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Front cover photo

During a Perseid meteor watch from Tenerife this -8 to -10 magnitude fireball flashed across the sky. The image was taken on 2010 August 10 at $23^{\mathrm{h}}43^{\mathrm{m}}$ UT using a modified Canon 350D with an 8.5 mm fisheye lens at $f/3.5$, ISO 800, exposure 1 minute. Photo courtesy: Bill Ward.

Future covers

Have you an interesting or spectacular meteor photograph that you think would look good on the cover of WGN? If so, please offer it to us. A brief description will also be required: this should say what the photograph shows, when and where it was taken, plus (if possible) technical details such as the camera and exposure. We can be contacted at `wgn@imo.net`, but remember to put 'Meteor' in the subject line to get round the anti-spam filters.

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 – Late summer joys

Javor Kac

Two highlights for meteor enthusiasts in late summer are definitely the maximum of the Perseids in August and the International Meteor Conference in September.

I had the opportunity to observe the 2010 Perseids on nine nights and a privilege to spend eight of these nights with my Mart[a] fellows at the Youth astronomical research camp in Medvedje brdo, a small village in central Slovenia. This summer, I was able to observe for more than 34 hours and record 1129 meteors, 736 of them being Perseids. Quite respectable numbers, especially considering many nights were partly cloudy, including the Perseids maximum night. We were pleasantly surprised by the number of very bright Perseid fireballs, with a handful of meteors brighter than magnitude −6.

The International Meteor Conference (IMC) is a once-per-year opportunity to meet meteor workers from around the globe, and a unique chance for amateurs to exchange experience with the professionals. This year, the IMC is taking place in Armagh, Northern Ireland. From the list of participants, I am glad to see the event has attracted many from overseas – I am certain everybody will find the conference an inspiration. I am looking forward to meeting old and new friends in Armagh.

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[a] MART is a Slovenian acronym for the Youth astronomical research camp

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Letter — RE: Texas State astronomers solve Walt Whitman meteor mystery

George John Drobnock

I am sending an open letter that was sent to Sky and Telescope (2 July 2010) and a similar discussion to Dr. Donald Olson, Texas State University.

In the July 2010 “Sky and Telescope” publication, Dr. Olson et al. published an article “setting the record straight” about Walt Whitman’s “Year of Meteors – 1859–1860.” In 2008, Alastair McBeath, Andrei Dorian Gheorghe, and myself prepared an article that was to appear within the WGN for 2008, but was not published there. The work was presented by Alastair and Andrei as a poster at the International Meteor Conference in Slovakia in 2008 September and electronically published on a limited number of compact disks.

Although Dr. Olson and his team had come to the same conclusions as the “Meteor Beliefs Project” article, the Sky and Telescope article has become a very concentrated definitive piece on crediting Olson et al. as finding the relationship between Whitman’s observations and a painting as to solving a literary mystery.

I have attached the clarification letter sent to “Sky and Telescope” stating that prior to Olson et al., there was discussion on the same subject, less the painting by Frederick Church.

As a reference to the July 2010 “Sky and Telescope” publication of Texas State physics professors Donald Olson and Russell Doescher, English professor Marilynn S. Olson and Honors Program student Ava G. Pope work publish on the “Year or Meteors 1859–1860” and the Church painting, I am obligated to point out that at the International Meteor Conference in Slovakia in 2008 September, a poster session was presented where the Walt Whitman “Year of the Meteors” poem was addressed and the implication of the poem to both meteor science and Whitman’s interest in human nature and pre-American civil war period commentary on natural and cultural events.

Prior to the IMO conference a CD of articles was prepared (available through the IMO, see their web site if interested,) including the article “Meteor Beliefs Project: Year of Meteors” edited for the co-authors and contributors to the IMC 2008 MBP, by Alastair McBeath & Andrei Dorian Gheorghe, Project Coordinators (2008 June 15).

The article in the IMO publication about the 1859–1860 meteor outbreak, pointed out that between 15 November 1859 to 2 August 1860 there were four notable fireball events reported in popular press. The event of bright fireballs was world wide, and that the Comet mentioned in the poem, was Comet C/1860 M1. The other review of literature of interest was an article in "Scientific American" of the period entitled the "Year of Meteors".

