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Front cover photo

Bright sporadic meteor photographed on 2009 October 23 at 01^h06^m UT from Grmada, Slovenia during the Orionid observing campaign. Nikon D80 digital camera set at ISO 1600 and 50-mm $f/1.2$ lens were used for this 30-second exposure. Photo courtesy: Rok Pucer.

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 — fireballs and meteorites

Javor Kac

It has long been hinted that spring brings higher rates of bright sporadic fireballs. Indeed, some of the well-known meteorite-producing fireballs were witnessed in the period from February to April, e.g. the Příbram (1959 April 7), Innisfree (1977 February 6), Neuschwanstein (2002 April 6), Park Forest (2003 March 27), and Jesenice (2009 April 9) meteorites. Being involved with the last meteorite fall from the list above, I was looking forward to what Spring this year will bring.

Unfortunately, the skies did not bring any extraordinary bright fireball over Slovenia this year. Nonetheless, a number of bright fireballs were witnessed across the world. Two most notable are highlighted below.

On 2010 February 28 at $22^h24^m46^s$ UT, a very bright fireball was seen from Hungary and Slovakia. Despite the mostly cloudy sky over this part of Europe, the fireball or its flashes have been recorded by many security cameras as well as the photoelectric sensors at several of the European Fireball Network stations. Data from the security cameras lead researchers to the Slovak town of Košice, where the meteorites were soon recovered.

The fireball footage sequence from a security camera near Budapest, Hungary is presented on this issue's back cover.

Several weeks later, another very bright fireball appeared over the American continent. On 2010 April 15 at about 03^h07^m UT, a brilliant fireball shot above SW Wisconsin. According to American Meteor Society's fireball log, the sightings were reported from 12 states in the the American Midwest. Dozens of witnesses, mainly from Wisconsin and Iowa, also reported about hearing sonic booms. Many video recordings of the fireball were secured. Also, the weather radar picked up the echo from the falling meteorites.

Less than a day later, first meteorites were already recovered near the town of Livingston, WI.

Two video records of the event have been posted on BBC web pages:
`http://news.bbc.co.uk/1/hi/world/americas/8624064.stm`

With the security cameras now being ubiquitous, and with an increasing number of specialized meteor and fireball cameras installed throughout the world, we may expect to hear even more about similarly bright fireballs in the future.

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Call for photographs

Javor Kac

We are frequently short of photographs for the WGN covers that we publish in colour (front cover) or black&white (back cover). If you think you have a suitable meteor-related photograph, please offer it to us. More or less any computer image format will do. You can send your photographs to `wgn@imo.net`, but remember to put 'Meteor' in the subject line to get round the anti-spam filters.

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History

Meteor Beliefs Project: Seven years and counting

Alastair McBeath[1], *George J. Drobnock*[2] *and Andrei Dorian Gheorghe*[3]

The Meteor Beliefs Project's seventh anniversary is celebrated with an eclectic mixture of meteor beliefs from the 1799 Leonids in Britain, the folkloric link between meteors and wishing in some Anglo-American sources, how a meteoric omen came to feature in Nathaniel Hawthorne's 1850 novel *The Scarlet Letter*, and a humorous item from the satirical magazine *Punch* in 1861, all helping to show how meteor beliefs can be transformed by different parts of society.

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1 Introduction (by AM & ADG)

Several times during the Meteor Beliefs Project to date, we have published occasional eclectic compilations of material discovered by ourselves or others. We have often used the Project's April anniversary to present such items, and we take the opportunity of this seventh anniversary to do so again. There is though a general theme of transformation of ideas running through the material below, in particular how the public perception of meteoric phenomena can differ significantly from what more scientifically-inclined thinkers are prepared to accept, and how this helps blur the lines between what various groups in society might consider 'fact' or 'fiction'. In doing so, we are delighted to welcome back as guest author George Drobnock, who was instrumental in locating much of the original detail used in the second half of this paper especially. As commonly at past Project anniversaries, we have attempted to add a deliberately humorous note with the final item discussed.

We use this anniversary article also to invite others to continue to contribute information for the Project's further advancement, concerning literary, poetic, mythological or folkloric references to meteors. Our inaugural article (McBeath & Gheorghe, 2003), and the Project's webpage, off the "Ongoing Projects" page of the IMO website, have notes on what is of most interest to us.

2 The 1799 Leonids from Britain

In discussions of the great Leonid storm of 1799 November 11–12 (e.g. Littmann, 1998, Chapter 4), we frequently find observations of it cited as made from the Americas east as far as Greenland and ships on the western Atlantic Ocean, occasionally with mention of a lone sighting from Germany in Europe. However, the storm was seen elsewhere in Europe too, including in the British Isles, where several reports from places scattered across England and south Wales featured in *The Gentleman's Magazine* (Vol. 69, Part II, 1799 November, p. 987), a leading current-affairs journal in Britain at the time. Despite the full Moon then, hundreds of meteors or more per hour were seen, many bright to very bright, leaving trains lasting two or three minutes at times.

At Hull on the Humber estuary near the east coast of England, "One of these meteors, more brilliant than the rest, illuminated the whole firmament, and by its apparent approximation to the earth created some alarm." (Note that in the *Gentleman's Magazine* quotes here, the original "long-s's" have been converted to the modern short form.) Further north, at Greatham near Hartlepool on the northeast English coast, "The general appearance was sublimely awful. To some spectators the sky appeared to open, and to display a number of luminous serpents moving in a perpendicular direction. These were soon afterwards broken into separate balls and fell towards the earth in a shower of fire." The Magazine's editors concluded the verbatim reports with the Aristotelian doctrine, still generally regarded as the most plausible for meteors among experts at the time: "These meteorous appearances, so frequent of late, may be accounted for by the great moisture of the earth which, being exhaled by the heat of the sun, produces these inflammable vapours."

Such a dismissive attitude seems to have prevented other Leonid sightings from being published after the event's immediate novelty had passed. However, among the notices following the 1866 Leonid storm, Dr David Gavine (personal communication), currently the BAA's Aurora Section Director, uncovered an item in the *Aberdeen Journal* newspaper for 1866 November 21, in which John Cruickshank (1787–1875) recalled the 1799 storm as he saw it from Banffshire near the Aberdeen coast of northeast Scotland, when he was twelve. He had left home on foot well before dawn, and remarked of others he met that, "Several persons who had set out earlier to carry their produce to a sea-port described the number of shooting stars as incalculable, and said they thought all the stars in the eastern half of the heavens had shot, believing that every train of light came from some star."

These quotes neatly framed both the common and learned beliefs about meteors in Britain in 1799 – fiery sky-serpents or dragons able to cause fear, and perhaps

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real damage, to the Earth, while each meteor was also a falling star. At the same time, they were 'really' only ignited vapours in the upper atmosphere, so of proto-scientifically little significance.

3 Meteors & wishing

As discussed in the Project previously, (cf. most recently Avilin, 2009), making a wish on seeing a meteor was a belief found in various places. Burke (1986, p. 215, and the references in notes 2 & 3 on p. 353) suggested it was common in Europe, Eurasia and North America, sometimes requiring the wish to be made before the meteor vanished to be successful. Opie & Tatem (1989, p. 376) cited examples from the British Isles between 1839 and 1957, such as, "Whatever you think of when you see a star shooting, you are sure to have", from 1851, or, "Wish quickly while the star falls", from 1953. Burke (loc. cit.) gave the view of some of his cited authors that the belief related to the idea of a star falling from the sky when the gods opened the heavenly dome to view the Earth, and that the star extinguishing was due to this sky-door closing, after which the gods would no longer hear the wish. The implication of the plural 'gods' seemed to be that this was thought an ancient belief, albeit one without foundation, and likely one simply constructed as an explanation by scholars in the late 19th and early 20th centuries, judging by the dates of Burke's references.

It seems more plausible the wishing-on-a-meteor concept may have originated from a human desire to try to control the capricious nature of meteors perceived as omens, which latter, as we have explored before, had genuinely ancient roots. Transforming a portentous meteor into one where its implied power could be redirected towards a desired personal goal, instead of a random one, would thus have given a quick-witted witness a share in that supposed power.

A further aspect of this is the belief of wishing on an ordinary star, such as the first one spotted in the evening twilight (Opie & Tatem, loc. cit.). This could not have related to the idea of a door opening and closing, as suggested for meteors, yet it may still have been connected to meteors, possibly having originated as an easier task than trying to wish on an unpredictable, brief, 'shooting-star'. It is not clear though when this ordinary-star wishing concept began. Opie & Tatem cited the first recorded instance from Britain as 1958, but their 1964 entry indicated it was in use by circa 1914. It famously featured in American movies in 1939 ("The Wizard of Oz", in the song "Somewhere Over The Rainbow") and 1940 ("Pinocchio", the song "When You Wish Upon A Star"), so was a well-known theme by then. There is a degree of ambiguity in just what 'star' might have meant in both songs, which could have encompassed 'meteor' as well. For instance, even modernly, the Walt Disney Company's logo at the start of their movies features the opening notes from "When You Wish Upon A Star", while a star leaving a curved trail shaped like a rainbow passes over a stylized 'Magic Castle', sufficient to perpetuate the connection between meteors and wishing in many people's minds into the 21st century.

Though not directly related to wishing, another song in "The Wizard of Oz" described the heroine Dorothy as having arrived in the land of Oz by falling from a star, a star named 'Kansas', her home state in the USA on Earth, something which further linked to each star on the USA's flag representing a state within the Union. As her arrival killed one of two wicked witches, and freed the locals from her evil domination, that too could be seen as fulfilling their wish to be free.

4 Hawthorne's *The Scarlet Letter*

In 1850, American author Nathaniel Hawthorne (1804–1864) published his second historical novel, *The Scarlet Letter*. This was set in the formative days of the Massachusetts Puritan colony on America's east coast, two centuries earlier. It particularly centred on events surrounding a few of the colony's principal characters, most originally real, the leading four imaginary, from the key Massachusetts towns of Salem, Hawthorne's birthplace and where he wrote the book, and Boston, which replaced Salem as the colony's capital in September 1630. The linking thread in the tale was the eponymous 'Scarlet Letter', an 'A', which recurred in different forms throughout the work, always as a red letter set on a dark background.

The meteoric 'A' occurred in Chapter XII, the middle chapter of the novel, "The Minister's Vigil". The minister was the invented clergyman Arthur Dimmesdale, who, with much on his mind, had been wandering about Boston on a cloudy, thus very dark, night, supposedly in early May, running thoughts through his mind, and imagining various unpleasant possibilities. One such thought caused him to shriek aloud, but only two people elsewhere seemed to have heard this, and briefly looked out into the night with lit lamps from their bedrooms. Hawthorne used this as a cue to begin others stirring however, because it seemed this cry had coincided with the death of the colony's first governor, John Winthrop (1588–1649 — he actually died on 1649 March 26, not in May, however). Weaving this genuine death into the novel provided a date for the associated events, of course. Dimmesdale first saw the Reverend John Wilson (1591–1667, really minister of the First Church of Boston), returning home from attending Winthrop's deathbed. Then he saw his secret lover Hester Prynne and their equally secret daughter Pearl, who had also been with Winthrop when he died. Dimmesdale spoke with Hester and Pearl for some time.

Then suddenly, "a light gleamed far and wide over all the muffled sky. It was doubtless caused by one of those meteors, which the night-watcher may so often observe burning out to waste, in the vacant regions of the atmosphere. So powerful was its radiance, that it thoroughly illuminated the dense medium of cloud betwixt the sky and earth. The great vault brightened, like the dome of an immense lamp. It showed the familiar scene of the street, with the distinctness of mid-day, but also with the awfulness that is always imparted to familiar objects by an unaccustomed light" (Hawthorne, 2007, p. 121).

As explanation for what followed, Hawthorne added a note between Dimmesdale's looking upwards and describing what he saw there. "Nothing was more common in those days, than to interpret all meteoric appearances, and other natural phenomena, that occurred with less regularity than the rise and set of sun and moon, as so many revelations from a supernatural source. Thus, a blazing spear, a sword of flame, a bow, or a sheaf of arrows, seen in the midnight sky, prefigured Indian warfare. Pestilence was known to have been foreboded by a shower of crimson light" (op. cit., pp. 121–122).

What the minister saw was what seemed to him the lines of a large, dull-red, letter 'A', due to some thinning of the dark, overcast clouds, as the meteor itself passed unseen. Naturally, his guilt interpreted this as 'A' for 'Adulterer', but others who were abroad then, and who also saw the sky light-up, such as the town's sexton, interpreted it as 'A' for 'Angel' – "For, as our good Governor Winthrop was made an angel this past night, it was doubtless held fit that there should be some notice thereof", as the sexton put it (op. cit., p. 124).

As the central event of the novel, this meteoric 'Scarlet Letter' signalled the start of changes for the book's characters and their community, since the death of the Puritan founding-father John Winthrop would ultimately bring in new people to the colony's administration, whose ideas would be different to his, and which contrast Hawthorne wished to explore. It was thus a particularly pivotal moment, as Washizu (2008) noted.

There were several other points of importance. Hawthorne had an active interest in astronomy, and was alive and writing at a time of significant meteoric and cometary events (such as the 1833 Leonids, Comets 1P/Halley in 1835–36, and C/1843 D1). His description suggested he was familiar with the appearance of meteors generally, and may indeed have witnessed a brilliant fireball illuminating a cloud-sheet. He was equally aware of the links in folklore between meteors and portents, and meteors and death (cf. Gheorghe et al., 2006), when deciding to make a meteoric event such a central transformative force in his novel.

However, no such meteoric omen was associated with the death of the real John Winthrop in 1649 – cf. Washizu (2008). There was though a comet, C/1652 Y1, seen from mid December 1652 to early January 1653, which was taken as a portent in Massachusetts as foretelling the death of millennialist preacher John Cotton (1585–1652) on 1652 December 23. Cotton was a contemporary of Winthrop's, and had sailed in Winthrop's fleet from England for Massachusetts in April 1630. It seems likely that Hawthorne deliberately reinterpreted this genuine cometary portent preceding John Cotton's death, into a meteoric one immediately following John Winthrop's, in his book. Winthrop, as such a leading figure in the colony's society, would have been an ideal subject for such a celestial commemoration, had the meteoric omen lore been accurate, and this fitted particularly well into the novel's symbolic idiom.

5 "Meteors for the Million"

An item from the British satirical magazine *Punch* (Vol. 41, 1861 August 24, p. 75) forms our final piece this time. Entitled "Meteors for the Million", it cast a sarcastically comic eye over some meteor observing instructions, claimed as sent to the magazine "by an eminent astronomer". We have been unable to ascertain whether some original instructions really lay behind this, or if the entire text was simply a spoof based on pricking the pomposity of scientists unable to provide readily-comprehensible information. It was written as if the instructions were genuine, certainly. This was the period when collecting accurate positional data for meteors was becoming increasingly important, of course, and it says much for the level of interest in meteors in 1861 that such an article should have featured in *Punch* at all.

Punch's editors cited from the instructions as follows:
"Let a smooth tree or firm erect post, 5 or 6 inches (12 or 15 cm) thick, be selected, and the ground made level about it. The observer, provided with a piece of chalk, will embrace the tree with his clasped hands at full arm's length, the head and body being held erect. At the appearance of a Meteor, the body will be swung about until the bole of the tree or post intersects upon the heavens the central point of the Meteor's path, and there, without deranging body or eye, he will chalk at the centre of the tree's face a small figure (1), and note at once opposite to a similar number in a book or form of registry the hour of an imaginary clock-dial, towards which the Meteor might be judged to have shot from the centre outwards, 12 o'clock being imagined at the top of the post."

While applauding the exercise thus afforded to the observer, the editors expressed concern for the after-dinner witness having to hold the post at full stomach's distance too, and that derangement of mind, let alone body, eye or dress, was liable to result for any ample-bodied observer attempting such gymnastic feats, simultaneously jotting down notes on the meteor, yet still clasping the tree firmly with both hands! Worse still, the instructions continued by requiring additional notes to be taken, regarding the time, appearance, brightness and path-length for "all the successive meteors [...] that appear within the hour of observation". Finally, a 'horizon circle' and 'south line' were to be chalked on the tree, the distance from the observer's eye to the 'horizon circle' measured, along with the 'horizon circle's' circumference, and measurements for the heights above this 'circle' and distance east from the 'south line' for every meteor figure marked on the pole.

The editors concluded their commentary by noting the instructions still seemed incomplete, and wondered, "what observers are to do in case a meteor falls behind them", or, "if to corroborate their scientific evidence they must dig up the tree or post by which they made their observations, and send it to the *savant* to whom they send their notes." They also warned of the danger of mistaking a policeman's bull's-eye lantern light for a meteor, "especially at eventide and after a good dinner, when their vision, if not double, is not the most distinct"!

6 Conclusion

For all its humorous intent, "Meteors for the Million" reminds us that what may seem clear to one person is not necessarily so for others. Such differing perceptions about meteors as we have explored here illustrate how such beliefs can be manipulated into new forms. This is just as well, since it is how science progresses too. Looking back 210 years to 1799, it is fascinating to note the popular beliefs about meteors then, are closer to what we would consider correct scientifically now, than the Aristotle-inspired 'ignited rising vapour' concept, the learned paradigm of its day.

