number. The activity profile (Figure 8) is quite flat, with traces of a weak maximum at January 7. In the full activity interval, the ZHR stays below two, which is why this shower is close to the limit for visual meteor observers.

The shower fits well to alpha Hydrids, IAU shower No. 331. Alpha Hydrids were first detected by Molau (2007) as his shower number 89. Next, Brown et al. (2008), confirmed the shower by using the meteor orbit radar. They reported the activity interval from $\lambda_\odot = 281°$-$289°$ (corresponding to January 1 to 9), a maximum at $\lambda_\odot = 285\overset{\circ}{.}5$ at $\alpha = 127\overset{\circ}{.}6$, $\delta = -7\overset{\circ}{.}9$ and a geocentric velocity 43.6 km/s.

This analysis therefore further confirms the existence of Alpha Hydrids as a weak annual meteor shower.

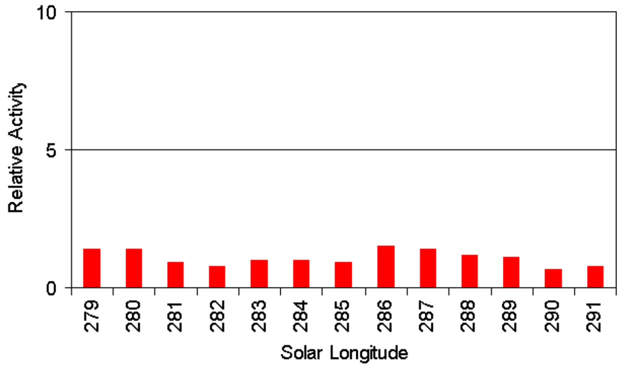

Figure 8 – Long-term activity profile of Alpha Hydrids.

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Table 1 – Observers contributing to January 2009 data of the IMO Video Meteor Network.

Code	Name	Place	Camera	FOV	LM	Nights	Time (h)	Meteors
BENOR	Benitez-S.	Las Palmas	TIMES5 (0.95/50)	⊘ 10°	3 mag	9	31.2	50
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	12	106.7	543
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	15	140.8	403
			BMH2 (0.8/6)	⊘ 55°	3 mag	17	141.5	397
CRIST	Crivello	Valbrevenna	STG38 (0.8/3.8)	⊘ 80°	3 mag	1	11.0	33
		Genova	C3P8 (0.8/3.8)	⊘ 80°	3 mag	19	135.9	871
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	6	45.1	174
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	18	145.3	742
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	5	26.2	80
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	25	174.1	444
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	13	76.6	373
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	7	86.4	978
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	9	56.6	194
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	5	21.1	112
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	4	13.4	24
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	8	10.2	22
KOSDE	Koschny	Noord-wijkerhout	TEC1 (1.4/12)	⊘ 30°	4 mag	11	91.1	150
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	12	100.8	630
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	8	74.4	886
			MINCAM1 (0.8/6)	⊘ 60°	3 mag	19	90.3	220
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	20	93.1	275
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	19	68.5	243
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	21	134.6	305
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	3	9.1	23
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	12	85.9	316
STORO	Stork	Ondrejov	OND1 (1.4/50)	⊘ 55°	6 mag	1	2.8	11
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	19	105.7	463
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	12	69.2	372
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	13	98.8	782
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	4	39.0	101
					Overall	31	2 285.4	10 217

Results of the IMO Video Meteor Network — February 2009

Sirko Molau [1] *and Javor Kac* [2]

The IMO Video Meteor Network cameras observed in all 28 nights in 2009 February. Seventeen observers used 28 video cameras to collect 1 765 hours of observing time and capture 3 611 meteors. From the IMO working list of meteor showers, δ-Leonids and meteors from the Antihelion Source were detected. For the first time, α-Antliids were detected in the optical domain. The radiant drift and activity profile are presented.