The initial article (September 2008) was followed by a related article for John Brown's Anniversary on the raid on Harpers Ferry and his death in December 1859. The Whitman Poem identifies John Brown as a meteoric figure (WGN December 2009, pp. 191–194).

As Alastair, Andrei, and I tried to identify the social effect of the 1859–1860 meteors display, with meteor metaphors appearing in commerce and the identification of villains and heroes. I found this contemporary passage for Church, "Church's meteoric rise in the 1840's and 1850's, as one critic has said, was fueled by the tumult of the times. ...". And indeed the period of the poem and painting were presented was fluid and dynamic.

The event observed by Church, Whitman, and others was more than just a local event observed by artist on the July 20th, 1860. Newspapers and related journals, found the event to be spectacular. Even medical journals. From the "American Medical Times" this was located, Vol 1, page 72, July 26, 1860. "Remarks on the Weather (from New York City)," (July) 20 Clear and Hot. A brilliant planetary Meteor Crosses the horizon from west to east at a great altitude at 9 1/4 P.M."

With the information available beginning in 1859 to the end of 1860, the earth's orbit passed through a series of cosmic dust trails (possibly the 1860 Comet), as the year of meteors was observed through out the world. A publication by Heis and Neumayer (1867), (On Meteors in the Southern Hemisphere) discuss a series of fireball (circa 1860) observed from Southern Hemisphere. An illustration by Lydwig Becker from Australia, October 1860 shows a bright fireball over the landscape, as Church.

An opinion shared with Alastair, the 1859–1860 event was the threshold for scientist and others to begin studying meteors as a discipline of astronomy. I know 1833 Leonid outbreak was an event that began some scientist of the period to rethink meteors, not as water vapours, or volcanic rock from earth but from outside the earth. A review of literature after the 1859–1860 event, finds more observational logs and publications beginning to be focused on the study of meteor and meteorites. The event of 1859–1860 was the beginning of the acceptance of meteor observations.

Thank you for your time.

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Letter — Meteor Beliefs Project: Clarification of "Meteors in Australian Aboriginal Dreamings"

Alastair McBeath[1]

The paper in the June issue by Duane Hamacher & Ray Norris (2010), entitled "Meteors in Australian Aboriginal Dreamings", was actually intended to be published as part of the Meteor Beliefs Project. Unfortunately, that wording was left out of the title. This note is to clarify the situation, and to confirm that, as the authors had specifically requested, the article will be available some time after the end of 2010 as a PDF file on the Project's CD-ROM, along with all the other published Project articles.

Further information on the Project generally can be found on the IMO's website, off the "Ongoing Projects" page, or those interested may contact me directly instead, as one of its coordinators.

References

Hamacher D. W. and Norris R. P. (2010). "Meteors in Australian Aboriginal Dreamings". *WGN, Journal of the IMO*, **38:3**, 87–98.

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History

Origin of limiting magnitude counting triangles and squares

Paul Roggemans [1]

Meteor astronomers worldwide struggled for over a century with the problem of how to calibrate visual meteor counts. Although the effect of variable sky conditions was already recognized in the earliest studies of meteor counts, it took until the end of the 1940s before the limiting magnitude was commonly considered as the parameter to calibrate the sky conditions. The brilliant idea to use counting areas in the sky for limiting magnitude determination was proposed by Hugo van Woerden in the 1950s. This method is still used today and helped the IMO to fulfill the expectations of Hugo van Woerden many years after it was first published.

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1 Introduction

When I was reading about meteor streams as a beginning amateur in the early 1970s, meteor astronomy to me looked almost underdeveloped and poorly documented, but with many challenging questions. Exceptionally favorable weather conditions in the summer of 1975, resulting in many clear nights, offered excellent opportunities to start systematic visual observations. In those days, we already had the advantage of having at our disposal a fairly good observing guide containing detailed instructions on how to calibrate the sky conditions. We all understood the importance of such a sky condition calibration for the statistical usefulness of our counts and, therefore, assumed that this had been recognized ever since meteor counts were done. However, that was not the case.

2 Some history

Years later, when I systematically searched astronomical journals, I found many reports mentioning meteor counts. Some journals contained systematic reports on meteor observing, covering roughly the period from 1800 till present. However, this literature search proved to be of no help for studying the evolution of meteor stream structures as the sky conditions were completely ignored in all these observations.