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Ongoing meteor work

Analysis of the SonotaCo video meteoroid orbits

Peter Vereš and Juraj Tóth [1]

Since 2007, the Japanese video network has provided a significant amount of meteor data observed by the multi-station video meteor network located in Japan. The network detects meteors generally up to magnitude +2 and is probably the most accurate and largest freely accessible video meteor database to date. In this paper, we present our analysis on the qualitative aspects of the meteoroid orbits derived from the multi-station video observations and of the separation of the stream members from the sporadic background.

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1 Introduction

The SonotaCo database of meteor orbits consists of 38710 entries. Of those, 37% were identified as shower meteors. Data were taken by 35 video meteor stations in Japan during 2007 and 2008 (SonotaCo, 2009). The survey goal was to cover the entire year. Each database entry is equivalent to the heliocentric orbit derived from the multi-station video observation. In addition to the heliocentric orbit, the meteor is identified as a shower or a sporadic meteor, based on the apparent position on the sky plane, angular velocity, magnitude and derived physical parameters such as geocentric velocity, relative height of the meteor trail above the surface, duration of the visible trail, etc. All parameters were derived by the UFOAnalyzer software and all orbits derived by the UFOOrbit software, both made by SonotaCo. The notable advantage of the database is the very similar camera setup of all the network stations (e.g. lenses and CCD video cameras) and unique tool for astrometric and velocity reduction (UFOAnalyzer), which almost eliminates individual observer influences. This makes the database very homogeneous.

2 Database reduction

In order to separate high-quality orbits, we set multiple constraints on the database. The constrained parameters are presented in the parentheses. Usually we adopted a quality determination according to the Q3 condition for the high-precision computation (internal set of parameters for UFOOrbit). Most importantly, the entire meteor trail had to be inside the field of view of at least two video meteor stations (inout = 3). Astrometric accuracy and velocity determination increase with the observed trail length, so the meteor trail had to be longer than 1 degree ($Q_\mathrm{o} > 1$) and the duration of the trail was over 0.3 seconds (dur > 0.3). At the NTSC frame rate of 30 frames per second, this provides at least 10 positions and velocity measurements per meteor trail. These parameters were set with respect to the network camera setup. Also the parameter Q_c (cross angle of two observed planes) had to be larger than 20 degrees. The apparent velocity and derived velocities from two stations may differ; our constraint requires the difference to be less than 10% ($\mathrm{d}\,v_{12}\% < 10$). One trail observed from two stations must be detected to reach at least 50% overlap ($Gm\%$) and the ground projection of the same meteor observed and derived for two different stations must not have a larger deviation than 0.1 degrees ($\mathrm{d}\,GP$). Finally, the total quality assessment parameter must be larger than 0.7 (QA).

The number of meteor orbits that fulfill the quality constraints is 8890. 47% are meteoroids identified as stream members (IAU established meteor showers and showers from the IAU working list). 292 meteoroids are on hyperbolic orbits ($a < 0$ and $e > 1$), of which 144 are sporadic and 148 were assigned to a meteoroid stream (mostly Perseids, Orionids, Leonids, December Monocerotids, σ-Hydrids).

The three-step algorithm of the meteor shower identification by SonotaCo is the following. A particular meteor must be observed during the known meteor shower activity (defined in J6 catalog (SonotaCo, 2009)) plus 10 days variation. The back-traced meteor trail must lie within 100% of known meteor radiant. The geocentric velocity must be within 10% of the known mean geocentric velocity of the shower.

3 Meteoroid stream identification

The assignment of a meteor to a meteor shower is not a trivial task. In our analysis, we employed orbit similarity criteria to distinguish shower meteors from the non-shower component of the SonotaCo video meteor database. Particularly, the Southworth–Hawkins D-criterion (D_SH) was used for selected meteoroid streams (Southworth & Hawkins, 1963). Considering the individual behavior of meteoroid stream orbits in comparison to the mean orbit, we calculated the distribution of the D-criterion for the Perseids (reference mean orbit by Kresák & Porubčan (1970)), Orionids (Kresák & Porubčan, 1970), Geminids (Lindblad et al., 2003), Leonids (Kresák & Porubčan, 1970), σ-Hydrids (Jenniskens, 2006), and Southern δ-Aquarids (Kresák & Porubčan, 1970). The histogram of the D-criterion of the mentioned meteoroid streams derived from all meteors (independently from the UFOOrbit identification of meteor showers) is shown on Figure 1. The limiting D-criterion for a particular stream was derived from

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Table 1 – Meteoroid stream identification according to the UFOOrbit algorithm and the Southworth–Hawkins D-criterion. $D_{\rm SH}$ is the obtained limit for the identification of the specific meteoroid stream; All $< D_{\rm SH}$ is the number of stream members derived according to the D-criterion from the entire subset of data (shower and non-shower); '%' is the percentage of stream members in the stream component according to UFOOrbit that did not fulfill the D-criterion; 'Data' is number of stream members identified by UFOOrbit; 'Non' is the number of sporadic meteoroids according to UFOOrbit, but belonging to the stream according to the D-criterion.

	Our data		SonotaCo		
Shower	$D_{\rm SH}$	All $< D_{\rm SH}$	%	Data	Non
PER	0.30	907	3.5	931	9
ORI	0.20	408	8.8	416	29
GEM	0.20	881	3.9	916	1
LEO	0.20	90	15.2	105	1
HYD	0.30	200	11.2	215	9
SDA	0.15	103	2.0	104	1

the point where the distribution of the D-criterion became eventually dispersed in the sporadic background (dashed lines in the plots of Figures 1 and 2). If the meteoroid orbit has a lower value of the specific D-criterion, we consider it a stream member. Finally, we compared how many particular shower meteors belong to the sample of 8890 according to the method by UFOOrbit and the D-criterion. According to the D-criterion, some of the shower meteors (according to the UFOOrbit classification) do not belong to the meteoroid stream and on the contrary, some sporadic meteors (according to the UFOOrbit) do belong to the meteoroid stream, but only in a few cases. The results are presented in Table 1.

Although 47% of the 8890 meteors are sporadic meteors according to UFOOrbit classification, our investigation on six meteor showers implies that the sporadic population in the database is contaminated by shower meteors in a very small number (see Table 1, column 'Non'; Figure 4). To obtain a rough estimate of the sporadic meteor population, we applied the Southworth-Hawkins D-criterion equal to 0.25 for 16 major streams that may make the most significant contribution to the sporadic background of the SonotaCo database. We used reference mean orbits of these meteor showers: Quadrantids, Lyrids, π-Puppids, η-Aquariids, Arietids, σ-Hydrids, June Bootids, Southern δ-Aquariids, Perseids, Draconids, Orionids, Southern Taurids, Northern Taurids, Leonids, Geminids, and Ursids (mean orbits taken from the photographic data (Jenniskens, 2006)). The radiant positions after the first separation procedure are plotted in the density graph in Figure 3. We examined the higher density of radiants at solar longitudes $265° \pm 30°$ ($\alpha = 75°$ to $115°$, $\delta = 10°$ to $28°$) and considered it a contamination from the Taurid complex (the position of the clump was similar as if the Taurids were active for a longer period; the meteoroids have similar geocentric velocities and orbits). To separate the assumed Taurid complex contamination, we used Steel's D-criterion equal to 0.2 for the mean orbit of

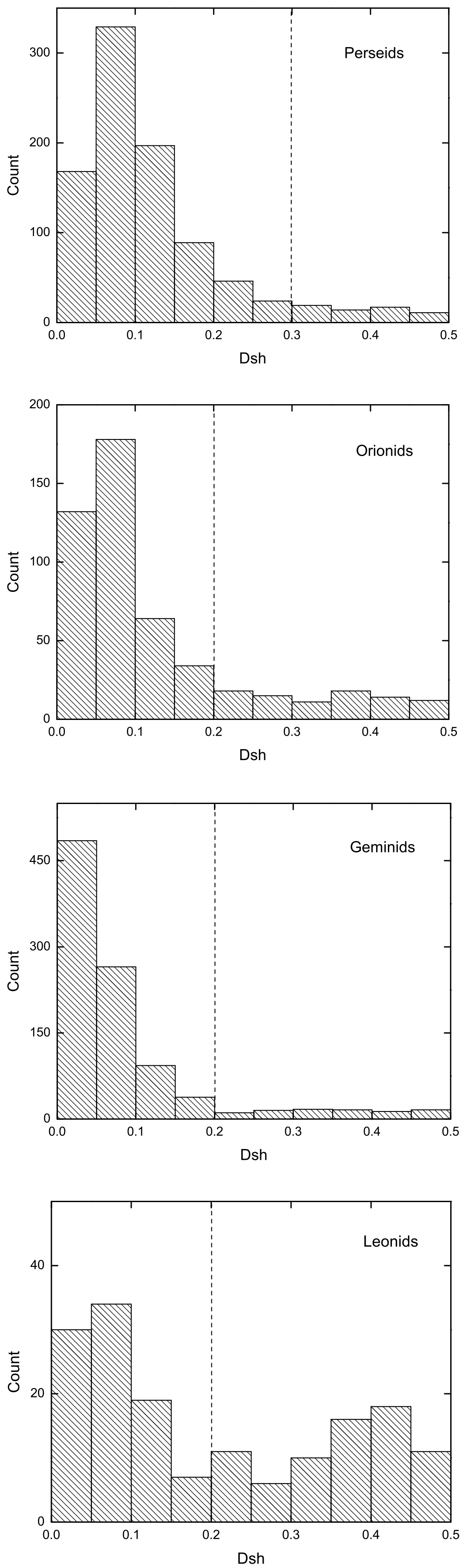

Figure 1 – Southworth–Hawkins D-criteria for stream orbits from the reduced database. The dashed line represents the limit that we adopted to distinguish stream members from the sporadic background.

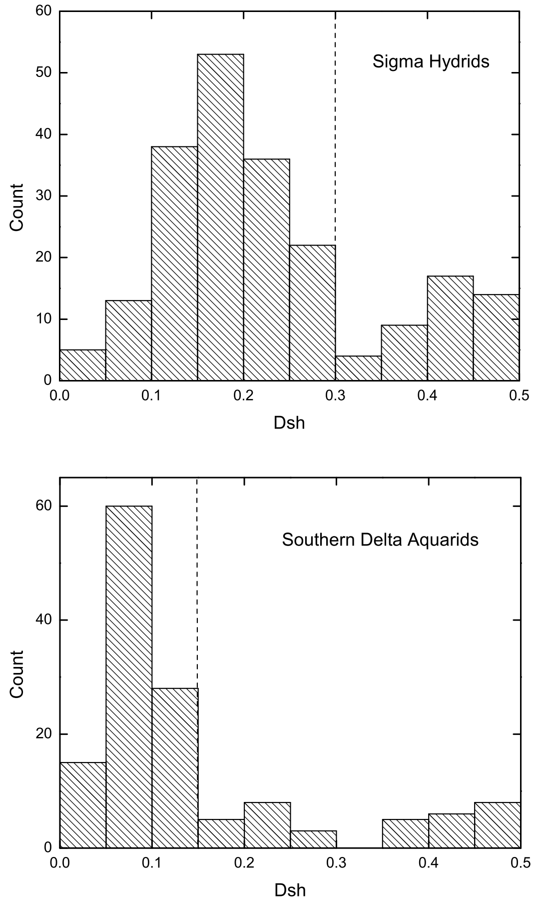

Figure 2 – Southworth–Hawkins D-criteria for the σ-Hydrids and the Southern δ-Aquariids. The dashed line represents the limit that we adopted to distinguish stream members from the sporadic background.

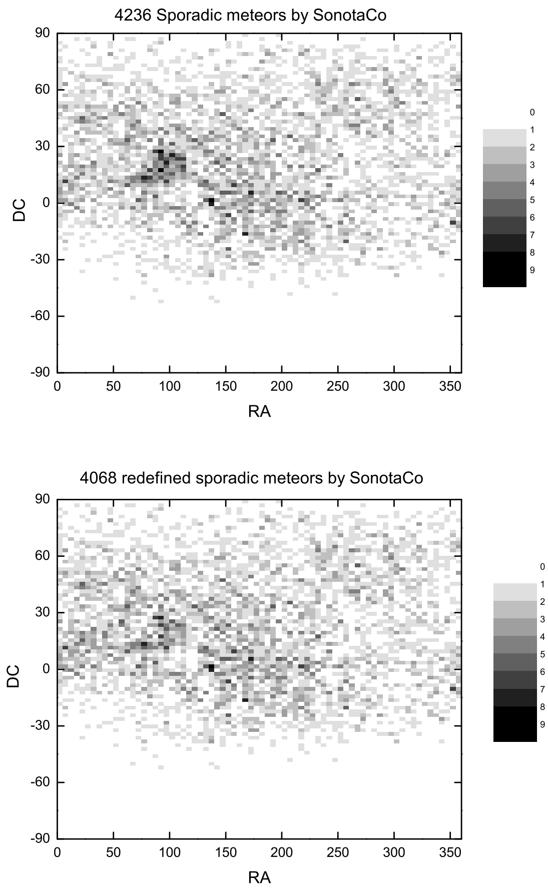

Figure 3 – Density plots of sporadic population radiants from the reduced UFOOrbit orbit database (top) and the corrected sporadic population (bottom); confident meteoroid stream members were separated using D-criteria.

the Southern and Northern Taurids (Steel et al., 1991; Porubčan et al., 2006). This criterion is not sensitive to the argument of the perihelion and the ascending node and, therefore, it distinguishes similar orbits from the sporadics even when the meteor was observed beyond the established activity period. Finally, the sporadic meteor count was derived to be 4068. The all-year activity is plotted in Figure 3. There are two visible sources of sporadic meteors on the apex-corrected radiant distribution in ecliptical coordinates (Figure 5). The apex source contains meteoroids with high geocentric velocities, orbits with high inclinations and eccentricities. In contrast, the antihelion source contains slow meteoroids with moderate eccentricities and low inclinations. We may assume that the meteoroids from the apex and toroidal sources have a cometary origin and the meteoroids from the antihelion source are of near-Earth asteroid origin.

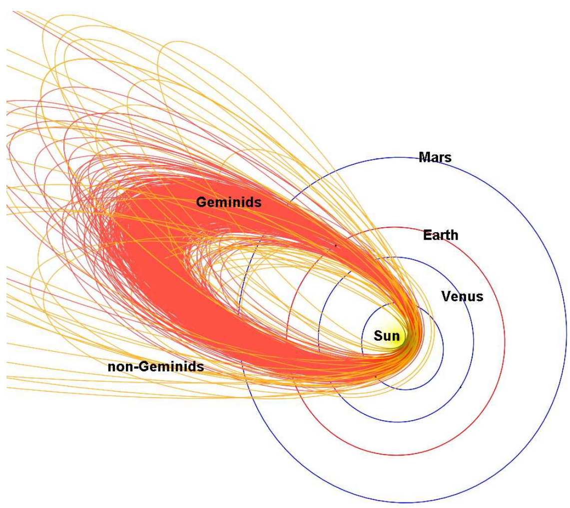

Figure 4 – Orbits of the Geminids meteors derived by the UFOOrbit algorithm. Non-Geminids were identified as Geminids by UFOOrbit but did not fulfill the D-criterion for orbital similarity and are apparently displaced from the standard meteoroid stream.

4 Conclusion

The database of video meteors by SonotaCo contains meteors that, among the high quality subset of data, are relatively well distinguished as shower or sporadic meteors. For further analysis of a meteoroid's membership in a particular stream, we recommend the use of additional tools for the stream identification such as

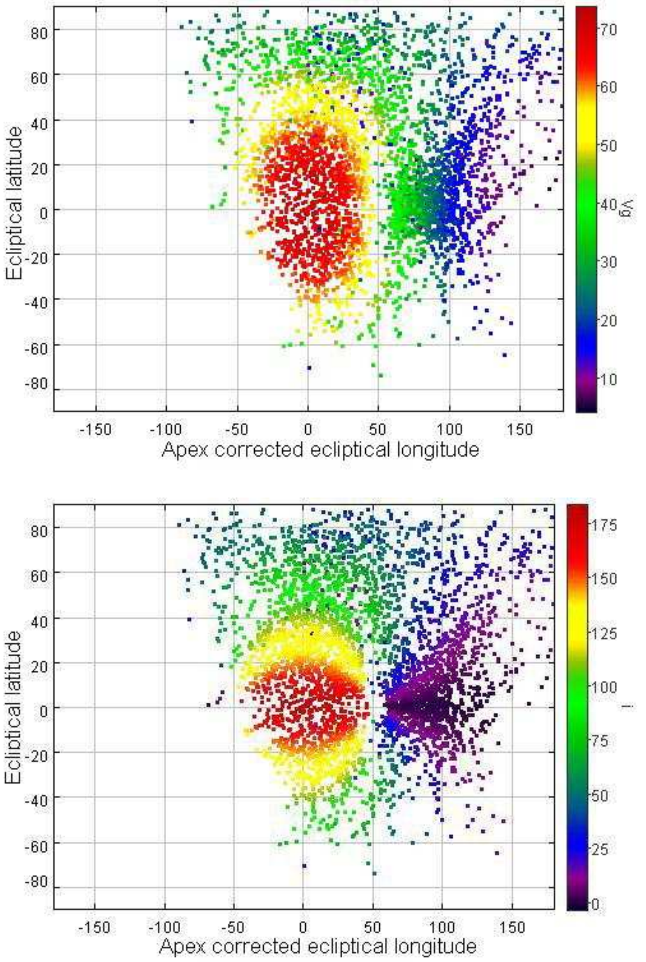

Figure 5 – Ecliptical coordinates of sporadic meteor radiants corrected for the Earth's apex. The color palette scales represent the geocentric velocity distribution and the orbital inclination, respectively.

the orbit similarity *D*-criteria and the orbital evolution with respect to the mean reference orbit of the stream and the assumed parent body. Meteoroids that were misidentified as stream members for several examined meteoroid streams represent only small numbers of the shower group identified by UFOOrbit. The separated sporadic meteors demonstrated the expected sky-plane distribution with respect to the Earth's apex with an exceptional, denser region which might be a part of the wide Taurid complex. After all, the subset of video meteoroid orbits we selected provides reliable data for both stream and sporadic meteoroids.