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1 Introduction

Such a clear North-South gradient with respect to the observing conditions as in the last month is exceptional. In northern Europe, the conditions were catastrophic – not even one observer north of the Alps managed to get more than 50 observing hours. In Slovenia, the situation became slightly better, and observers in Italy and Portugal enjoyed almost permanent clear skies after February 10. Our American observers also got many clear nights in February. In total, we collected an acceptable 1 700 hours of effective observing time and 3 600 meteors altogether (Figure 1 and Table 1).

2 δ-Leonids

With respect to meteor shower activity, February is a poor month. The IMO meteor shower working list contains just one northern shower, namely the δ-Leonids. It was not detected in the automated meteor shower search, though. A closer inspection of the radiants at individual solar longitudes reveals that the δ-Leonids seem to be at least partly active. They are most prominent in the following intervals (listed are 2-degree intervals centered at the given value of $\lambda_\odot$):

$\lambda_\odot$ [°]	α [°]	δ [°]	Velocity [km/s]	Number of meteors
334	161.6	13.0	25	18
335	162.0	13.5	25	25
338	166.0	12.0	24	25
339	169.6	16.0	24	12
341	167.3	14.5	27	18

According to the IMO handbook (Rendtel & Arlt, 2008), the radiant position at maximum is $\alpha = 168°$, $\delta = +16°$, which fits reasonably to the values given above. Also the velocity of 23 km/s matches approximately.

3 Antihelion source

Besides the δ-Leonids, only the Antihelion source is reasonably active. It has, however, no clearly defined radiant, but only a diffuse radiant area. So it comes as no surprise that the meteor shower analysis reveals a number of individual Antihelion radiants.

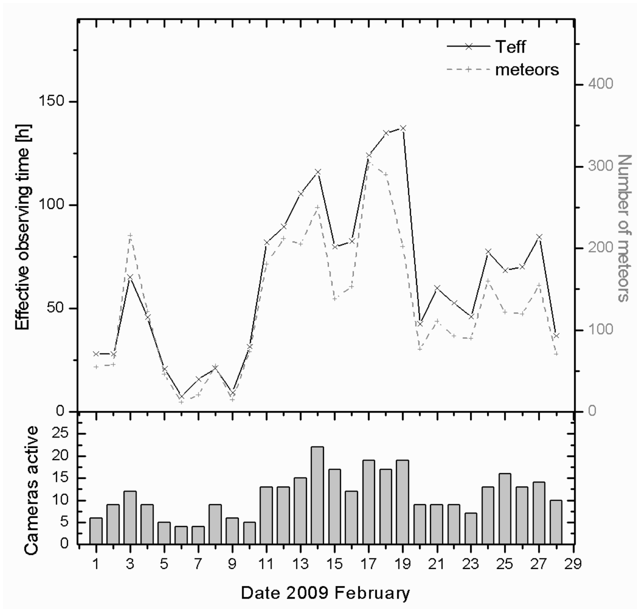

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2009 February.

4 α-Antliids

Also for February, the 2008 video meteor database analysis (Molau, 2009) yielded a number of meteor shower candidates, which are unknown in the IMO shower list. The candidate with least scatter is a possible weak shower from February 2 to 7 (solar longitude 313–318°), based on just 66 shower members. On February 4, the average radiant lies at $\alpha = 162°$, $\delta = -14°$ (Figure 2). The mean meteor shower velocity is 45 km/s.

It seems that this shower has not been detected in the optical domain so far. However, the IAU Working list of meteor showers lists the α-Antliids (AAN) shower

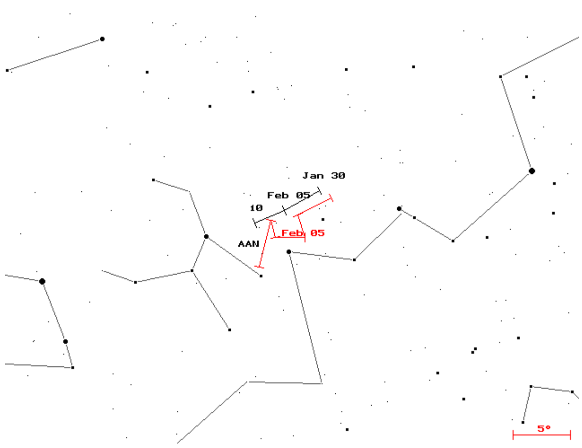

Figure 2 – Radiant position of the α-Antliids (AAN) in the constellation Crater. The reference position (straight black line) was taken from the CMOR data.