When the Belgian astronomer Adolphe Quetelet[a] (1796–1874) summarized his findings of meteor events in ancient literature (Quetelet, 1861), he referred to the influence of different sky conditions on the number of meteors. When he attempted to compare the Perseid activity in different years for the period 1800–1860, he concluded that the counts were too irregular and insufficiently continuous to allow any conclusions, except for the series of one observer, Remi Armand Coulvier-Gravier (1802–1868). This amateur astronomer provided rather consistent series of meteor counts and was appointed as astronomer in 1850 by François Arago in Paris. Quetelet comments on this observer, as follows: "*Il serait bon de savoir, du reste, comment M. Coulvier-Gravier, qui observe ces phénomènes avec persévérance, a tenu compte de la présence plus ou moins grande des nuages pendant les observations, et de l'influence de la lumière lunaire vers les époques des néoménies; il faudrait savoir également s'il a toujours exploré les mêmes régions du ciel et avec les mêmes observateurs; il conviendrait, enfin, d'avoir des résultats parfaitement comparables*". Concisely translated, this reads as follows: "It would be good to know how Mr. Coulvier-Gravier has taken the presence of clouds into account, and the influence of moonlight; also, if he always observed the same area of the sky with the same observers; it would indeed be appropriate to have perfectly comparable results." The awareness of the influence of sky conditions existed, but these early meteor observers did not manage to develop a reliable sky calibration.

Only a few years later, Giovanni Virginio Schiaparelli (1835–1910) introduced the zenith distance correction for the radiant position, but still failed to calibrate the sky conditions (Schiaparelli, 1871). Later meteor researchers, such as William Frederick Denning (1848–1931), Charles Pollard Olivier (1884–1975), Cuno Hoffmeister (1892–1968), all referred to the evident influence of the sky conditions on the observed hourly rates, but none of them used a reliable calibration method.

Charles Olivier established the *American Meteor Society* in 1911. He focused mainly on visual radiant determination, inspired by the work of Denning. For many years, Olivier published regular reports in the journal *Popular Astronomy.* He encouraged meteor observers to evaluate the sky conditions using a subjective scale according to the personal interpretation of the observer. The *American Meteor Society* developed an international network of correspondents shortly after the First World War, promoting the observing method worldwide. This way, meteor counts without reliable sky calibration were organized worldwide. Nevertheless, the need to calibrate sky conditions for comparing hourly rates was mentioned in many observing reports of the 1920s and 1930s, but then mostly as an excuse to justify why reported rates varied so much. The literature contains almost no reports with usable data for ZHR calculations predating 1945.

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[a] In the literature, including covers of books and articles he authored, one also encounters the spellings *Quételet* and *Quételet* besides *Quetelet.* As Quetelet wrote his own name without accents, we adhere to the last spelling.

3 Limiting magnitude determination

The calibration of observed hourly rates requires a reliable estimate for the sky conditions, which considers the sky transparency, darkness, and contrast, and this with acceptable accuracy monitored throughout the observing period. The most suitable parameter is the (stellar) limiting magnitude, beyond which no star can be detected by the naked eye. The limiting magnitude as a tool for sky conditions calibration appears in meteor papers published after 1945. The Giacobinid outburst of 1946 observed by the Slovak observers from the *Skalnaté Pleso Observatory* is—to the author's knowledge—one of the very first events where sky conditions received proper attention in analyses (Kresák and Slančíková, 1975).

Also Belgian-Dutch meteor teams were instructed from the late 1940s onward to document the sky conditions properly. Sequences of stars with known magnitude were used, but this method soon proved to be deceptive: through auto-suggestion, observers tended to believe seeing invisible stars where they expected them to be. Instead, the IMO today uses the so-called limiting magnitude counting areas. These are the well-known polygonal areas the corners of which are easily visible stars indicated on the gnomonic star maps used by observers. From the number of stars visible within such an area, the limiting magnitude can readily be derived. But when and by whom was this counting method established?

4 Origins of the limiting magnitude counting fields

During a coffee break at the meeting of meteor observers which took place in Heesch, the Netherlands, in late October 2009, Hugo van Woerden told me that he introduced the limiting magnitude counting fields in the mid 1950s. In view of its importance in the IMO visual observing method for reducing meteor counts, which are then subsequently used to analyze meteoroid stream structure, it seemed worthwhile to study the origins of the counting fields as a tool to determine limiting magnitudes in more detail.