Acknowledgment

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SPA Meteor Section Results: 2005

Alastair McBeath [1]

A review of analyzed data and other information submitted to the SPA Meteor Section from 2005 is presented, with some discussion. Events covered include: the radio Quadrantid maximum on January 3; a spectacular daylight fireball seen across England and Wales at $9^{\mathrm{h}}55^{\mathrm{m}}20^{\mathrm{s}} \pm 10$s UT on February 20; the η-Aquarid near-maximum activity recorded visually and by radio; a very well-observed visual Perseid return in July-August, and notes on the radio near-peak activity; a survey of radio meteor activity in late September to early October for the daytime Sextantids; radio data concerning the October 5/6 video outburst; the Taurid 'swarm' return and the unusually large number of fireball sightings it helped generate in October–November; the radio Orionid and Leonid maximum findings.

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1 Introduction

Difficulties in getting material published in WGN in recent years led to the regular SPA Meteor Section results papers here at first being delayed (so the 2004 quarterly papers were published only in mid 2007, as McBeath, 2007b, c, d & e; see also McBeath, 2005a), and then postponed. Of the articles prepared from data collected during 2005 and later, only that on the 2005 radio Draconids was actually published in this journal (McBeath, 2007a). Preliminary reports, with further discussion in places, were instead published primarily online in the SPA's fortnightly Electronic News Bulletins (ENBs). Many of these are archived on the SPA's website, freely available to anyone who wishes to see them. As part of the Society's activities for the International Year of Astronomy 2009, the Section's webpages have been fully upgraded and updated, so there is now also a series of indexes linking to the various meteoric ENB topics per year from 2005 to the present, available via the Section's homepage, at:
`http://www.popastro.com/sections/meteor.htm` .

In returning to publishing the Section's results in WGN again, and following discussions with the current Editor, it was felt impractical to resume with the previous detailed quarterly reviews of meteor activity, because the time elapsed meant the information was no longer so nearly topical. To avoid a break in the calendrical sequence however, it was decided to prepare annual summary articles covering the earlier of the 'missing' years, before restarting that more usual approach. Consequently, this current paper sketches an overview of the main events of 2005, updating some of the preliminary ENB reports in the process, and including materials which have not been published previously.

2 Observing totals and observers

In general, 2005 brought an improvement in meteor observer activity compared to 2004 for the Section. Visual meteor watching from the UK continued to be at a relatively poor level compared to past decades, however. Aside from the obvious, normal, problems posed by the temperate maritime climate of the British Isles, observers and former observers have commented that one of the main difficulties has been a continual increase in light pollution across most of the country, such that few people have the luxury of access to a sufficiently dark sky near enough to their homes to make routine meteor work viable, and even travelling some distance from the major conurbations often provides skies less suitable than they were only a decade or so ago. In addition to this decline, many of the Japan-based radio observers stopped providing their regular data to the Radio Meteor Observation Bulletins (RMOBs; `www.rmob.org`) in late 2004, which to-date (late-2009) sadly has not been resumed. This was unfortunate, since it reintroduced something of a gap in coverage over Far Eastern longitudes. Thankfully, one long-standing Japanese radio observer, Sadao Okamoto, did continue to submit his results to the RMOBs throughout 2005, so the data-gap was not total, but the tally of viable radio data was considerably down on that in 2004. On a more positive note, the video totals increased significantly during the year's final quarter, when Italian observer Enrico Stomeo began providing routine, detailed summaries from his automated meteor camera, alongside those of the late Steve Evans in England. Table 1 provides the year's main totals.

The contributing observers involved are listed below. Abbreviations used in the list include 'R' = radio observations were provided, 'Vi' = video, while '+ V' indicates visual data were submitted as well as any other kind. Where no letter is appended, only visual results were made by that person. Many of the contributed data arrived in the form of reports in publications, including in the American Meteor Society's (AMS's; `www.amsmeteors.org`) journal *Meteor Trails* kindly provided courtesy of its editor Robert Lunsford, the Arbeitskreis Meteore's (AKM's; `www.meteoros.de`) journal *Meteoros* thoughtfully sent in by Ina Rendtel, and the RMOBs, regularly made available monthly by its editor, Chris Steyaert. Some observers' data featured in more than one place, and some sent in separate reports directly or via a third person as well, with Rainer Arlt, Valentin Grigore (the SARM-Romania reports) and Richard Taibi particularly helpful in forwarding useful results from other people. Observers who reported electronically sometimes used a pseudonym, and where no other name could be established for such

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IMO bibcode WGN-382-mcbeath-spams2005
NASA-ADS bibcode 2010JIMO...38...58M

Table 1 – Visual, video and radio hours' totals, visual and video meteor numbers recorded (with a partial breakdown of visual types), per month. At most three main showers per month, plus the Antihelions, ANT, have been listed for the visual breakdowns to conserve space. Though the ANT were not recognised as such in 2005, various near-ecliptic sources that now form part of the ANT were, and these have been simply combined here.

Month	Visual						Video		Radio
	Hours	QUA			ANT	Meteors	Hours	Meteors	hours
January	47.9	162			1	588	33	126	5485
February	34.4	–			35	227	–	–	4509
March	11.1	–			12	83	–	–	5711
		LYR	ETA						
April	34.8	82	0		2	233	7.5	22	5326
May	93.7	–	275		93	844	0.04	2	5958
		JBO							
June	74.9	9			86	609	–	–	4031
		SDA	CAP	PER					
July	133.8	85	114	164	81	1440	3.1	14	4411
August	441.8	99	142	6940	199	10523	5.5	44	4881
		AUR	DAU						
September	134.4	50	122		99	1266	–	–	4036
		ORI	STA	NTA					
October	119.9	223	197	100	–	1398	51.8	192	6688
		LEO							
November	96.8	107	120	116	–	1047	113.1	433	7712
		GEM	URS	COM					
December	55.1	618	14	3	–	1058	32	457	7986

people, these have been given within quotation marks. In general, where an observer submitted data to more than one place, just one option has been selected to indicate where those results may be found.

"A" (UK), "aditir" (India), Enric Algeciras (Spain; R, RMOB), Rainer Arlt (Germany; AKM), Jure Atanackov (Slovenia; AMS), Pierre Bader (Germany; AKM), Tom Banks (France), Lukas Bolz (Germany; AKM), Mike Boschat (Nova Scotia, Canada; R, RMOB), Jay Brausch (North Dakota, USA), Jeff Brower (Colorado, USA & British Columbia, Canada; R, RMOB), Alessandro & Giuseppe Candolini (Italy; R, RMOB), Alexandru Conu (Romania; SARM-Romania), Tim Cooper (South Africa), Mike Dale (Scotland), Al Degutis (Illinois, USA; AMS), Maurice de Meyere (Belgium; R, RMOB), Gaspard De Wilde (Belgium; R, RMOB), Clive Down (Wales), Audrius Dubietis (Lithuania), David Entwistle (England; R, RMOB), Frank Enzlein (Germany; AKM), Steve Evans (England; Vi), Mike Feist (England), Stela Frencheva (Germany; AMS), Dave Gavine (Scotland), Valter Gennaro (Italy; R, RMOB), "Geoff" (England), Christoph Gerber (Germany; AKM), Ghent University (Belgium; R, RMOB), Vincent Giovannone (New York, USA; AMS), George Gliba (West Virginia, USA; AMS), Bill Godley (Oklahoma, USA), Shelagh Godwin (France), Lew Gramer (Florida, USA; AMS), Robin Gray (Nevada, USA; AMS), "Gregger" (England), Valentin Grigore (Romania; SARM-Romania), Matthias Growe (Germany; AKM), Patrice Guérin (France; R, RMOB), Peter Gural (California, USA; AMS), Steve Hansen (Massachusetts, USA; R, RMOB), Robert Hays (Indiana, USA; AMS), Alan Heath (England; R + V), Thilina Heenatigala (Sri Lanka; AMS), Zoltan Hevesi (Hungary), Carl Johannink (Netherlands; AMS), Ed Jones (Arizona, USA; AMS), Javor Kac (Slovenia; AMS), Szabolcs Kiss (Hungary; R, RMOB), André Knöfel (Germany; AKM), Peter Knol (Netherlands; R, RMOB), Ralf Kuschnik (Germany; AKM), "Lance" (England), Pete Lawrence (England), "Lawrie" (UK), Robin Leadbeater (England; Vi + V), Ian Lee (England), Robert Lunsford (California, USA; AMS), Hartwig Lüthen (Germany; AKM), Tony Markham (England), Nick Martin (Scotland), Pierre Martin (Québec & Ontario, Canada; AMS), Paul Martsching (Iowa, USA; AMS), Alastair McBeath (England), Tom McEwan (Scotland), Norman McLeod III (Florida, USA; AMS), Cliff Meredith (England), Patrick Mergan (Belgium; R, RMOB), Russell Milton (Oregon, USA; AMS), Danut Mitrut (Romania; SARM-Romania), Sirko Molau (Germany; AKM), Sven Näther (Germany; AKM), Stan Nelson (New Mexico, USA; R, RMOB), Adriana Nicolae (Romania; SARM-Romania), Diana Ogescu (Romania; SARM-Romania), Sadao Okamoto (Japan; R, RMOB), Mike Otte (Illinois, USA; R, RMOB), TianJing Ouyang (Hubei Province, China; R, RMOB), Mark Parrish (England), Nicholas Payne-Roberts (England), Ian Ransom (England), Jürgen Rendtel (Arizona & California, USA, Germany & Tenerife; AKM), Petra Rendtel (Germany; AKM), G M Ross (Michigan, USA; AMS), Robin Scagell (England), Marcel Schneider (Luxembourg; R, RMOB), Jonathan Shanklin (England), SKiYMET radar (Norway; R, RMOB), Andy Smith (England; R, RMOB), Mark Smith (England), George Spalding (England), Christopher Stephan (Oregon, USA; AMS), "Steve P" (England), David

Stine (Oklahoma, USA; AMS), Enrico Stomeo (Italy; Vi), Wesley Stone (Oregon, USA), Magda Streicher (South Africa), Dave Swan (England; R, RMOB), David Swann (Oklahoma & Texas, USA; AMS), Richard Taibi (Maryland, USA; AMS), Diana Tampu (Romania; SARM-Romania), Cristina Tinta (Romania; SARM-Romania), Istvan Tepliczky (Hungary; R, RMOB), Robert Togni (Arizona, USA; AMS), Raul Truta (Romania; SARM-Romania), Yung Cheich Tsao (Taiwan, China; R, RMOB), Simona Vaduvescu (Ontario, Canada; SARM-Romania), Michel Vandeputte (Belgium; AMS), Patrick Vanouplines (Belgium; R, RMOB), Felix Verbelen (Belgium; R, RMOB), Jan Verbert (Belgium), Mark Vints (Belgium), Roy Watson (Scotland), William Watson (New York, USA; AMS), Bob White (England; R), Roland Winkler (Germany; AKM), Chris Woodcock (England), Robert Wright & son (England), Kim Youmans (Alabama & Georgia, USA; AMS), Brad Young (Oklahoma, USA; AMS), Ilkka Yrjölä (Finland; R, RMOB), Mengling Zhang (China; AMS).

Analyses of the results received were performed much as previously. The visual ZHR computation method was effectively that given by Chapter 9 of Rendtel & Arlt (2008), though usually the calculations were carried out using a fixed r-value per shower, typically that given in the IMO's 2005 Meteor Shower Calendar (McBeath, 2004a). The raw radio observations were examined using the method developed for the SPA radio-meteor analyses, as detailed most recently in McBeath (2004b). The increased amount of video data received during the year led to the occasional need for a rate-analysis as well. A crude approximation of the visual ZHR computation method was used, to generate an hourly video-rate per main shower for each separate video system, correcting for LM, any field clouds, and the radiant elevation. The actual numerical values so-generated have no real meaning, being often greatly inflated because of the commonly very poor LMs compared to visual results, aside from other problems, but the relative strength of the values generated can be used to indicate potentially interesting times of higher or lower shower activity per system, useful for comparison with the results collected by other methods, primarily close to a major shower's peak.

3 Quadrantids

The Quadrantid peak was expected around $12^{\mathrm{h}}20^{\mathrm{m}}$ UT on January 3 (McBeath, 2004a, p. 2), with a waning Moon throughout the second half of the night, when the radiant can be best-seen. European visual and video observers were never going to catch the best from the shower if this timing proved correct, and poor northern winter weather over Europe and North America did nothing to assist. Consequently, it was difficult to usefully assess the very limited results collected by either method, beyond noting that rates were at their best overnight on January 3/4. Fortunately, a more useful analysis of the radio data was practical. Figures 1 to 3 give a representative sample of the more complete datasets across the Quadrantid peak.

Most of the eleven radio datasets judged sufficiently

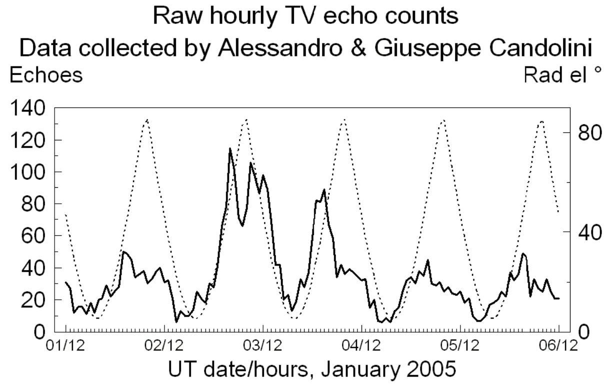

Figure 1 – Raw hourly longer-duration (D $\geq$ 1s) TV echo counts across the 2005 Quadrantid maximum, in data collected by Alessandro & Giuseppe Candolini, extracted from RMOB 138, January 2005. The thicker, irregular line, keyed to the left-hand y-axis, shows the raw hourly echo count values, while the thinner, daily-symmetrical, curve (keyed to the right-hand y-axis) gives the Quadrantid radiant elevation for their site. Longer-duration echoes are ordinarily thought due to what would be visually brighter meteors. The Quadrantid maximum probably happened with the radiant at less favourable elevations for Europe on January 3, hence the 'triple-peak' appearance of the activity line.

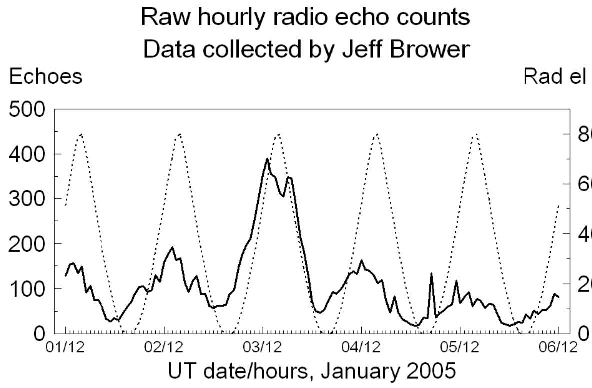

Figure 2 – As Figure 1, but giving all-echo raw radio counts from data collected by Jeff Brower. The Quadrantid peak was perfectly-timed for radio observations in North America, and its dominance is very clear here. The two sharp, minor peaks on January 5 were likely due to unidentified interference.

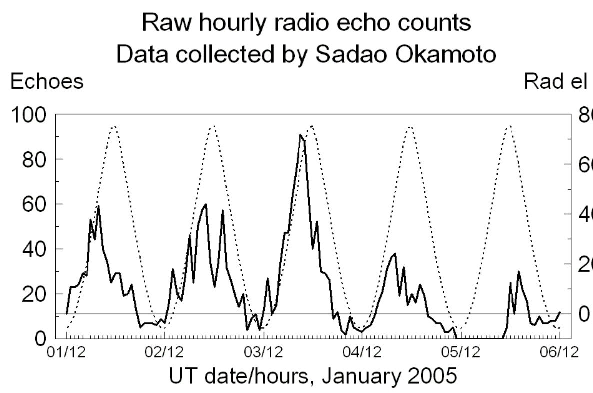

Figure 3 – As Figure 1, though now showing all-echo raw radio data collected by Sadao Okamoto, here taken from RMOB 139, February 2005. Even though Japan was expected to fare worst for the Quadrantid maximum, the later stages of the post-peak phase were very obvious. The zero counts on January 5 were due to interference problems.

complete and accurate for use in examining the Quadrantid maximum interval concurred that elevated activity near the main peak happened between 11^{h}–16^{h} UT on January 3. A weighted mean of those datasets giving a peak somewhere between these times, yielded a maximum centred at $\sim 12^{h}45^{m} \pm 1h$ UT on January 3, $\lambda_{\odot} \sim 283.^{\circ}18$. While this was pleasingly close to the prediction, it needs to be treated with caution in the absence of significant amounts of confirming visual data. As in 2004, there was no sign of the secondary, mainly radio, peak, found most recently in 2001, but possibly again in 2003 (McBeath, 2001c, 2003, 2005b, 2007b). The actual strength of the radio peak, while very difficult to judge, seemed probably comparable to other Quadrantid returns when the visual ZHRs have been fairly normal, inferring a likely typical peak rate too.