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NASA-ADS bibcode 2009JIMO...37...75M

Table 1 – Observers contributing to February 2009 data of the IMO Video Meteor Network.

Code	Name	Place	Camera	FOV	LM	Nights	Time (h)	Meteors
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	13	30.0	96
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	14	87.2	130
			BMH2 (0.8/6)	⊘ 55°	3 mag	16	89.7	127
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	19	148.1	387
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	9	50.9	104
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	18	172.1	429
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	21	172.6	277
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	24	143.6	207
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	8	52.9	143
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	10	49.7	68
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	12	80.4	187
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	11	41.4	62
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	15	55.2	77
KOSDE	Koschny	Noord-wijkerhout	TEC1 (1.4/12)	⊘ 30°	4 mag	2	11.6	14
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	16	103.3	269
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	7	39.5	239
			MINCAM1 (0.8/6)	⊘ 60°	3 mag	11	28.8	47
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	12	49.3	91
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	13	32.9	58
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	18	107.3	207
PRZDA	Przewozny	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	9	15.0	37
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	9	26.4	39
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	11	74.2	143
			MIN26 (1.0/2.6)	⊘ 120°	2 mag	2	23.2	30
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	5	17.7	28
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	3	10.8	13
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	4	19.2	40
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	4	31.7	62
					Overall	28	1 764.7	3 611

(No. 110) with quite similar characteristics ($\alpha = 140°$, $\delta = -10°$, $v_{\rm inf} = 43$ km/s) on February 2. It appears that the shower was first detected by the Advanced Meteor Orbit Radar (AMOR) at $\alpha = 162°$, $\delta = -13°$, $v_{\rm inf} = 43$ km/s (Galligan & Baggaley, 2002). The shower was also found by the Canadian Meteor Orbit Radar (CMOR) (Brown et al., 2008). According to their latest analysis, α-Antliids are active between solar longitude 308 and 321 degrees. On February 4 the shower lies at $\alpha = 162°$, $\delta = -12°$ (reference position in Figure 2). Also the meteor shower velocity (44 km/s) matches well to the video data. Thus the existence of the α-Antliids is now also proved in the optical domain.

The naming of the shower is somewhat surprising, since α Antliae lies about 30° south. According to Peter Brown (personal communication, 2009), the original radiant position must have been significantly in error or the name was chosen by mistake. In order to prevent further confusion, the original name has still been kept up to now.

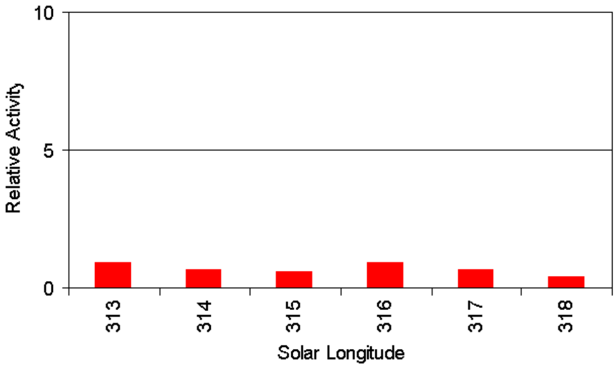

Figure 3 – Long-term activity profile of the α-Antliids.

The activity profile (Figure 3) shows that the ZHR will hardly exceed 1 in the full activity interval.