At the end of World War II, limited freedom and blackouts inspired many young students and amateur astronomers in the Netherlands and the Flemish part of Belgium to observe meteors. After the war, they they shared the Dutch-language journal *De Meteoor*, in which observational results were published and commented. In these first few years after the War, the data were typically presented in a rather raw format, often resulting in a significant spread in the hourly rates of different observers in the same night.

While browsing the issues of *De Meteoor* that appeared in the 1950s, I could not find a single analyses aimed at revealing the structure of a meteoroid streams. The observing coordinator, Hugo van Woerden, nevertheless repeatedly stressed the importance of a reliable calibration of visual meteor counts. In his concern to provide a reliable method to determine limiting magnitude, Hugo van Woerden had the brilliant idea to introduce carefully selected areas in the sky where star counts during the meteor observation allowed a rather accurate limiting magnitude derivation from conversion tables after the observation.

In 1957, the first 6 counting fields were published, and, in 1958, some extra fields were added (van Woerden, 1957, 1958). This "official list" of counting areas was published after a few years of experience with the new method during meteor observations. In 1956, Hugo van Woerden used it during a Perseid campaign at Onsala Space Observatory, Sweden, together with Bertil Anders Lindblad.

Each counting field was selected in such a way that, in the magnitude range relevant for meteor observing, subsequent stars in order of brightness differ not too much in magnitude. For example., counting 14 stars implies that the faintest visible star in the field has magnitude 5.57. As the invisible 15th star has magnitude 5.79, one can reliably estimate the limiting magnitude at 5.7. Furthermore, using different counting fields contributes to a better coverage of the observed field of view and to minimizing the risks of errors due to believing seeing stars which are actually not visible (van Woerden, 1958). In his article, Hugo van Woerden concludes with these almost prophetic words: "I expect that the described method will lead to accurate results, results that will be usable in an international context for a long time to come." This is indeed exactly what the IMO has achieved.

After the publication of van Woerden's article in 1958, visual meteor observing suffered a severe blow from the astonishing achievements of Fred Lawrence Whipple (1906–2004) obtained with the Super Schmidt Meteor Cameras. The enthusiastic group of young meteor observers of the late 1940s and the early 1950s believed that these cameras made visual observing obsolete, and many of them quit meteor observing. By the early 1960s, visual meteor work was virtually dead in the Netherlands and Belgium.

Luckily, visual meteor observing regained some popularity after favorable observing conditions for the Perseids in 1970 and, especially, in 1972, due to the continuing encouragement of observers by the persistent stream of articles about meteor observing by the Dutch meteor enthusiast Ben Apeldoorn. This renewed interest led to the publication of the *Handleiding visuele meteoorwaarnemingen* (Manual for visual meteor observing), edited by Eddy Van Den Broecke, then director of the Flemish *VVS Meteor Section* (Van Den Broecke, 1974). In it, the limiting magnitude counting fields, as they appeared 16 years earlier in *De Meteoor*, were republished. This visual observing manual proved a great help for the many amateurs who contributed to the visual observing campaigns of the 1970s. The limiting magnitude counting method was also advocated in the *Handboek visuele meteorenwaarnemingen* (Betlem and Roggemans, 1980), which was revised in 1982 (Roggemans, 1982) and subsequently updated and translated in English in 1987 as the *Handbook for Visual Meteor Observations* and republished by *Sky Publishing Corporation* in 1989. This served as the main start for the

IMO visual meteor observing and reporting standards, which are currently described in the *Handbook for Meteor Observers* (Rendtel and Arlt, 2009), available from the IMO (http://www.imo.net/imo/publications).

Acknowledgement

The author wishes to thank Hugo van Woerden for providing the information about the limiting magnitude counting areas. This reliable method to estimate the limiting magnitude as a sky calibration parameter for meteor observing has beyond any doubt been one of the most crucial factors in the success of the global efforts of IMO to map meteoroid stream structures using visual meteor counts. The meteor community is for ever indebted to Hugo van Woerden for his brilliant idea. Finally, the author also wishes to thank Cis Verbeeck (*Royal Observatory, Brussels*) for providing him with a copy of van Woerden's 1958 paper in *De Meteoor*.