4 February 20 daylight fireball

Among 63 fireballs (meteors of −3 mag and brighter) seen from the UK and nearby during the year, away from the times of major shower maxima, probably the most spectacular was this one, seen widely across England and Wales at $9^{h}55^{m}20^{s} \pm 10s$ UT on February 20. The precise timing was based on the start time for a strong, single-meteor, radio signature recorded by Andy Smith, as compared to estimates provided by the 31 witnesses who reported to the Section. The object was conservatively suggested as peaking in the magnitude range −12 to −18, and its colour generally suggested as blue-green. This magnitude range is almost certainly an under-estimate, as several witnesses had their attention drawn to the fireball by its brilliance on what was a generally bright, sunny morning over much of England.

Although no images were secured, an approximate trajectory for it was established, based on 28 visual observations, as shown in Figure 4. The trajectory trended roughly south-east to north-west, apparently at a very shallow angle of $\sim 6^{\circ} \pm 3^{\circ}$ from the horizontal, thus almost grazing the atmosphere. Its start may have been around 100 km altitude above western Dartmoor near Marytavy in Devon, some 7 km north-northeast of Tavistock ($\sim 4.^{\circ}1 \pm 0.^{\circ}1$ W, $\sim 50.^{\circ}6 \pm 0.^{\circ}1$ N). A major fragmentation event occurred, breaking the main body into several pieces quite late in its flight, perhaps 15 km or so northwest of St David's Head in southwest Wales (the northernmost of the three Welsh peninsulas the more probable track passed over or very close to; $\sim 5.^{\circ}4 \pm 0.^{\circ}8$ W, $\sim 51.^{\circ}9 \pm 0.^{\circ}1$ N), at about 85 ± 10 km altitude above St George's Channel. The end was at circa 80 ± 10 km altitude, roughly 40 km east-northeast of Wexford Harbour, County Wexford, Ireland, over the sea near $6^{\circ} \pm 0.^{\circ}6$ W, $52.^{\circ}4 \pm 0.^{\circ}15$ N. As the spread of tracks in the Figure suggests, this fragmentation point, and especially the trajectory's visible end, were quite poorly-constrained. The altitude and general location notes here were based on the more probable trajectory, while the spread in geographic coordinates covered the range of the most likely tracks. With a visible atmospheric path length of around 235 km and an estimated mean total flight duration of $\sim 5 \pm 1$ s, the implied mean intra-atmospheric velocity, not allowing for deceleration, was $\sim 47 \pm 10$ km/s.

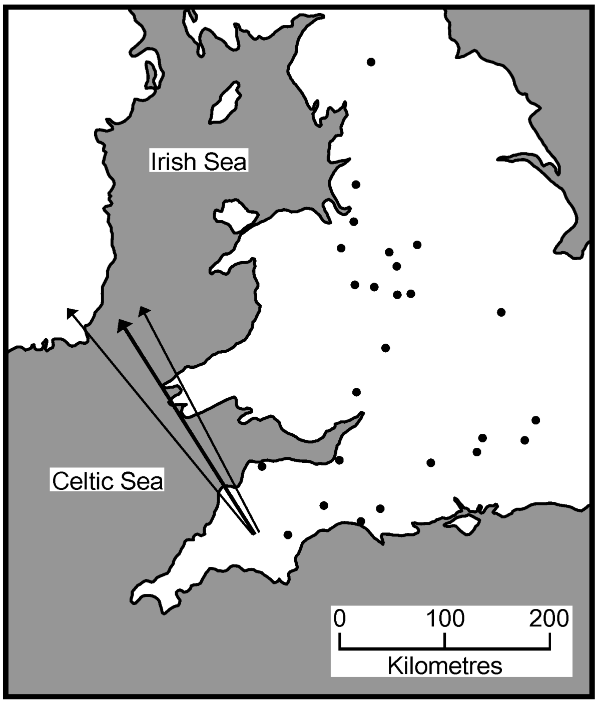

Figure 4 – A sketch map of part of the British Isles and the seas nearby, showing the more probable projected surface track for the February 20 daylight fireball (the thickest arrowed line). The thinner arrowed lines to either side of this show the possible outlying alternative tracks. Witness' locations are indicated by the filled circles, sometimes representing several different observers too near one another to separate at this scale.

The shallow approach angle and uncertainties in the trajectory made estimating any potential meteorite fall zone nearly impossible. However, any surviving solid bodies following the centre-line of the trajectory, after the end of its visible flight, might have splashed-down into the North Atlantic north-west of a point roughly between the Rockall Rise and the island of Barra in the Outer Hebrides off western Scotland, out as far as a landfall in western Iceland, or a sea-fall offshore of south-east Greenland, an enormous zone that was really just a best-guess. Especial thanks are due to André Knöfel of IMO's FiDAC for rapidly providing copies of sightings of this event sent directly to him, and also to Section correspondents John Lambert and Paul Sutherland for rounding-up several other sightings and forwarding media notices about this meteor.

5 η-Aquarids

Moonlight circumstances were favourable for the η-Aquarid maximum, due around 24^{h} UT on May 5 (McBeath, 2004a, pp. 4–5), and quite a healthy number were seen, including the first two such shower meteors Steve Evans had been able to record by video (as identified by the MetRec software). Table 2 gives a combined magnitude distribution for all the better-sky visual η-Aquarid and May sporadic meteors reported to the Section. While the quantities of meteors in either

Table 2 – Global magnitude distributions for the 2005 η-Aquarids and May sporadics seen under better sky conditions (cloud cover < 20%, LM = +5.5 or better), including mean LMs and corrected mean magnitudes. Data were collected between May 5 and 8.

Shower	≤ -3	-2	-1	0	$+1$	$+2$	$+3$	$+4$	$\geq +5$	Total	LM	$\overline{m}_{6.5}$
ETA	0	2.5	5.5	14	18.5	39	73.5	60.5	29.5	243	+5.79	+3.59
SPO	0	0	1	0	8	10.5	21	14.5	2	57	+5.79	+3.50

category were not large enough for real certainty, especially in the case of the sporadics, this information suggested the η-Aquarids were fainter than normal in 2005. ZHRs were computed for the shower using an assumed r = 2.4, which consequently could have under-estimated the real rates. However, the mean ZHRs derived from around 02$^\mathrm{h}$ UT on the mornings of May 5, 6 and 8 respectively were 108 ± 11, 87 ± 8 and 85 ± 14, with significantly lower rates found on May 4 ($\sim 15 \pm 8$ at 09$^\mathrm{h}$ UT) and later on May 8 ($\sim 40 \pm 12$ at 08$^\mathrm{h}$ UT). Following from Dubietis (2003), it had been anticipated that the shower's suggested cyclical ZHRs might have peaked around 50 to 60 in 2005, so these values seemed unexpectedly strong. The highest η-Aquarid rates tend to average ~85, for instance. If the May 5 rates were the strongest the shower produced this year, that would also have meant the maximum falling almost 24 hours earlier than expected.

However, this strength and type of activity was not well-supported by the radio results, where most datasets suggested fairly similar echo-counts on each of the first ten days of May or so. Occasional stronger maxima were seen in a few datasets, but these were not generally confirmed by the majority of viable observations. A careful examination instead found a general, small, peak in radio meteor echoes on both May 5 and 6, coincident with the η-Aquarid radiant's detectability, with rates rising on May 4, falling on May 7. There was thus nothing to support either a strong, or an increased faint meteor, component in the radio η-Aquarids. Indeed, the overall activity in this part of May seemed quite typical of that found in previous radio examinations (McBeath, 2001b). Without more visual data, it is unlikely this apparent contradiction can be examined further, unfortunately.

6 Perseids

This moonless shower maximum helped generate much observer interest and activity, especially during August, as Table 1 has already demonstrated. Predictions for various possible maximum timings, based on theoretical meteoroid-trail examinations, were issued electronically (see the summary in Rendtel, 2008). With the proposed peak timings in McBeath (2004a, p. 9), these suggested potential maxima around 04$^\mathrm{h}$, 09$^\mathrm{h}$ and 17$^\mathrm{h}$–19$^\mathrm{h}$30$^\mathrm{m}$ UT on August 12, perhaps with the 'tertiary' peak, not seen since 1999, recurring near 03$^\mathrm{h}$ UT on August 13.

The excellent observer response allowed equally good temporal coverage during the shower, with every date between July 27 and August 18 receiving at least one

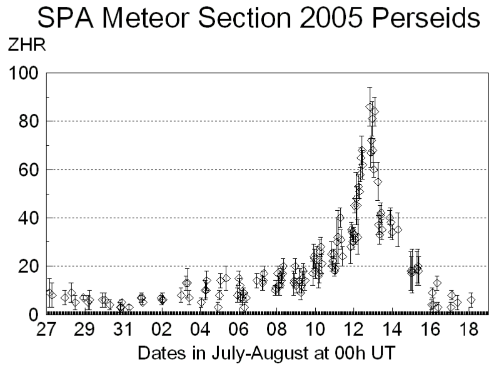

Figure 5 – Perseid ZHRs during July–August 2005, calculated assuming $r = 2.0$.

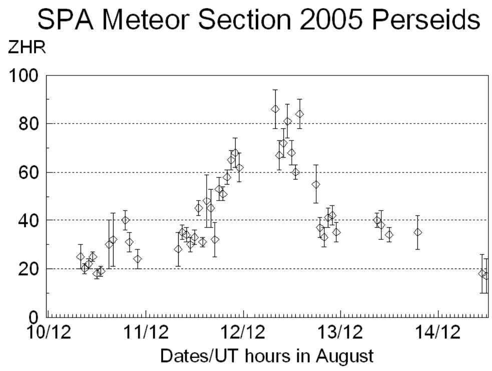

Figure 6 – Perseid near-maximum ZHRs extracted from Fig. 5, between midday UT on August 10 and 0$^\mathrm{h}$ on Aug. 15.

datapoint, as Figure 5 shows. Initially, and into the preliminary reports in the SPA ENBs, Perseid ZHRs were computed much as usual, using an assumed $r = 2.6$, but observers' comments, and then some early magnitude distribution investigations began to suggest the shower meteors had been brighter than normal in 2005. Once the bulk of the data was collected, some time after the preliminary reviews were published, closer investigations of this facet were practical. They showed the Perseids had been consistently somewhat brighter than normal throughout the period above. Checking the data from individual nights when sufficient information was available, including August 11/12 and 12/13, showed no significant difference to the overall mean. This suggested $r = 2.0$ was probably closer to the actual activity in 2005, and the ZHRs were recomputed accordingly, something that Rendtel (2008) helpfully

Table 3 – Global magnitude distributions for the 2005 Perseids and July–August sporadics, seen under better sky conditions (cloud cover < 20%, LM = +5.5 or better), including mean LMs and corrected mean magnitudes. Data were collected between July 27 and August 18.

Shower	≤ -3	-2	-1	0	$+1$	$+2$	$+3$	$+4$	$\geq +5$	Total	LM	$\overline{m}_{6.5}$
PER	46.5	62.5	114	249.5	414	601.5	473.5	302	126.5	2390	+6.42	+1.96
SPO	1	3	8	20	61.5	152.5	180.5	136.5	84	647	+6.41	+2.99

confirmed for the near-maximum period subsequently. Table 3 gives global magnitude distributions for the Perseids and July–August sporadics.

Given that the SPA results formed a subset of the IMO ones, it is hardly surprising the SPA peak appeared to be similarly broad, as Figure 6 illustrates. Three possible sub-peaks were apparent on August 12/13, around $20^{\rm h}$ (ZHR $\sim 86 \pm 8$; $\lambda_\odot = 140\overset{\circ}{.}12$), $23^{\rm h}$ (ZHR $\sim 81 \pm 7$; $\lambda_\odot = 140\overset{\circ}{.}24$) and $02^{\rm h}$ UT (ZHR $\sim 84 \pm 6$; $\lambda_\odot = 140\overset{\circ}{.}36$), though the gap in results from about midday to $\sim 20^{\rm h}$ UT on August 12 meant these timings were not definitive.

Many of the radio results failed to show an especially clear Perseid maximum signature, with some systems finding little difference in echo-counts on August 11, 12 and 13. This was not wholly unusual, as other 'normal' Perseid years have shown similarly-protracted good activity. The 2005 data were hindered further by interference problems. Careful examination of those reports apparently less-affected by such difficulties, suggested a Perseid maximum sometime between $\sim 16^{\rm h}00^{\rm m}$ to $20^{\rm h}00^{\rm m}$ UT on August 12. The majority (9 of 11 systems) favoured a peak centred at $18^{\rm h}00^{\rm m} \pm 1$h UT ($\lambda_\odot \sim 140\overset{\circ}{.}04 \pm 0\overset{\circ}{.}04$), including 5 of the 7 viable European, and all the surviving North American and Far Eastern, datasets. That this timing did not tally with any of either the IMO or SPA visual peaks, urges caution, but it is intriguing so many of the radio systems indicated it, despite the different observing circumstances in the three main geographic areas. This would otherwise have given an indication that this was the true peak. The European radio results continued to imply good, though probably below-peak, Perseid activity persisted through till $\sim 01^{\rm h} \pm 1$h UT on August 13.

7 September 25 to October 11 radio survey

Discussions with various radio observers prompted a survey of the radio results from late September to early October, to examine again those peaks around this time of year found in the Forward Scatter Meteor Year (FSMY) investigations previously (see McBeath,2001b). This was planned in advance of the unexpected October 5/6 bright-meteor outburst recorded by video, and the Draconid return, which were both examined as well. The Draconid event was discussed earlier (McBeath, 2007a). The original purpose of the survey was to try to better establish which of the minor radio peaks during this interval might be more likely due to the daytime Sextantids shower, as first discussed in McBeath (2005d). Although usually considered just to show a single, moderately strong, peak around September 27 ($\lambda_\odot = 184\overset{\circ}{.}3$), recent observations have indicated the Sextantid maximum may not be consistent in strength or timing. There have been suspicions that minor radio maxima into the first ten days of October may have been due to additional Sextantid sub-maxima. Table 4 gives a list of the main findings of the 2005 survey in comparison to the FSMY findings.

The previously-identified minor maxima were in general recovered about as expected, within the kind of variability seen before (part of which is due to the one-degree binning intervals), including for the 'main' Sextantid peak, which appears capable of falling sometime between roughly September 26–30 on occasion. Although this examination suggested several of the minor peaks could be due to this shower, making such shower identifications from radio results alone is not straightforward, as a shower radiant within some tens of degrees of the expected Sextantid one could give a similar response. The $\lambda_\odot = 188°$–$189°$ minor maximum seemed most likely due to the shower from the general pattern seen in the radio reports related to the Sextantids' radiant elevation during the day, oddly even more convincingly than the expected main peak in late September. The apparently multiple nature of the peaks seen near this time in some years, and the relatively stronger one around $\lambda_\odot = 191°$, though not found in 2005, could indicate part of this spell represents a second maximum period for the shower. Radar results would be needed to determine just what is happening in the daytime sky around this time, however.

8 October 5/6 video outburst

By-chance, the September-October radio survey period covered this event too. As various reports indicated, e.g. Molau (2005), Jenniskens et al. (2005), an unexpected number of bright video meteors was recorded from a compact radiant in Draco around $\alpha = 162°$, $\delta = +79°$, with a suggested geocentric velocity of ~ 45 km/s, between $\sim 19^{\rm h}$ to $\sim 02^{\rm h}$ UT on October 5/6 (using one-hour counting bins), with a peak between $\sim 19^{\rm h}$ to $\sim 21^{\rm h}$ UT. Curiously, visual observations made simultaneously failed to detect anything unusual. Two very bright fireballs were reported to the SPA from the UK between $19^{\rm h}$–$02^{\rm h}$ UT that night. Both were seen by single witnesses only, and for neither could a definite radiant be determined. One may have originated in the northern circumpolar sky, but the other most likely radiated from on or west of a line between Pisces–Aries–Andromeda.

Table 4 – A comparison of the FSMY radio peaks located in previous years between September 25 (in 2005, $\lambda_\odot = 182°$) to October 11 ($\lambda_\odot = 198°$), with those peaks detected in this period of 2005. An indication of whether a given peak may have been due to the Sextantids is also given. Peak strengths are described using a subjective 'weak, medium, strong' scale based on the numbers and geographic locations of the available radio systems that detected the event, and the relative number of echo-counts compared to days nearby. For ease of comparison with the FSMY findings, data have been binned in one-degree solar longitude periods, but the Sextantid possibilities were determined using the detailed one-hour data-bins of the original, individual reports, and assuming the Sextantid radiant, around $\alpha = 152°$, $\delta = 00°$ on September 27, was detectable between roughly 04^h to 16^h local solar time daily.