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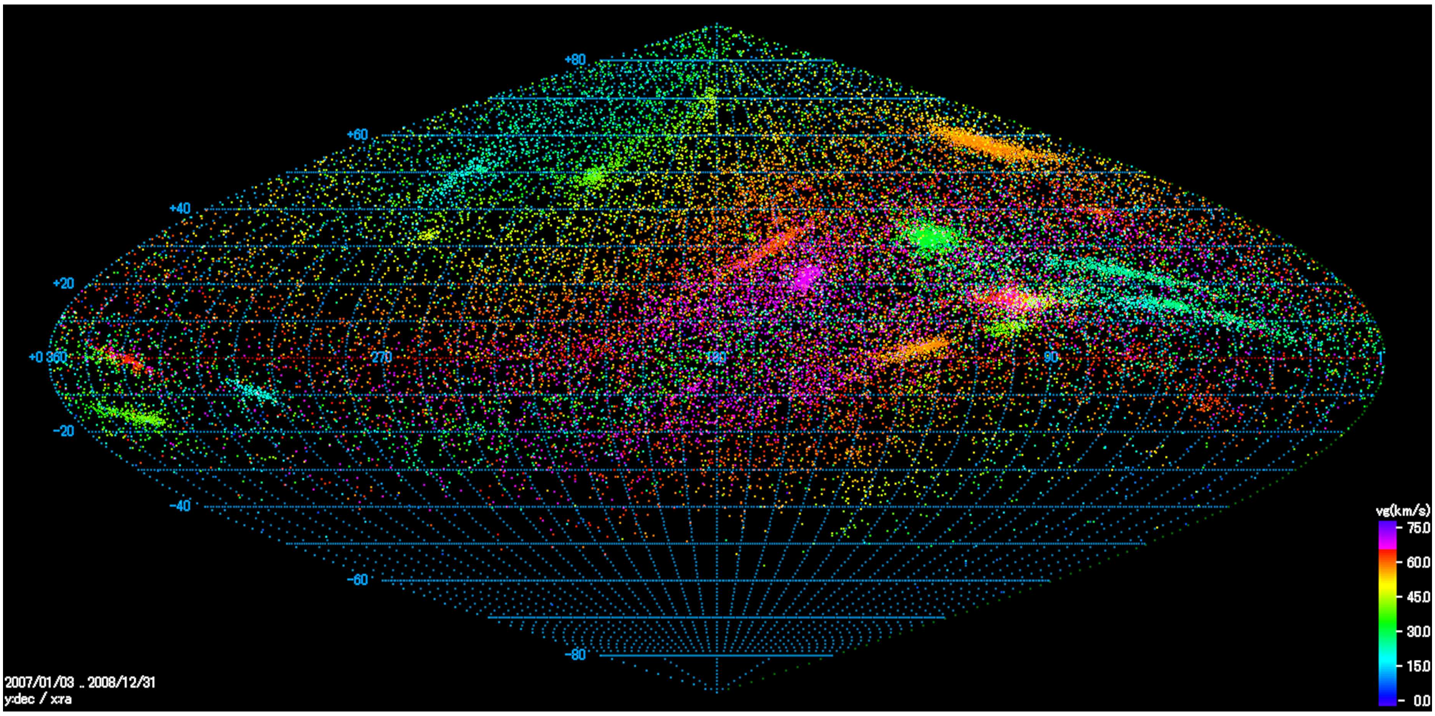
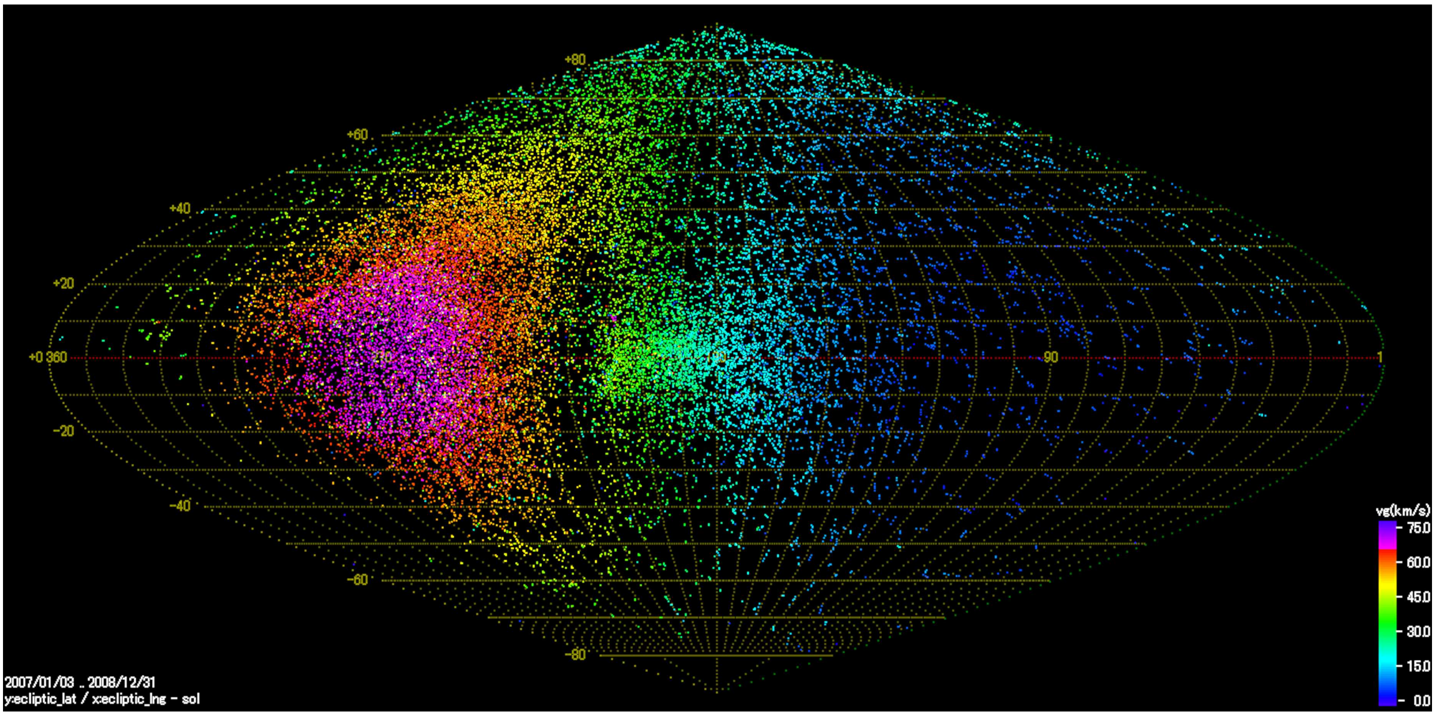
Radiant plots of the SonotaCo Network



Radiant of 39 208 meteors observed over two years, in a sinusoidal projection with the right ascension α on x-axis and the declination δ on y-axis (J2000.0). The geocentric velocity is colour coded.



Radiants of 24 837 non-shower meteors in coordinates of x-axis: ecliptic longitude minus solar ecliptic longitude ($\lambda - \lambda_\odot$), y-axis: ecliptic latitude. This projection shows the (season independent) solar direction from the Earth (0, 0), the apex direction (270, 0), and the antihelion direction (180, 0). Most of the radiants occur in the range of $\lambda - \lambda_\odot = 90$ to $270°$. This almost corresponds to the zenith direction at 18^{h} and 06^{h} local time. The high density area around the apex is the maximum of geocentric velocity and it gradually decreases towards (90, 0). It means that the velocity of the Earth's orbital motion dominates the meteor velocity. We find a low-density area around (220, 0). This is the region of Sun-grazing meteors, which are not on stable orbits.

For more information and full analysis of their video data, see SonotaCo's paper on page 55.