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Handling Editor: Marc Gyssens

Ongoing meteor work

What is the difference between image intensifier and CCD meteor observations?
II. Comparison of the results

Masahiro Koseki [1], *Masayoshi Ueda* [2] *and Yoshihiko Shigeno* [3]

Image intensifiers can register dim light and therefore also the higher part of meteor paths compared to a CCD. Minor but long term meteor activity that produces occasionally bright meteors can be monitored with CCD equipment. Image intensifier observations are affected by the sporadic background of mainly faint meteors that cannot be detected by CCD devices. It is very natural that meteor showers detected by two different video techniques will dependent on the properties of the observing devices.

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1 Measurements and calculation of orbits

Shigeno has been a member of the photographic meteor observing network (KPM) and used a developed version of the former calculation program. He detected the meteors and determined their positions manually. He also analyzed the errors in the measurements (Shigeno & Yamamoto, 2010). He claimed that the radiant should not be estimated as a point but as an ellipse, which is the probable area of observed meteor paths' intersection. He estimated the mean long axis of this ellipse to be 0.6 degree and 1.5 degree under poor conditions. He set the observational points in function of the radiant point in case of major shower activity to reduce the size of the ellipse compared to the average values.

Ueda described his method in WGN (Ueda & Okamoto, 2008). He used an automatic detection and calculations of the meteors.

Both Shigeno and Ueda published their calculated results on the web. Shigeno will add the latest results used in this study in the near future. All the results can be consulted on the following pages:
Shigeno: `http://www.imo.net/files/data/msswg/`
Ueda: `http://meteor.chicappa.jp/TVMeteorsOfOrbitsln20042005.html`

2 Properties of video observations

2.1 Errors in the results

Koseki (1986) estimated the practical errors in photographic meteor observations. He selected meteors recorded within an area at the hemisphere delimited with the following coordinates as possible Perseids (see Part III of this paper – forthcoming):

1. $\lambda_\odot = 115^\circ - 155^\circ$
2. $\lambda - \lambda_\odot = 275^\circ - 295^\circ$
3. $B = +30^\circ - +45^\circ$.

The Standard deviation on the geocentric velocity could be used as a measure for the observational error margins. In Table 1 the same area at the hemisphere is adopted for our CCD and image intensifier (II) observations. The results are compared with the Harvard graphical reduction results, with precise data and with former Soviet data.

It is clear that both CCD and image intensifier observations could get slightly better results than the velocities obtained from graphical data. Both can produce comparable useful information of meteor activity. We will discuss the slight difference in mean geocentric velocity between the two and why we used the Perseids and not the Geminids in Part III of this paper (forthcoming).

2.2 What is the faintest magnitude we record, the beginning height and ending height?

Meteoroid properties determine its beginning and ending height. These heights depend on the meteor velocity, the meteoroid mass, the zenithal distance of its radiant and on the limiting magnitude of the observational technique. However, here we consider the comparison of the characteristics of image intensifier and CCD observations and not the meteoroid properties.

Beginning heights for slower meteors are lower than for faster ones (Figures 1 and 2) and, therefore, we divided the observations into four groups ranging from $V_\mathrm{g} < 20$ (km/s), $20 <= V_\mathrm{g} < 40$ (km/s), $40 <= V_\mathrm{g} < 60$ (km/s) and 60 (km/s) $<= V_\mathrm{g}$. We studied the correlations between the magnitude, the beginning and the ending heights for each of these ranges (Figures 3, 4, 5 and 6). Of course image intensifiers can register fainter meteors and record a fainter part of the meteor paths than a CCD. Brighter meteors have also longer paths. Comparing the figures of the four velocity classes, we see that the limiting magnitude of observed meteors decreases with increasing geocentric velocity. Faster me-

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NASA-ADS bibcode 2010JIMO...38..118K

Table 1 – Supposed practical errors in meteor velocity determinations for Perseids.

	CCD	II	graphical	precise	Soviet
mean V_g (km/s)	57.8	58.3	59.8	58.6	59.4
SD in V_g	2.32	2.39	2.92	1.48	2.77

Table 2 – Derived limiting magnitudes of observable meteors.