FSMY peak interval (sometimes extended interval), $\lambda_\odot$; relative strength	2005 radio peaks, $\lambda_\odot$; relative strengths	Peak due to Sextantids?
183° (182°–183°); strong	184°; medium	Probably
185°–187°; weak, but strong at 186° in 1999	186°; weak	Possibly
190°–192° (189°–195°); medium at 191°, otherwise weak, up to 3 maxima in some years	188°–189°; medium 190°, 192°, 194°; weak	188°–189° very probably 190°, 194° probably 192° possibly
195° (195°–196°); usually weak, but up to strong if Draconids present	195°–197°; weak [Draconid peak in 195° interval discounted here]	195° probably 196°–197° possibly
198°–199° (198°–200°); weak	198°; weak [End of surveyed period]	Probably not

A close examination of the radio results for October 5 found 75% of the viable datasets gave a marginal increase in echo counts that day as a whole, compared to dates on either side, but only 37% (3 of 8 datasets) registered slight, significant, differences during the $\sim 19^h$–21^h UT window of the video maximum, those collected by David Entwistle, Ghent University and Stan Nelson. There were indications the event may have been due to brighter meteors, and the activity seemed strongest from roughly 18^h–19^h UT. It may have started as early as 17^h UT, judging by the dataset from Ghent University alone, and continued till $\sim 20^h$. The weighted mean peak time from these three datasets was $18\overset{h}{.}7 \pm 1$h UT, $\lambda_\odot = 192\overset{\circ}{.}55 \pm 0\overset{\circ}{.}04$. It is important to stress how very minor this event was in the radio data however, since without the video reports identifying the key timing, the event would almost certainly have passed unnoticed.

A small peak in radio meteor activity on October 5/6 ($\lambda_\odot \sim 192°$) was first identified as of potential interest in this journal more than a decade ago, from radio data collected by James W Riggs in California (McBeath, 1996). It was confirmed in most years subsequently (McBeath, 1997, 1998a,b, 2000, 2001a,b, 2005c,d). As indicated above and in Section 7, this minor $\lambda_\odot = 192°$ peak was recovered as expected, and gave no close coincidence in timing to the video event. Thus there is no good reason to think the 2005 October 5/6 bright-meteor outburst was at all linked to this annual minor radio-meteor peak.

In terms of other past possible activity from this 2005 source, in 2002, a small cluster of three fireballs occurred over the UK and near-Continent on October 4/5 and 5/6 (McBeath, 2005c). Of these, only one was well-enough reported for an approximate atmospheric trajectory to be computed, a $-12/-15$ mag event at $04^h53^m \pm 1$m UT on October 6. This had a general north-northeast to south-southwest track, which might have implied a potential north-circumpolar origin. However, it also had a very low estimated atmospheric velocity, V_∞ likely of order < 20 km/s, and an apparently shallow angle of descent of $\sim 15°$. It was extremely unlikely this meteor came from the same Draco source as the 2005 event.

As I indicated previously (McBeath, 2006), calling this shower the 'October Camelopardalids' was rather unfortunate, as this name was already coined more than 35 years ago for what seemed likely a different shower, active in early October (Sekanina, 1973). Sekanina identified the original October Camelopardalids as paired with another radar stream present at the same time, the λ Draconids. In the Synoptic Year study (Sekanina, 1976), only the latter could be confirmed, the October Camelopardalids apparently being absorbed as part of another stream (*ibid.*, pp. 303–304, regrettably without indicating which; presumably the λ Draconids). There was one candidate stream in the Synoptic Year lists which gave a somewhat better match to the estimated orbital details of the Jenniskens et al. (2005) 'October Camelopardalids', the M Camelopardalids, albeit this stream's nodal passage (as with all the Sekanina data, for epoch 1950.0), was October 8.9. As Sekanina's papers also showed, there are numerous other minor radar streams with active northern circumpolar radiants for much of the year, a problem which extends to previous visual minor stream studies too, as Terentjeva (1966, 1968) demonstrated, although in neither of these latter papers was there a close match to the suggested parameters of the 2005 October 5/6 event, nor among the fireball streams of (Terentjeva, 1989).

9 Taurids

As David Asher had predicted more than a decade previously (Asher, 1994), the 'swarm' of larger particles within the Taurid meteoroid stream produced enhanced activity again in October–November 2005, with numerous fireballs – see Dubietis & Arlt (2006) for the IMO overview. It was clear from early in the event that unusual numbers of fireballs were being reported night after night, even by casual witnesses, which prompted

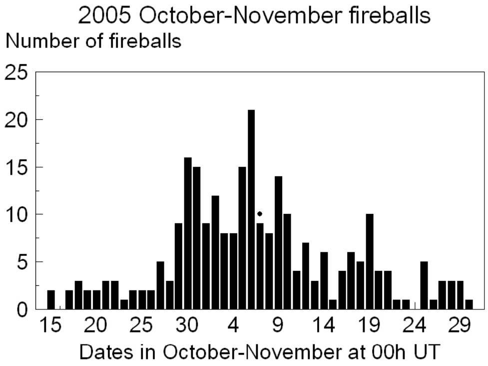

Figure 7 – Counts of individual fireball-class meteors reported by meteor observers and casual witnesses per night in October-November 2005, as given by various sources submitted to the SPA Meteor Section, and from the IMO's VMDB. The dot above the column for November 7 indicates a lunar impact flash detected by NASA observations, identified as due to a Taurid meteoroid strike on the Moon (Phillips, 2005).

a series of rolling visual and radio analyses to be begun by the Section to establish how the Taurids had behaved from late October well into November. Ultimately, these analyses extended to cover the period from October 15 to November 30.

Visually, the results unsurprisingly concurred generally with the IMO findings, with enhanced Taurid ZHRs above the usual ~ 10 level from roughly October 29 to November 12, at best around October 31/November 1 when ZHRs reached ~ 15–20 (the IMO peak rate was identified at 15 ± 3 on November 1/2). There was an indication in the magnitude reports that the STA may have been somewhat brighter overall, but this pattern was obscured by the fact around one-third of the Taurid meteor total was made up from shower meteors whose branch could not be identified, and whose mean magnitude was almost identical to that of the STA.

Similarly, no clear pattern could be identified from just the fireball observations, though the predominance of Taurid or suspected Taurid fireballs over those from other sources can be inferred from many reports being of slow or very slow meteors, where no other information could be determined. The simple fireball-occurrence graph in Figure 7 is suggestive too, with its three main peaks on October 30–31, November 5–6 and November 9, during the protracted period of enhanced fireball activity (assuming a 'normal' fireball level is ~ 0–3 events per night) from October 27 to November 14. A second 'cluster' of fireball sightings fell around the Leonid maximum later in November.

The radio results gave a less clear signature during the Taurid enhancement than that found in 1998, when the radio results alerted analysts to the possibility of unusual Taurid rates before that was noticed in the visual data (McBeath, 1999). The anticipated FSMY radio peaks were all recovered between October 27 and November 14, but the best-confirmed peaks happened on November 2, 3 and 7, that on November 3 not found previously. These dates are interesting, considering the timing of other identified Taurid events in this period.

10 Radio Orionids & Leonids

Due to the extended analysis period prompted by the Taurid fireballs, both these badly moonlit shower maxima were examined in the radio data too. Orionid activity was most obvious from October 21–24, with an unusually clear maximum on October 21. Typically, past radio results have simply shown better activity that persisted for several days across the expected Orionid peak, so this appeared to be quite a clear confirmation that the 2005 prediction was correct. This might suggest the strongly enhanced Orionid activity observed for several days in 2006 and 2007 (see Rendtel, 2007 and Arlt, Rendtel & Bader, 2008 respectively), actually began during the moonlit 2005 return. Mean ZHRs for October 20/21 and 21/22 in 2005 from SPA data were $\sim 65 \pm 10$ and $\sim 55 \pm 10$, but these values should be treated with considerable caution given the very poor skies the observations were made under (LM averages were just $+4.5$ and $+4.6$ on these two nights).

Two Leonid maxima were predicted, the nodal crossing time around $14^{\rm h}30^{\rm m}$ UT on November 17 (McBeath, 2004a, p. 12), and a partial intersection with the 1167 AD dust trail, predicted by Jérémie Vaubaillon in the autumn of 2005, to be encountered close to $01^{\rm h}10^{\rm m}$ UT on November 21 (Vaubaillon, 2005). Figure 7 illustrated a minor peak in fireball activity happened on November 19, perhaps running from November 17–19, but too few of those meteors could be identified with certainty to know if the Leonids alone were responsible. The radio data however found two maxima, on November 18 and 20, the latter the better-confirmed and generally stronger, but a significant number of results showed at least a modest enhancement in activity persisted through from November 17 to 22 inclusive. There seemed not to be a consensus in the radio maximum timings beyond this, with the better counts coinciding mainly with the Leonid radiant's better observability on any given date. Checking near the two predicted peak timings found no evidence to support them having produced anything unusual, though given the nature of radio meteor data, this cannot be considered wholly conclusive.

11 Conclusion

Overall, despite the number of stronger showers lost to the Moon in 2005, the year can be considered exceptionally successful, as well as very busy from August onwards, particularly thanks to the unprecedented run of fireball sightings arriving almost constantly throughout late October and November. My grateful thanks go to all our contributing observers and correspondents for making the continuance of these analyses here possible. Clear skies for all your future observations!

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Preliminary results

Searching for meteor ELF /VLF signatures

Jean-Louis Rault [1]

For more than two centuries, credible reports about various audible sounds appearing simultaneously with visible meteors have been collected. Knowing that the sound velocity is much lower than the light velocity, it was impossible to explain such a phenomenon until some theories predicted that an electromagnetic wave vector could be the reason for such simultaneous light and sound observations. Several optical/sound/radio recording campaigns have been performed in the last decades but with no conclusive reports. The present study simply aims to examine the low frequencies electromagnetic activity during a meteor shower and to search for any interesting correlations with meteors detected by VHF forward scatter means. Preliminary results tend to show a significant correlation between certain meteors and the time-correlated corresponding ELF/VLF events.

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1 Introduction

Audible sounds heard at the same time as fireballs are in view have been reported for many years by hundreds of credible witnesses. As the speed of sound in our atmosphere is around 340 meters per second and fireballs generally appear at altitudes of tens of kilometers, the sounds associated to the fireballs should be delayed by several hundreds of seconds. To explain these anomalous sounds appearing simultaneously with meteors, Keay (1980) proposed that some ELF/VLF (extremely low frequency/very low frequency) electromagnetic energy is radiated by the decaying meteor and then transduced into audible sounds at the observer location. This ELF/VLF high speed vector is supposed to explain the observed simultaneity of sound and meteor light. A Global Electrophonic Fireball Survey performed by Vinković et al. (2002) suggests that the electrophonic meteors, as Keay named them, produce a very wide family of hissing, swishing, rustling, buzzing, whooshing or crackling sounds. Keay's theory states that trapping and twisting the earth magnetic field lines in the turbulent wake of the largest meteors and then releasing them suddenly could be the reason for producing high power ELF/VLF radiation in the 100 Hz to 10 kHz range. Beech and Foschini (1999) explained that Keay's theory was only able to explain the long duration noises such as hisses and other high-pitched whistles, but not the pops, ticks and other claps which were often reported. They developed their own "space charge model" theory which states that some sharp shock waves occurring in the meteor trail plasma could induce some sudden electrical field transients. Depending on the authors, the magnitudes of the electrophonic fireballs vary from magnitude −10 (Beech et al., 1995) to −6.6 (Beech & Foschini, 1999). Price and Blum (2000) state that many weaker meteors can also radiate detectable ELF/VLF electromagnetic energy (Drobnock, 2001 and 2002). In fact, due to the extreme rareness of the phenomenon, instrumentally recorded electrophonic meteor data are very scarce. Keay (1994) for example presents an observation by Watanabe et al. (1988) about one single coincidence between a particular ELF radio spike and a photographed fireball. Beech et al. (1995), thanks to a VLF receiver associated to a photometer, observed during their Perseids 1993 campaign a single VLF event coupled with a magnitude −10 fireball. During the 1999 Leonid return, Price and Blum (2000) detected an important increase of the number of VLF spikes in the 300 Hz frequency range, but did not correlate the observed radio spikes to any particular discrete meteors. Garaj et al. (1999) detected during a 5.5 hours record session in Mongolia some coincident meteor light flashes and VLF radio emissions, but no correlated audible sounds. During the 2001 Leonids, Trautner et al. (2002) detected an enhanced activity in the ULF/ELF electric field, but again no particular meteors were associated with any of the recorded ELF-ULF events. More recently, Guha et al. (2009) argued they detected some long VLF meteor signatures in the 6 kHz range during the Geminids 2007 meteor shower, but they did not correlate them with any discrete observed meteors. Due to the lack of convincing detections of electrophonic meteor VLF radiations, the Keay magnetic field theory and the Beech et al. electrical field transients theory still have to be confirmed by more experimental data associating light, sound and/or ELF/VLF radio wave sensors. The purpose of the present experiment, "Searching for meteor ELF/VLF signatures" is simply to verify, by means of statistical analysis of coincidences between radio and meteor events and by spectral analysis of the candidate VLF radio events, that some meteors entering the Earth atmosphere are radiating some detectable ELF/VLF electromagnetic energy.

2 Experiment

2.1 Experiment principle

The aim of this study is to record in parallel as many ELF/VLF events and meteor detections as possible, to compare any incident radio signals (in the 20 Hz–20

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kHz range) with any occurrence of meteors in the radio field of view of the observer, and to determine statistically if the radio events are significantly correlated with the incoming meteors. A signature analysis of each radio event related to a particular meteor is also performed in the frequency and in the time domain, as an attempt to perform a kind of taxonomy study of the meteor radio signatures, if any. To detect as many meteors as possible, the radio forward scatter method was selected (Rault, 2007), rather than the optical observation method. Compared to the visual/video meteor observation method, the forward scatter radio method is offering more opportunities to detect faint and bright meteors (up to several hundreds of radio echoes from sporadic meteors per hour), and is not subject to disturbances from the Sun and Moon light or from any masking clouds or fog. A radio meteor detection system is able to work 24 hours a day, except for the few periods when an anomalous radio propagation phenomenon occurs, such as Es (apparition of a sporadic E layer ionized cloud) or in case of tropospheric propagation. The idea behind this is that by multiplying the number of meteor detections, the chances should be higher to identify interesting temporal correlations between the meteor arrivals and the ELF/VLF events. It has to be noted that the data reduction of such records is quite challenging, because the ELF/VLF spectrum is crowded with natural and man-made signals. Each coincidence between a radio and a meteor event has therefore to be processed manually. Many technical details are given in this publication, the goal being to encourage others to investigate in this domain.

3 Observational set-up

As is shown in Figure 1, the observational set-up is mainly made of:

- a VHF reception chain dedicated to the forward scatter detection of meteor pings,
- an ELF/VLF sensor,
- a stereo digital recorder.

The equipment is designed to be portable, self powered and as light as possible. The reason is that it has to be run in remote areas only, i.e. as far as possible from any power lines, cities, or railways which always radiate a lot of hum and various anthropic noises. The data crunching set-up consists of a laptop computer fitted with a spectral analysis software whose purpose is to process and to display simultaneously the data coming from the stereo channels.

Most of the laptop computers are poor field audio recorders because most of them radiate a lot of various radio noises in the VLF to VHF domain. Furthermore, their embedded audio sound chipset does not generally fit the dynamic and frequency range required for the ELF/VLF records. This is the reason why a good quality digital recorder has to be preferred.

The data recorded in the field are stored on Compact Flash memories whose contents can be easily transferred to any computer for further analysis. As is shown in Figure 2, the portable equipment is protected by a watertight container and powered by a 12 V car battery. This portable recording system design is presently subject to variations and permanent improvements. The current configuration (2009 June) consists of:

- a VHF antenna (50 MHz dipole or 4 elements Yagi 143 MHz beam, depending on the forward scatter transmitter to be used),
- an AOR AR5000A general coverage receiver (10 kHz to 3 GHz, all modes) dedicated to meteor ping reception, but also occasionally used to receive some time stamps from several VLF or short wave time signal transmitters,
- an ELF/VLF cylindrical antenna,
- a home-brew ELF/VLF receiver,
- an M-Audio Microtrack II digital recorder fitted with a exchangeable 8 Gb Compact Flash memory card,
- a 12 V/ 54 Ah car battery giving a recording autonomy of more than 48 hours,

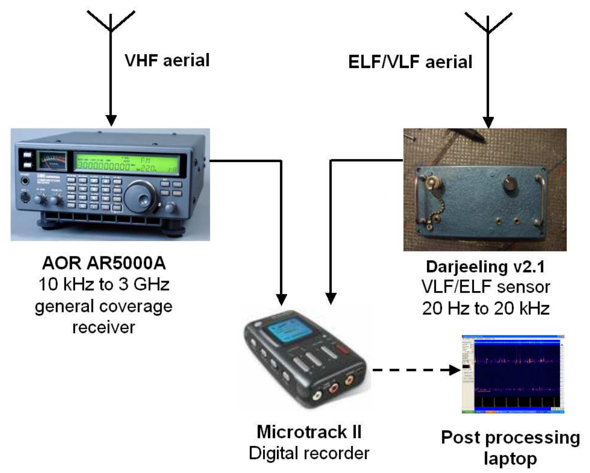

Figure 1 – Instrument configuration.