	$V_g < 20$	$20 \le V_g < 40$	$40 \le V_g < 60$	$60 \le V_g$
II	12.4	12.2	11.0	12.2
CCD	5.7	5.1	3.9	3.6

teors do not produce enough radiation to be detectable by a cell of the device because of the meteors' angular velocity.

Figures 3, 4, 5 and 6 show that the ending heights of image intensifier and CCD observations are about the same but the beginning heights of image intensifiers are almost always higher than those of the CCD's. A meteoroid enters into the Earth's atmosphere and begins to emit faint luminosity which can only be detected by highly sensitive devices. Then it becomes bright enough for smaller cameras while it descends deeper into the atmosphere. Meteors disappear suddenly and both image intensifiers and CCDs fail to register anything further although a meteorite dropping candidate could be visible enough to produce an extended luminosity. An ordinary rather fragile meteoroid cannot survive its path through the dense atmosphere and optical techniques cannot detect anything of its dispersed fragments.

We estimate the limiting magnitude of image intensifier and CCD meteors for ideal conditions from the intersection of the lines in the graphs (Table 2). For example, in Figure 3, two image intensifier lines which show the beginning and ending height seem to converge on (Mag$_{\text{abs}}$, Height) = (12.4, 89.5). This point marks the extreme limit of the image intensifier observations for meteors of $V_g < 20$ (km/s).

Obviously a more sensitive device can register fainter meteors and the derived limiting magnitude of image intensifiers is as faint as the +12 magnitude. The intersection angle of the lines for the range $40 \le V_g < 60$ (km/s) is so small that the estimated limiting magnitude is slightly lower. But, this estimation would be too optimistic, because Figures 3, 4, 5 and 6 show that for fainter meteors the ending heights become higher. On the other hand we may be unable to record easily higher parts of a meteor path. To record higher parts of a meteor trajectory more light radiation must be captured and this requires a larger lens with a longer focus and a smaller field of view. Someone might think that a more sensitive device would detect fainter meteors, however such meteors can only leave a few frames on the records which may be regarded as background noises rather than as a meteor.

In any way, it is clear now that image intensifier observations can register the faintest optical meteors. We can obtain data from the image intensifier observations for the intermediate population of meteors between radar and the usual optical devices. CCD observations cover the range of the so-called Super-Schmidt camera and give enough accurate orbits for future studies (Figure 7).

NOTE: IAUMDC data are stored for FORTRAN users indicated as FORTRAN format. If you read the data as PC data it requires special attention to the format. The IAUMDC data uses 'blank' for no data or that the figures are not significant enough. FORTRAN reads such data as '0', but PC programs reads such blank characters as blank, e.g. spread sheets read a blank as a blank. For example, if data were written as '4_7' (_ is a blank), FORTRAN reads it as '40' but a PC takes it as '4'.

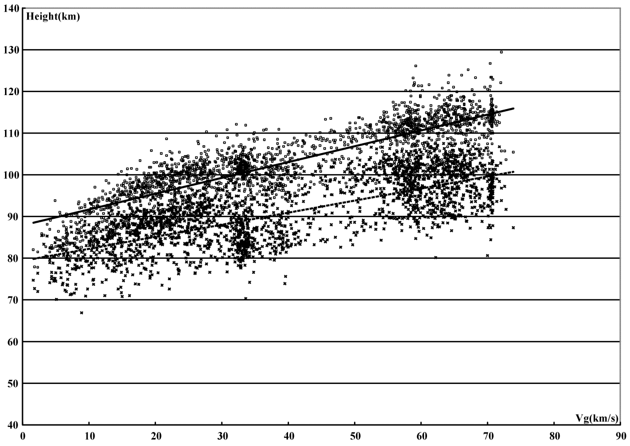

Figure 1 – Beginning and ending height for image intensifier meteors. The two linear regression lines indicate that both the beginning and ending heights change with geocentric velocity.

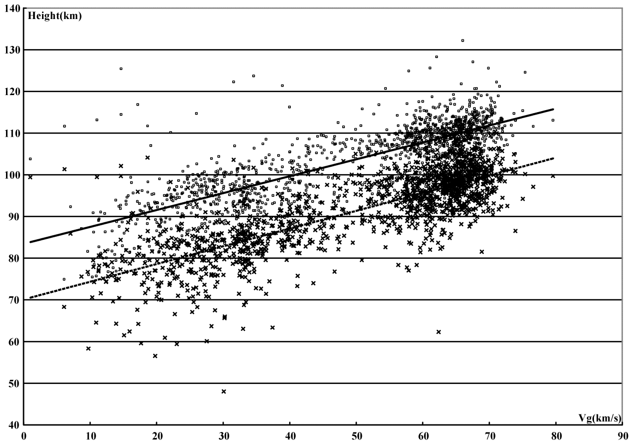

Figure 2 – Beginning and ending height of CCD meteors.

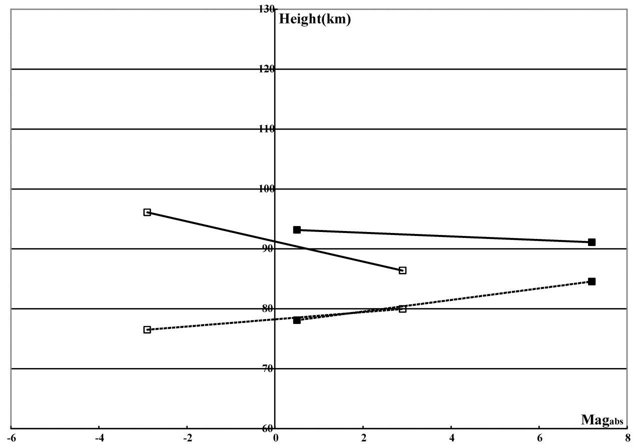

Figure 3 – Beginning and ending heights obtained from the least square solutions for $V_g < 20$ (km/s) meteors in function of the absolute magnitude. Image intensified meteors and CCD meteors are respectively represented by black boxes and squares.

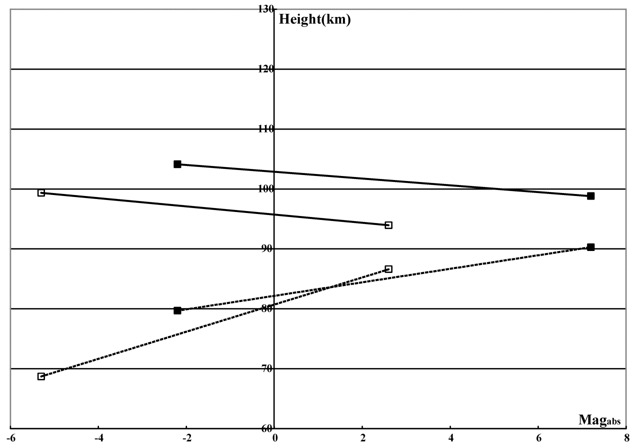

Figure 4 – Beginning and ending heights obtained from the least square solutions for $20 \leq V_g < 40$ (km/s) meteors in function of the absolute magnitude. Image intensified meteors and CCD meteors are respectively represented by black boxes and squares.

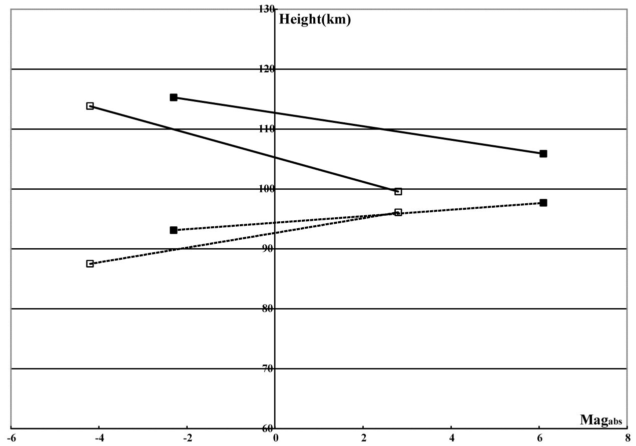

Figure 5 – Beginning and ending heights obtained from the least square solutions for $40 \leq V_g < 60$ (km/s) meteors in function of the absolute magnitude. Image intensified meteors and CCD meteors are respectively represented by black boxes and squares.