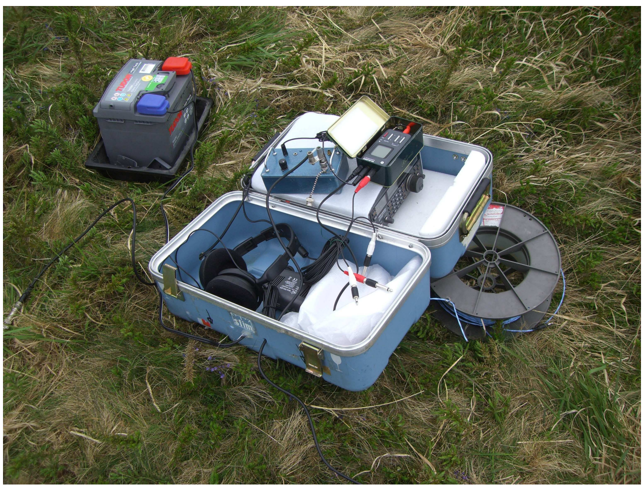

Figure 2 – Actual field installation.

- a 12 V/5 V DC/DC converter used to enhance the autonomy of the internal battery of the digital recorder,
- several ancillaries such as a 12 V LED light, a set of headphones, a batch of various cables, a laptop computer to control the records in the field and a "survival toolkit" including various tools, spare parts and a 12 V DC soldering iron.

The general coverage AOR receiver and the Microtrack II digital recorder are commercial equipment, so all the technical details can be found in the manufacturer specifications available on the Internet. More details about the ELF/VLF antenna and its associated receiver are given below, because they where specially developed for the present experiment. The specification requirements for the ELF/VLF reception chain were as follows:

- cut-off frequency as low as possible,
- high dynamic range,
- low distortion,
- light weight,
- low cost,
- low power consumption.

The frequency response of the Microtrack II recorder (20 Hz to 20 kHz ± 0.3 dB) and its dynamic range (101 dB) at 48 kHz sample rate were used as metrics for the development of the associated ELF/VLF antenna and receiver. The ELF/VLF part of the radio spectrum corresponds to very long wavelengths, ranging from 15 kilometers to more than 15 000 kilometers. It means that the antenna dimensions look necessarily very small compared to the wavelengths to be observed. Two types of aerials can be used in such conditions, the magnetic loops and the electrically short whips, which are respectively sensitive to the magnetic and to the electrical component of the incident RF electromagnetic field. An ELF/VLF magnetic loop is heavy, bulky and difficult enough to build (many turns of copper have to be wound on a very large and strong frame), so the electrically short whip principle was selected for this experiment. It has to be noted that such an "electrical field" receiver is sensitive to the electrical component of any incident electromagnetic wave, but also to any electrostatic field variations. Such a short whip presents a very high capacitive reactance in series with a very low radiation resistance.

The capacitance of such an aerial is:

$$C = \frac{24.2l}{\log\left(\frac{2l}{0.001d}\right) - 0.77353} \qquad (1)$$

with C expressed in picofarads, l (the length of the aerial) in meters and d (the diameter of the aerial) in millimeters. The radiation resistance can be neglected, as it is presenting a very low value which is in the $10^{-7}\Omega$

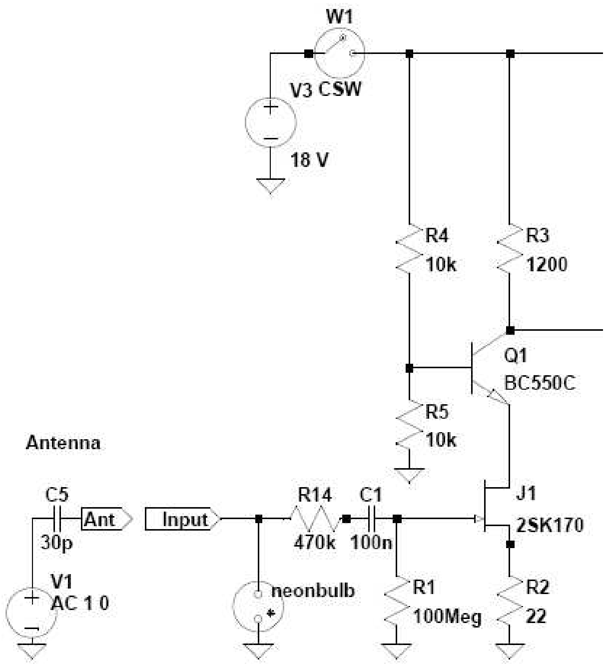

Figure 3 – Front end diagram of the ELF/VLF receiver.

range. The antenna built for this experiment is a one meter long metallic cylinder with a diameter of 50 mm, which gives a capacitance of about 29 pF. It consists of a rectangular piece of wire mesh wrapped around a plastic foam cylinder. Such vibrations dampening device was preferred to the usual thin and rigid whip aerial for two main reasons:

- it is less sensitive to the mechanical vibrations provoked by the strong winds which can be faced in the field,
- the capacitance of such a large diameter antenna is higher than the one of a thin whip, improving therefore the low cut-off frequency of the reception chain.

Such a low series capacitance antenna implies the use of a very high input impedance amplifier. A FET/BJT (Field Effect Transistor/Bipolar Junction Transistor) cascade front end design was selected, because of

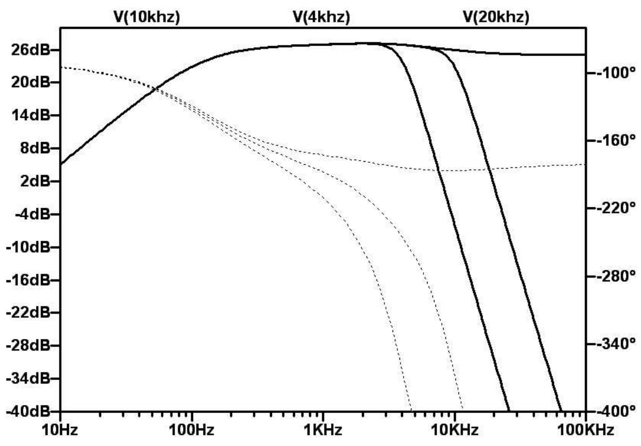

Figure 4 – Simulated bandwidth of the entire ELF/VLF reception chain (aerial, front end and switchable Butterworth filters).

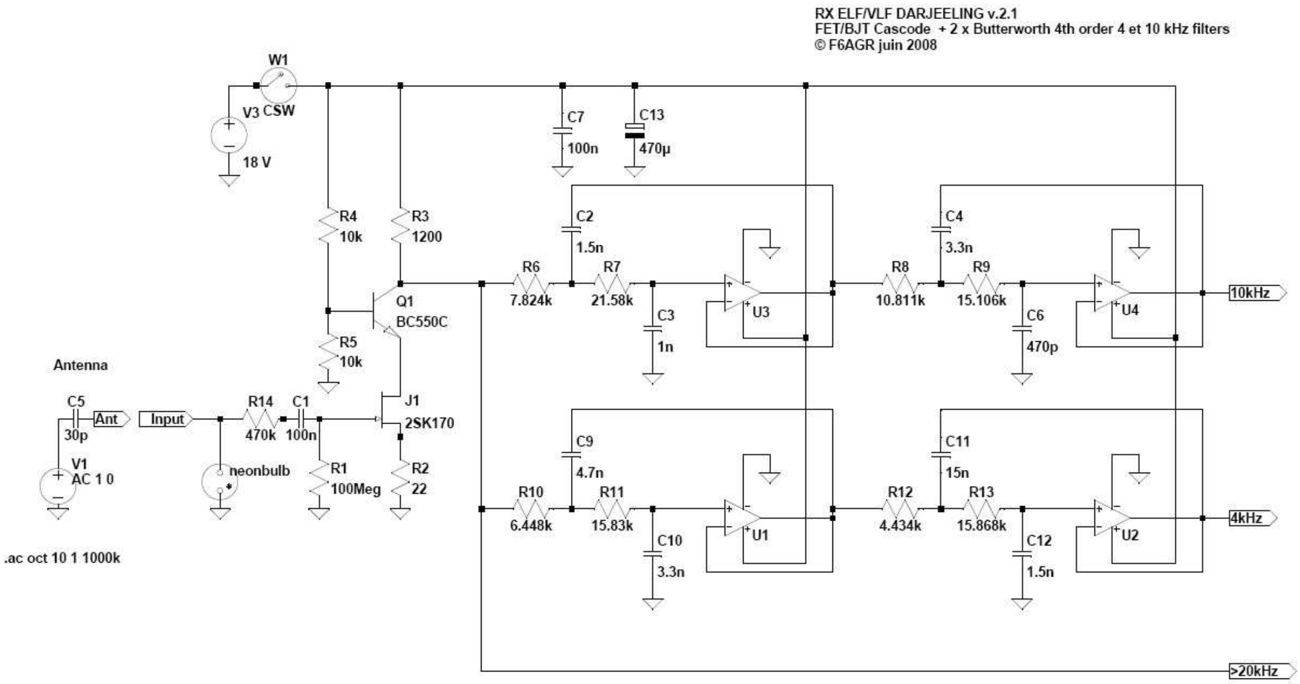

Figure 5 – Diagram of the entire ELF/VLF receiver.

its intrinsic qualities, such as high input impedance, low noise, low distortion, and high dynamic range. The detailed diagram of the front end stage of the receiver is shown in Figure 3.

The 2SK170 FET and BC550C BJT transistors were selected owing to their good performances in the noise, dynamic range, and distortion domains. The gate of the FET transistor is grounded thanks to a 100 MΩ resistance made of ten 10 MΩ low noise metallic film resistors wired in series. This very high value resistance is mandatory to keep the low cut-off frequency performance of the whole reception chain as low as possible.

The neon bulb is an attempt to protect the front-end against any high electrostatic discharges, but its effectiveness is not 100% certified. The 470 kΩ R14 resistor, which is not mandatory, is used to protect the receiver against any high level RF fields which could be received from nearby or powerful broadcast transmitters, if any. R14 can be removed if the receiver is to be used in radioelectrically quiet places.

The front end stage is followed by two selectable low pass filters. Each of them consists of a classical 4th order Butterworth filter presenting a theoretical roll-off rate of 80 dB per decade (see Figure 4). The first filter is a 4 kHz low pass filter, the second one is a 10 kHz filter. The frequency band-pass of the receiver is shown by continuous lines in Figure 4 (output amplitude in decibels versus frequency), depending on which filter — or no filter — is selected. The three dotted lines represent the corresponding phase shifts (in degrees). To obtain good filtering performances, it is important to respect as much as possible the values of the R and C components constituting the Butterworth filters. This can be achieved by using series or parallel combinations of resistors chosen in the 1% tolerance family. Figure 5 shows the diagram of the complete ELF/VLF receiver which is powered by two 9 V rechargeable batteries wired in series. Its consumption with a 18 V power supply is about 10 mA. Shielded cables must be used to connect the ELF/VLF and VHF receivers outputs to the digital recorder stereo inputs. The ELF/VLF antenna has to be kept away from the electronic devices. A low capacitance coaxial cable, whose length has to be as short as possible, must to be used to connect it to the receiver input. The type of cable used for car radio antennas is preferred for the present experiment. Its linear capacitance is about 37 pF/m, instead of 100 pF/m which is a typical value observed on most of the usual 50 Ω coaxial cables. The system must be grounded with the help of a ground rod driven in a moistened soil. It is recommended to install the digital recorder in a little tight metal box, because its front panel display is likely to radiate some unexpected noises.

3.1 Observation location

Choosing the right observation place is a delicate task. Finding a good location for the reception of the VHF forward scatter meteor pings is not difficult. The constraint is only to install the VHF aerial in a clear area which is free of any nearby obstacle masking the sky and the horizon.

On the other hand, the quality of the ELF/VLF data is subject to two main conditions:

- avoiding the presence of any objects (tree, bush, car, building, pole, etc.) or people in the vicinity of the antenna, because they all deeply attenuate the incoming signals,

- locating the system as far as possible (i.e. some kilometers if possible) from any power lines or buildings which always radiate a huge amount of hum, main harmonics, and various spikes.

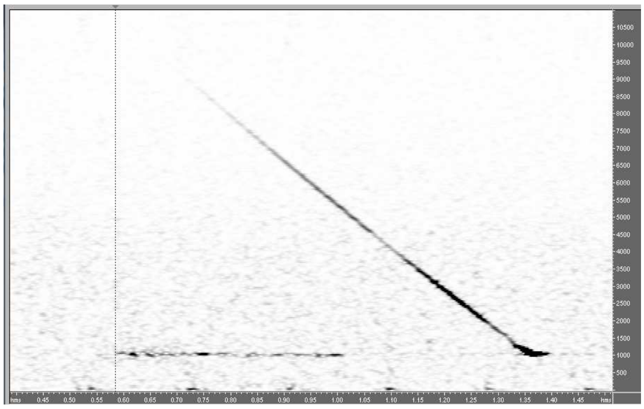

Figure 6 – Example of a meteor head echo displayed in the frequency domain.

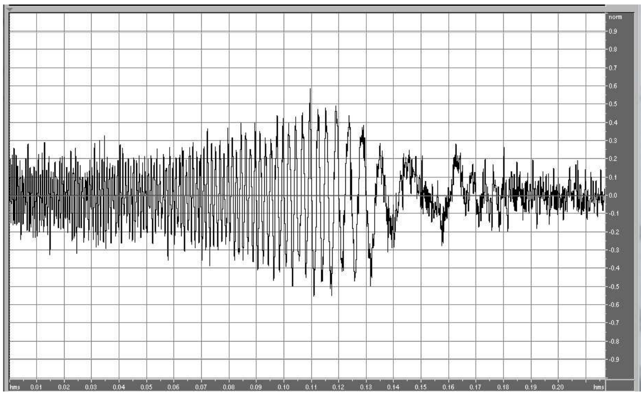

Figure 7 – Example of the same meteor head echo in the time domain.

The second condition is more and more difficult nowadays to meet in Europe. Each candidate location has to be carefully checked before installing and running the entire system. Using a light portable station consisting only of a 50 cm vertical whip, the ELF/VLF receiver and the digital recorder fitted with a pair of headphones allow to check quickly if there are no bad surprises in the selected field, such as a buried 220 V AC line, or some noisy sheep electric fences (as it happens often, even in “desert” regions of France such as the Aubrac or Larzac tablelands).

3.2 Tentative taxonomy of the event signatures

3.2.1 Event representation

The analysis of the signatures of the VHF meteor pings, of the ELF/VLF signals, and of their potential coincidence is performed by looking at the event signatures in the frequency and in the time domain, and by listening to them thanks to a stereo headset. For this purpose, a free Digital Audio Editor such as Audacity[1], or a more powerful but more complex Signal Analysis Toolkit such as Spectrum Lab[2] are perfectly suitable.

[1]http://audacity.sourceforge.net

[2]http://freenet-homepage.de/dl4yhf/spectra1.html

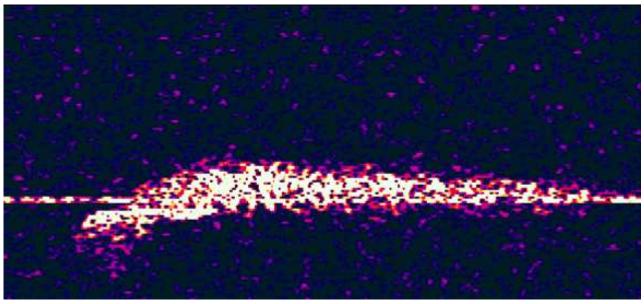

Figure 8 – Example of a Tt (meteor turbulent trail) echo.

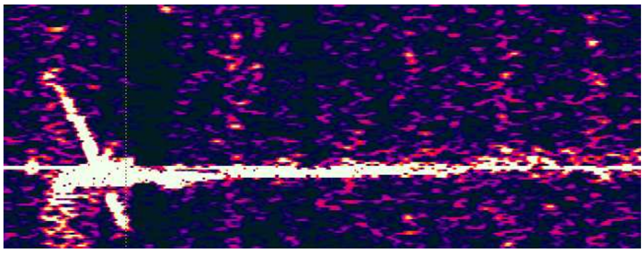

Figure 9 – Example of a HTt (head and turbulent trail) meteor echo represented in the frequency domain.

3.2.2 Meteor echo signatures

The VHF pings are radio echoes coming from a distant transmitter illuminating the meteors (or more precisely, illuminating the ionized trails and/or the plasma surrounding the meteoroids themselves). The actual echo radio frequency (around 50 or 143 MHz) is translated by the VHF receiver into audio frequencies (20 Hz to 20 kHz) which can be easily perceived by the human ear and processed thanks to a common PC sound card. A frequency analysis of the incoming meteor echoes is the most suitable tool to study the meteor pings, because it gives details on the speed of the meteor and/or its trail. For this study, the different types of meteor echoes have been classified as follows:

- the H type (H for head echo, see Figures 6 and 7)
- the T type (T for trail echo) including the two subclasses Tt and Ts, standing for turbulent trail echo (see Figure 8) and smooth trail echo.

In the two head echo examples above, the signal frequency of the echo decreases versus time, and this is due to the Doppler effect produced by the fast moving target (the plasma surrounding the meteoroid itself).

Figure 8 represents a trail echo which is frequency spread because of a heavy turbulence affecting the ionized trail. The overall shape of the echo looks like an inverted U, and this is due to the fact that the trail is moving at a speed of a few tens of meters per second, thanks to the high altitude winds.

A meteor head echo followed by its ionized trail echo is shown in Figure 9.

3.2.3 ELF/VLF event signatures

The 5 Hz to 24 kHz electromagnetic spectrum which we are looking at for this study is crowded with a lot of various anthropic and natural noises. Some examples of natural noises recorded during this study are shown

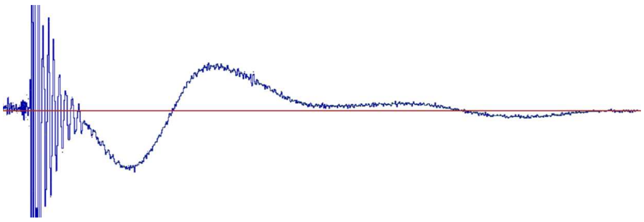

Figure 10 – Example of diurnal slow-tailed sferic (time domain).

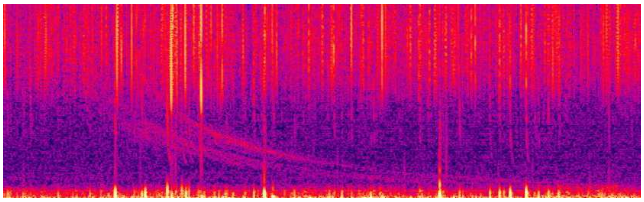

Figure 11 – Example of whistler (frequency domain).

Figure 12 – Burst of return strokes during a thunderbolt (time domain).

in Figures 10 to 12. These most common natural noises at the 40 to 50° North latitude locations are caused by several geophysical phenomena such as:

- sferics (distant lightning spikes propagating in the ionosphere-Earth waveguide during the daylight)
- tweeks (night sferics)
- whistlers (sferics propagated from the opposite hemisphere along the Earth magnetic field lines

The shape of the slow tail sferic (see Figure 11) is due to a propagation phenomenon of the VLF broadband spike within the Earth surface/ionosphere waveguide. The upper frequencies in such a waveguide travel according to a TM (transverse magnetic mode), and the lower frequencies (at the right of the figure) travel at a lower group speed according to a QTEM (quasi transverse electric magnetic) propagation mode. The TM mode presents a low frequency cutoff and the waves propagate with a higher velocity than with the TEM mode (Cummer, 1997; Delcourt, 2003). The various group velocities of the components of distant lightning spikes traveling in the magnetospheric plasma along the Earth magnetic field lines explain again the shape of

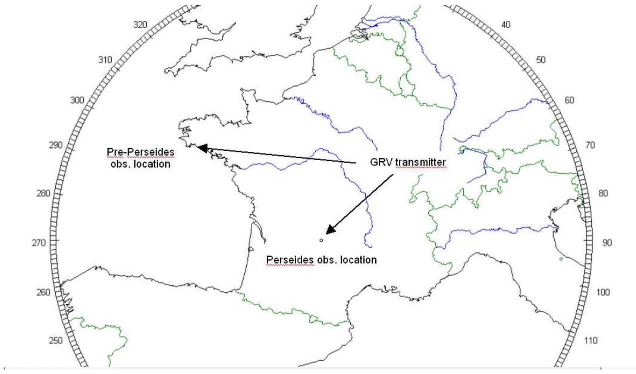

Figure 13 – Perseids 2009 observation locations.

a whistler. In Figure 12, the highest frequencies are reaching the observer before the lowest ones. The details above about all these kind of ELF/VLF events are given just to show that many natural event signatures are well known and quite easy to identify.

4 Results

A 143 MHz transmitter was preferred for this campaign instead of a 50 MHz one. The main reason for this choice is that the power of the meteor echoes decreases with the third power of the frequency, and their duration as the square, allowing thus to only detect the larger meteors. Furthermore, using a higher frequency scalpel provides more detailed echoes, and much better head echoes than on lower frequencies.

More than 20 hours of VLF and VHF radio observations, i.e. about 20 GB of data have been recorded during the pre-Perseids 2009 (August 6 in Brittany) and the Perseids 2009 (August 11 and 12 in Corréze). Ten hours and ten minutes of data records have been carefully analyzed, mainly during the first and second burst (i.e. around 8 AM and 6 PM UTC) of the Perseids but not during the third burst at 6 AM UTC on August 13, which was not recorded). During these 610 minutes, 500 meteors have been detected thanks to the French Graves military radar operating on 143 MHz (see Figure 13).

For these 500 meteors, 174 coincidences were observed with ELF/VLF events, which gives 35% of candidate meteors radiating some very low frequency electromagnetic energy when entering the Earth's atmosphere. Great care has been taken for deciding if an ELF/VLF event was related to a meteor or not:

- the time between a VHF meteor detection and a possibly related ELF/VLF event had to be less than 500 ms,
- The signature of the associated ELF/VLF event had to be of unusual amplitude or shape compared to the well known common natural noise signatures. The details about the different sorts of meteor and ELF/VLF events are shown in Tables 1 and 2.

In Table 1, the meteor echo signatures are identified as follows: \ : head echo; _ _ : head echo followed by

Table 1 – Meteor echoes sorted by type.

File	\	_ _	=_	----	====	Misc.	Total
40	6	15	0	13	2	2	38
42	4	14	0	9	7	3	37
68b	8	12	0	10	3	5	38
69b	131	37	0	21	5	28	222
78	34	4	2	26	1	33	100
79	4	1	1	2	2	5	15
80	5	3	7	1	2	5	23
81	10	2	2	2	5	6	27
Total	202	88	12	84	27	87	500

Table 2 – ELF/VLF events sorted by type.

File	ELF	VLF	Spikes	Tweek	Misc.	Total
40	7	1	12	1	1	22
42	7	3	11	0	3	24
68b	2	0	11	2	7	22
69b	9	5	24	0	11	49
78	5	2	4	0	13	24
79	1	0	6	0	2	9
80	1	0	6	0	4	11
81	2	0	8	0	3	13
Total	34	11	82	3	44	174

a trail echo; =_ : head echo with a turbulent trail at the beginning, followed by a smooth trail echo; ---- : smooth trail echo; ==== : turbulent trail echo.

In Table 2, the ELF/VLF event signatures are classified as follows:
ELF: extremely low frequency signal,
VLF: very low frequency signal,
Spikes: train of VLF spikes,
Tweek: night time sferics.
Some examples of remarkable coincidences are shown in Figures 14 to 19.

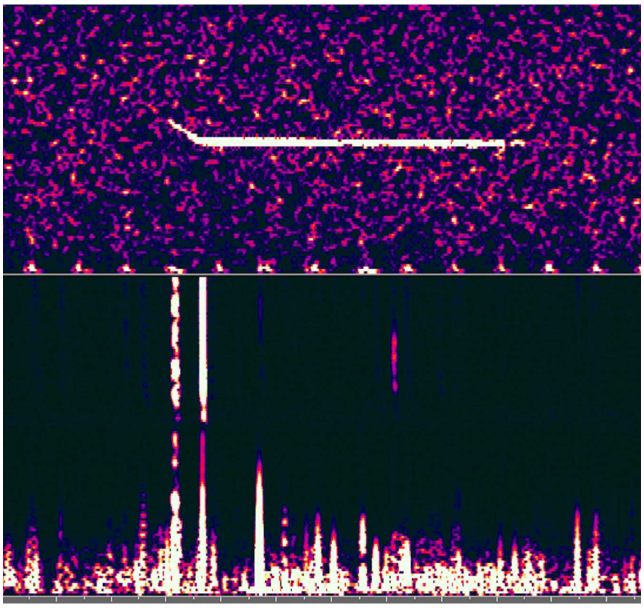

Figure 14 – VLF spikes during a meteor head echo (frequency domain).

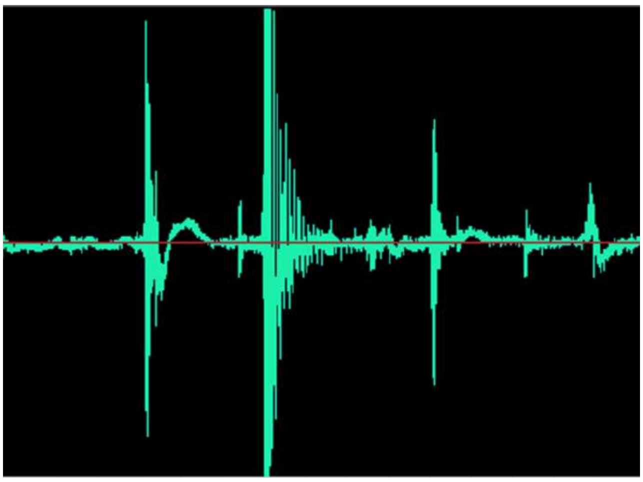

Figure 15 – Same VLF spikes but seen in the time domain.

All these examples were selected because they looked representative of interesting ELF/VLF meteor candidates, their low frequency radio signatures being different from the common natural noises. It is to be noted that almost all of the detected ELF/VLF meteor events occurred during the decaying phase of the meteoroids, and not during the trail echo phase. This is tending to prove that the radio frequency radiations, if any, occur mainly during the ablation phase of the meteors and are not generated by any persistent trail plasma phenomenon. No long duration ELF/VLF event signals at all were detected during this study. All of them belong to the short duration/spike category, unlike some recent observations (Guha et al., 2009) claiming long duration signals in the 6 kHz band. Figure 14 shows a typical low frequency burst accompanying the head echo of a meteor. Figure 17 is an example of an unusually large long-tailed spike (thirty four similar ELF spikes were identified during this study). Figure 19 shows a burst consisting of some uncommon saw tooth spikes with a period of around 4 ms. Figure 20 is an example of a VHF reflection on a cloud-cloud thunderbolt ionized column, which has nothing to do with a real meteor echo (Rault, 2005). Some thunder activity was localized in northern Spain (see Figure 21) at the time

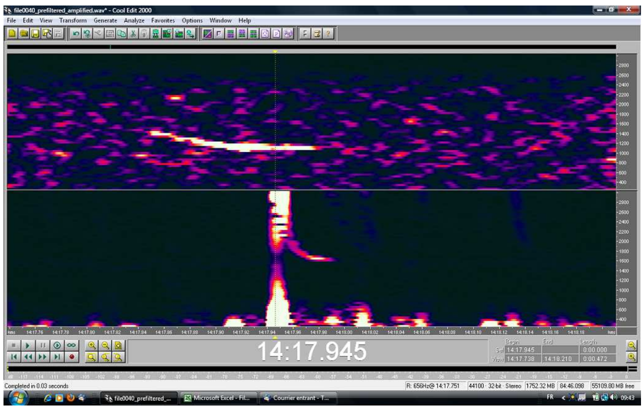

Figure 16 – ELF tweek associated to a VHF meteor ping.

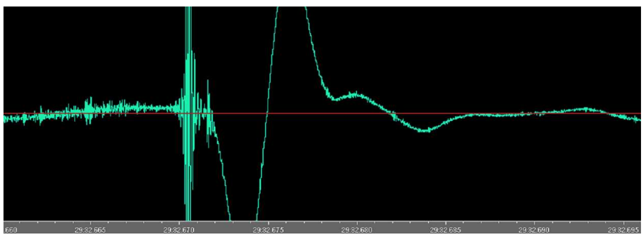

Figure 17 – Time domain representation of a very large ELF spike associated with a meteor ping.

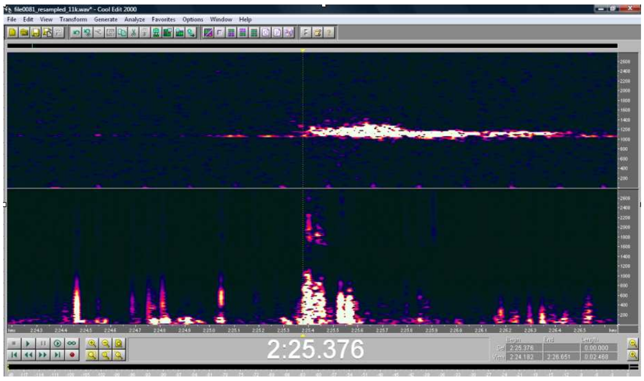

Figure 18 – Burst VLF spikes associated with the beginning of a turbulent meteor trail.

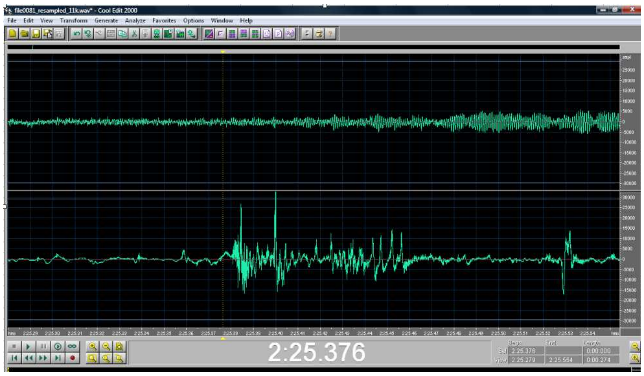

Figure 19 – Time domain representation of the above VLF burst.

several similar events were recorded. Such a thunderbolt event shows that the greatest care has to be taken when performing such an event analysis. A good knowledge about the VHF echo signatures and the ELF/VLF event shapes is mandatory for correctly identifying the potential candidate samples.

5 Discussion

Looking for correlations between meteors and ELF/VLF events is a very demanding and a very time consuming task. The dectection of the interesting events cannot be automated, because the ELF/VLF event signatures are not known in advance. At the beginning of this work, a statistical approach was envisaged. Determining the statistical rate of fortuitous coincidences between the meteors and any of the low frequency events and then comparing it to the observed rate was thought to be a good indication of any meteor radiated radio energy. One file containing 100 meteor pings, 24 coincidences at less than 500 ms and 2880 ELF/VLF radio events was therefore used to compute the statistical chances for fortuitous coincidences to appear. With the collected data, the chance for one VLF event to fortuitously appear at less than 500 ms from a meteor ping was around 42% for a one hour record. Compared to the 24% of observed correlations, this is clearly not a convincing indication of any meteor radio radiation. This is due to the fact that all the ELF/VLF events were taken into account, and the huge number of events was polluting the final result. So another approach was finally used for this work, which consists in selecting only the ELF/VLF events whose signatures are clearly different from the usual ones. These candidate meteor ELF/VLF signatures are listed in Table 2. 174 ELF/VLF events for 500 VHF meteor echoes (i.e. about 35%) is a very encouraging result.

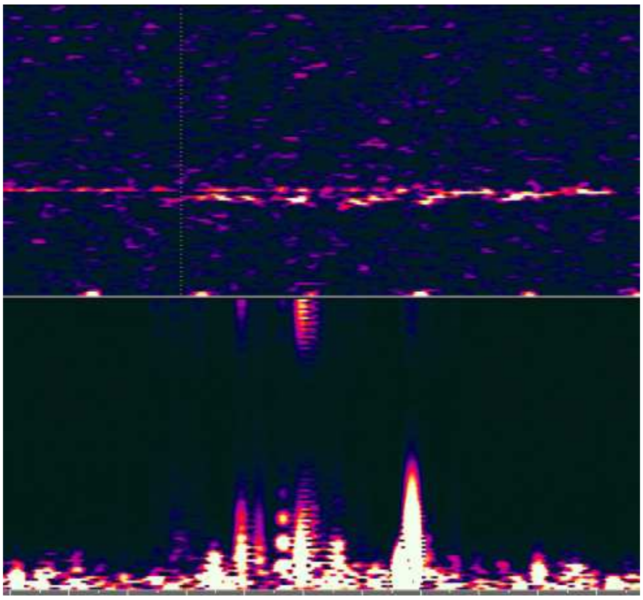

Figure 20 – Upper trace: VHF reflection on a lightning. Lower trace: associated VLF return strokes.

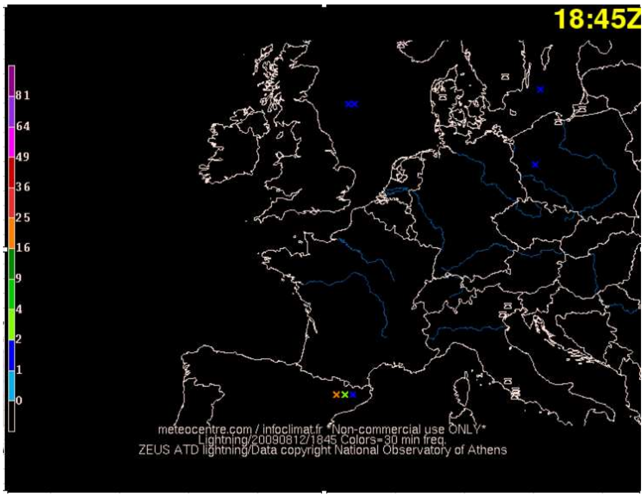

Figure 21 – Thunder activity (see ××× crosses in the northern Spain area) at 18:45 UTC of 2009 August 12.

6 Conclusions

The theories stating that some meteors can radiate low frequency electromagnetic energy seem to be supported by the present practical study which is based on hundreds of actual discrete observations of meteors and ELF/VLF events. It is to be noted that the 35% of the observed candidate correlations seem to happen most of the time during the beginning of the meteor radio reflections. However, more data are still needed to confirm such a conclusion. The next meteor showers (such as the promising Leonids 2009) should be the next opportunities to collect more interesting correlations.

Acknowledgments

Thanks a lot to Karl Antier and to Pierre Gaillard (Département Analyse et Surveillance de l'Environnement, CEA) for their useful advices about the statistical approach attempted during this work.

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Results of the IMO Video Meteor Network — January 2010

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

The weather across the IMO Video Network was poor in 2010 January. Still, 25 observers operated 39 cameras on all nights. More than 6 000 meteors were recorded in more than 1 500 hours of observations. The descending activity branch of the Quadrantids was well covered on 2010 January 3/4. High-resolution analysis of the video data covering years from 1993 to 2010 is presented. An asymmetric activity profile is discovered, with a steeper ascending branch and a gradual descending branch. The FWHM of the Quadrantids from the long-term video data is about 0.°7.

Received 2010 March 11

1 Introduction

For a number of observers (including the authors) 2010 January presented the worst weather conditions since the start of the camera network more than 10 years ago. Having a series of almost completely overcast skies lasting for seven weeks from late December to mid-February is unprecedented. Some of our most active observers in central Europe collected less than ten observing nights. Only our American and two Italian observers obtained more than 20 nights in January.

However, the nice thing about the IMO Network is its large size. Even under such poor conditions, we collected more than 6 000 meteors within 1 500 hours of effective observing time — the second best January result ever (Table 1 and Figure 1). And the IMO Network continues to grow! We are particularly delighted to welcome two new observers this month. With Mike Otte, we have the third American in our midst. Mike is observing from a site near Pearl City in Illinois with a Watec LCL-902K camera and different C-mount lenses. Even farther south is Steve Kerr, observing from Glenlee in Queensland, Australia. Steve is our first southern hemisphere observer since 2003 which makes his data particularly valuable. He operates a standard setup with GSTAR-EX camera (which is identical to the Mintron) and a Computar 3.8-mm f/0.8 lens. The camera Armefa from public Archenhold Observatory Berlin is now maintained by Eckehard Rothenberg.

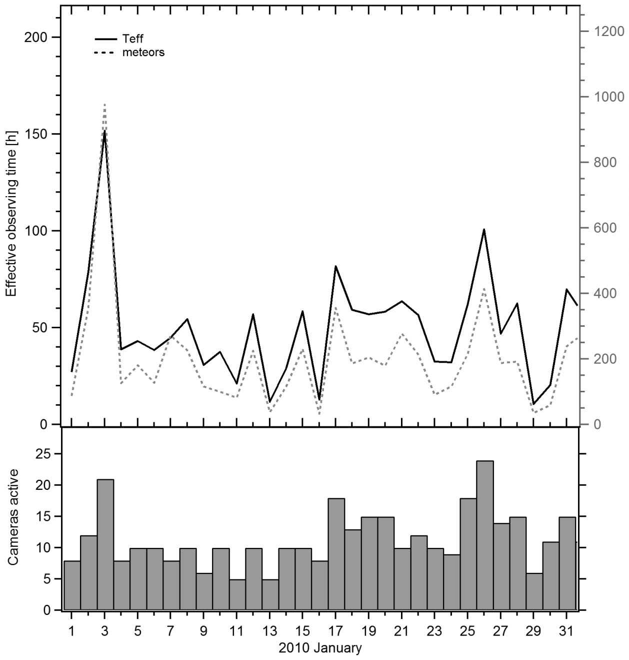

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 January.

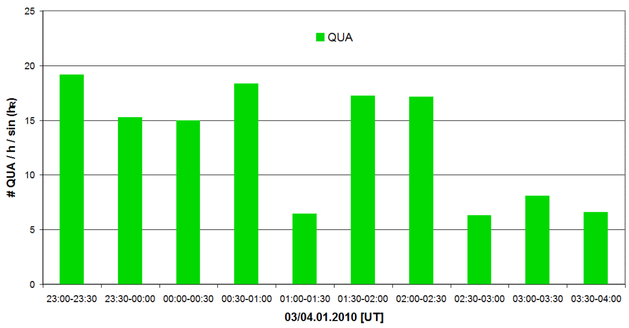

Figure 2 – Relative Quadrantid activity on 2010 January 3/4.

2 Quadrantids

With respect to meteor showers, the Quadrantids are the last highlight for northern hemisphere observers before the spring minimum starts with a significantly reduced meteor activity. This year, the maximum was expected for the early evening of January 3 (UT) together with a waning gibbous Moon (Rendtel & Arlt, 2008), so the observing conditions were not perfect. Still, a number of observers took advantage of the relatively good weather conditions that night and recorded the descending activity branch. Figure 2 shows the number of Quadrantids per half-hour interval averaged over seven cameras with mainly cloud-free skies, and corrected for the radiant altitude. There is an activity dip between 01^h00^m and 01^h30^m UT on January 4, and after 02^h30^m the rates decrease significantly.

The Quadrantids are well known for their extremely short activity period. Just one day away from the maximum, their activity has practically vanished. A detailed profile of the maximum was not obtained from video data so far, because at an interval length of two degrees as in the previous analyses, the maximum fills just one

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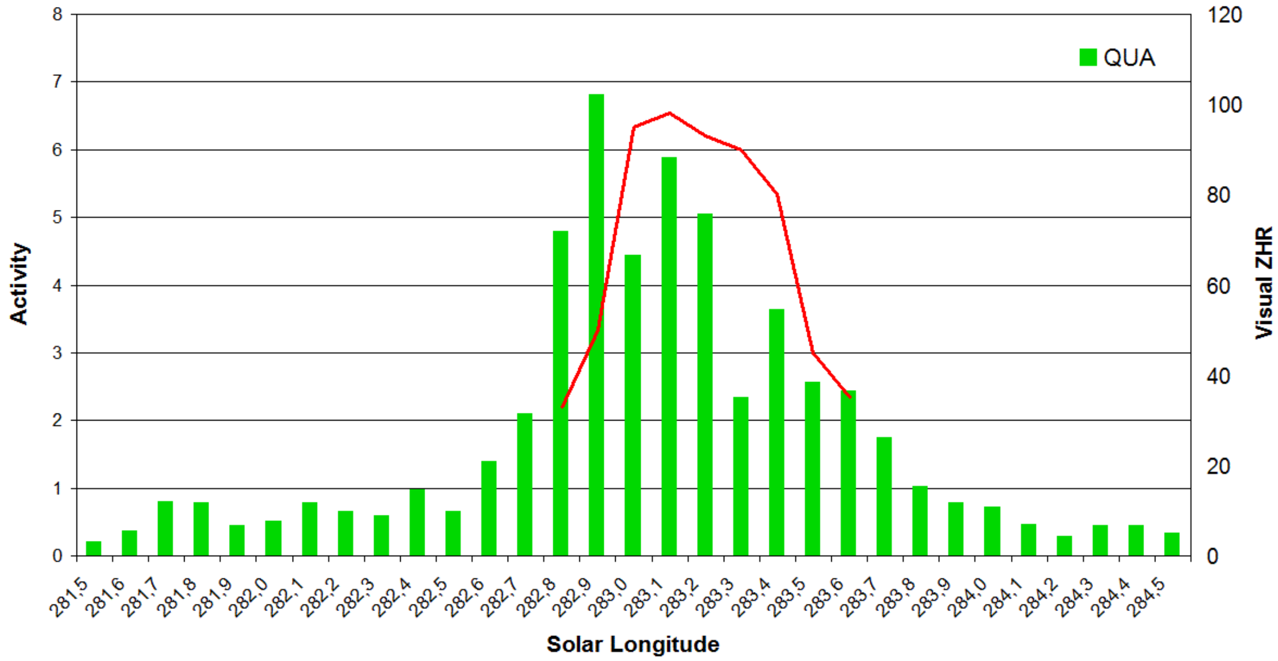

Figure 3 – High-resolution long-term activity profile of the Quadrantids from video observations between 1993 and 2010 (bars). The line represents the long-term average from visual observations.

bin. Similar to the October Camelopardalids (Molau & Kac, 2009), we now created a high resolution activity profile with non-overlapping bins of $0\stackrel{\circ}{.}1$ length in Solar longitude from all IMO Network data between 1993 and 2010. The data set contains a total of 3 800 Quadrantids. The result is given in Figure 3. Interestingly, the profile is not symmetric — the ascending branch is steeper than the descending branch. The full width at half maximum (FWHM) is $0\stackrel{\circ}{.}7$. For comparison: The FWHM of the October Camelopardalids was about $0\stackrel{\circ}{.}2$ (Molau & Kac, 2009). Half maximum occurs at roughly $\lambda_{\odot} = 282\stackrel{\circ}{.}8$ (ascending branch) and $\lambda_{\odot} = 283\stackrel{\circ}{.}5$ (descending branch). The center value of $\lambda_{\odot} = 283\stackrel{\circ}{.}15$ matches perfectly to the activity maximum given in the IMO handbook ($\lambda_{\odot} = 283\stackrel{\circ}{.}16$; Rendtel & Arlt, 2008) and to the values obtained from visual observations in 2008 ($\lambda_{\odot} = 283\stackrel{\circ}{.}3$; International Meteor Organization, 2008) and 2009 ($\lambda_{\odot} = 283\stackrel{\circ}{.}2$; International Meteor Organization, 2009). Due to the asymmetric shape, the highest video rate occurs slightly earlier at $283\stackrel{\circ}{.}0$ Solar longitude. For comparison, the high resolution visual profile printed in the IMO handbook is plotted as a line in Figure 3. That profile is asymmetric too, but shifted by $+0\stackrel{\circ}{.}1$ in Solar longitude.

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Table 1 – Observers contributing to 2010 January data of the IMO Video Meteor Network.

Code	Name	Place	Camera	FOV	LM	Nights	Time (h)	Meteors
BENOR	Benitez-S.	Las Palmas	TIMES4 (1.4/50)	⊘ 20°	3 mag	7	22.6	67
			TIMES5 (0.95/50)	⊘ 10°	3 mag	6	7.0	13
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	9	18.7	58
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	22	89.5	279
			BMH2 (0.8/6)	⊘ 55°	3 mag	18	88.9	270
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	20	96.1	367
			STG38 (0.8/3.8)	⊘ 80°	3 mag	14	51.7	135
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	5	21.2	81
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	10	63.1	305
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	12	53.7	193
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	9	34.1	162
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	9	31.4	83
			SALSA2 (1.2/4)	⊘ 80°	3 mag	22	82.2	232
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	1	7.8	20
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	8	21.2	103
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	8	48.5	270
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	5	16.4	47
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	3	9.8	48
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	2	7.4	92
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	5	20.8	92
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	8	47.9	353
KOSDE	Koschny	Noord-wijkerhout	LIC1 (1.4/50)	⊘ 60°	6 mag	11	29.6	173
			TEC1 (1.4/12)	⊘ 30°	4 mag	7	7.7	21
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	20	139.2	664
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	1	5.3	38
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	9	22.3	103
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	8	14.1	49
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	15	89.8	327
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	18	85.8	285
ROTEC	Rothenberg	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	8	15.2	34
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	9	15.7	57
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	1	9.4	40
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	12	77.3	359
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	11	88.8	481
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	4	5.4	20
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	3	7.6	23
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	1	10.6	33
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	2	7.9	23
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	15	77.8	256
					Overall	31	1 549.5	6 256

Results of the IMO Video Meteor Network — February 2010

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

The 2010 February results of the IMO Video Meteor Network are presented. All nights were covered by observations from 38 cameras operated by 23 video observers. Less than 1 300 hours of effective observing time were collected and about 4 400 meteors were recorded. The activity of two minor showers of February, the π-Hydrids and the β-Herculids, are presented.

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1 Introduction

With respect to the weather, February 2010 was another month that we should forget soon. Whereas the southern Europeans still had acceptable conditions, the more northern observers were almost fully clouded out. Only in the second half of February did the weather slowly improve. In the end, we collected less than 1 300 hours of effective observing time – less than any other month since June 2008 (Table 1 and Figure 1). The total meteor number was higher than in February 2009, though, because the hourly average was 3.4 meteors (compared to the long-term February average of 2.5 meteors per hour).

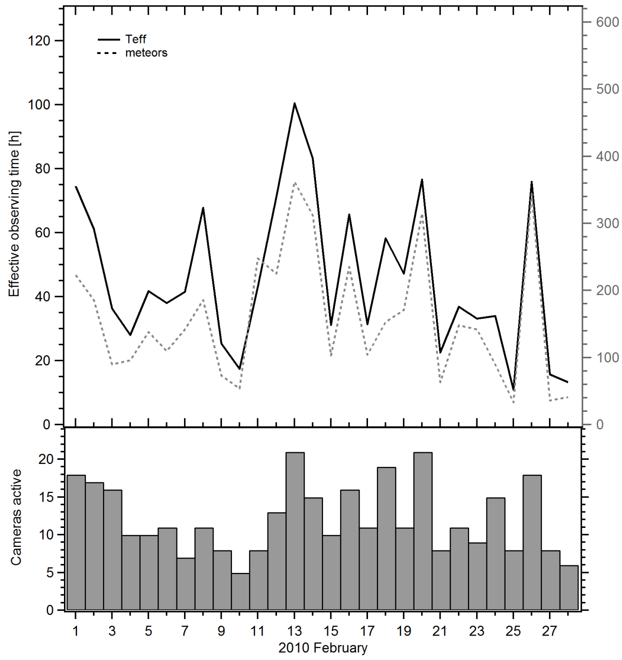

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 February.

2 Minor showers of February revisited

February is a month with almost no meteor showers. The IMO video meteor data analysis from 2009 (Molau & Rendtel, 2009) revealed just two active sources – the π-Hydrids (101 PIH) between February 4 and 8, and the newly discovered β-Herculids (418 BHE) between February 11 and 15. We checked whether these showers were present in this year's data as well by recomputing the meteor shower assignment of all observations with an adapted meteor shower list. The Antihelion source was used for comparison. The results are presented in Figure2.

A total of 39 π-Hydrids (76 ANT / 570 SPO) and 60 β-Herculids (152 ANT / 1025 SPO) were detected – the number of ANT and SPO in the same activity interval are given in brackets. Both showers show the expected profile with maxima on February 6 (PIH) and February 12 (BHE), respectively. This agrees well with data from the analysis of Molau & Rendtel (2009). The Antihelion source, in comparison, shows an almost constant activity in all of February. With respect to the plain meteor numbers, the Antihelion source was slightly more active than the other two showers.

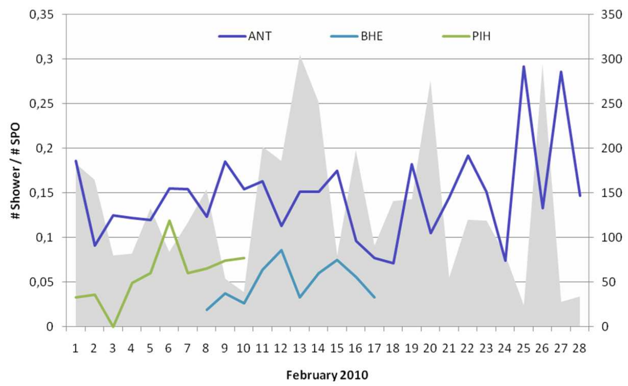

Figure 2 – The number of π-Hydrids, β-Herculids and Antihelion meteors relative to the number of Sporadics in the same night. The absolute number of sporadic meteors is shown in the background.

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Table 1 – Observers contributing to 2010 February 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	32.1	108
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	16	64.2	182
			BMH2 (0.8/6)	⊘ 55°	3 mag	14	64.9	191
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	14	55.3	193
			STG38 (0.8/3.8)	⊘ 80°	3 mag	2	3.1	7
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	3	11.4	27
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	7	41.9	139
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	10	38.8	102
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	18	56.1	149
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	8	16.7	32
			SALSA2 (1.2/4)	⊘ 80°	3 mag	22	100.6	241
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	6	16.0	48
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	12	29.2	71
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	6	52.4	329
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	2	1.4	10
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	4	4.6	12
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	4	11.5	23
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	2	7.8	16
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	9	63.3	417
KOSDE	Koschny	Noord-wijkerhout	LIC1 (1.4/50)	⊘ 60°	6 mag	14	51.8	288
			TEC1 (1.4/12)	⊘ 30°	4 mag	9	12.7	37
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	14	86.0	328
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	6	9.1	37
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	9	23.0	81
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	10	19.5	41
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	8	14.2	32
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	14	72.1	214
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	14	47.3	134
ROTEC	Rothenberg	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	11	13.2	49
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	10	18.6	61
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	12	58.1	224
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	9	49.9	180
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	9	59.4	219
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	6	14.6	37
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	1	1.5	3
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	2	9.2	36
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	4	24.0	67
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	7	26.7	58
					Overall	28	1 282.2	4 423

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Meteorite-dropping fireball in Slovakia

frame 4, t=0.6 s

frame 5, t=0.8 s

frame 6, t=1.0 s

frame 7, t=1.2 s

frame 8, t=1.4 s

frame 9, t=1.6 s

frame 10, t=1.8 s

frame 11, t=2.0 s

frame 12, t=2.4 s

frame 13, t=2.6 s

frame 14, t=2.8 s

frame 15, t=3.0 s

frame 16, t=3.2 s

frame 17, t=3.4 s

frame 18, t=3.6 s

On 2010 February 28 at $22^{h}24^{m}46^{s}$ UT a bright bolide lit the skies over the Central Europe. Almost 4 kg meteorites were recovered near Košice, Slovakia until end March 2010. The images show security camera frames from near Budapest, Hungary. Courtesy of Krisztián Sárneczky and László Kiss.