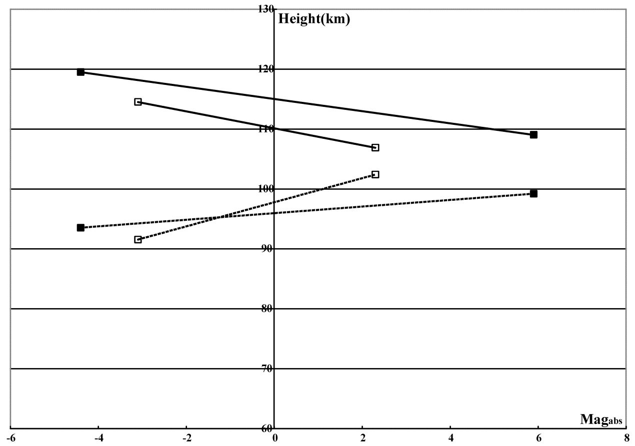

Figure 6 – Beginning and ending heights obtained from the least square solutions for $60 \leq V_g$ (km/s) meteors in function of the absolute magnitude. Image intensified meteors and CCD meteors are respectively represented by black boxes and squares.

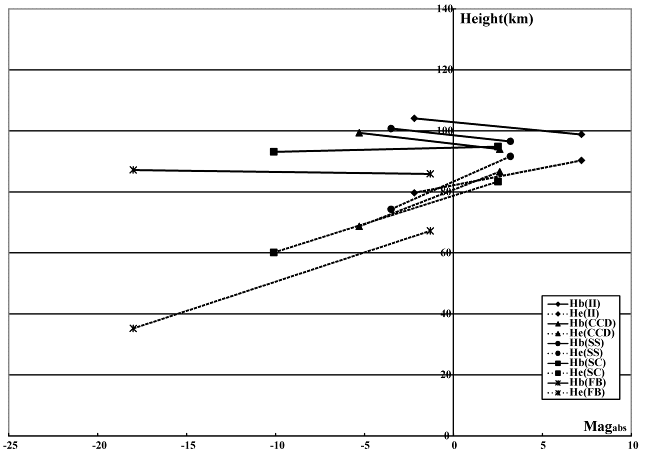

Figure 7 – Comparison of observational techniques for meteors $20 \leq V_{\mathrm{g}} < 40$ (km/s). The higher the sensitivity of the observing devices, the higher the beginning heights can be detected.

3 Meteor showers detected from the results

3.1 Ueda's list

Ueda and Okamoto (2008) reported 13 meteor showers. They compared the results with the IMO Handbook of 1995 (Rendtel et al., 1995) and included the Sagittarids which might be identical with the former MDC shower #163 μ-Sagittariids. Such an anti-helion source is a very difficult object and therefore we exclude this from later discussions.

3.2 Shigeno's list

Shigeno listed 22 meteor showers with 12 candidates. He will re-examine the list and publish it (Shigeno & Yamamoto, 2010) and, therefore, we only treat here the 22 meteor showers.

3.3 Comparison with other investigations

SonotaCo (2009) and Molau & Rendtel (2009) both published very important video meteor shower lists based on video meteors. We compared their results with these of Ueda and with these of Shigeno and we list the interesting summaries below.

There are three points worth commenting.

- Giacobinids (=October Draconids) are missing in all four lists because of its periodic nature. A meteor shower can change its activity level year by year and it may remain undetectable anytime and in any way.

- Ueda could detect less meteor showers although he recorded more than fifteen hundred meteors. Probably meteor showers cannot always be observed by visual meteor observers. (He started CCD observations with double stations in April 2004 and could not observe the Quadrantids 2005 due to bad weather). He reported thirteen meteor showers which were all well observed by others.

  It is recommended to use the term 'established shower' for such meteor showers and not for occasional or periodic showers. The term 'established shower' should be used for meteor showers observable by two different techniques and identified as the same stream by many researchers.

- Shigeno reported twelve and Molau obtained ten candidates for new meteor showers, and there is no overlapping between these new candidates. As for SonotaCo's fourteen meteor showers, Shigeno noticed one and Molau listed eight. Image intensifier and CCD observations have different functions although both are so-called 'video' observations.

Shigeno did not list both Taurids although he recorded sufficient numbers of Taurids. On the other hand, he listed Southern iota-Aquariids, which is not mentioned by others. The four lists are each derived with different definitions of 'meteor shower' and we do not consider the problems of the different definitions. We will discuss this problem in part III of this paper.

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Table 3 – Comparison of the number of meteors classified as shower meteors for four video shower lists sorted by MDC No. (*; not included in 'established showers') We will discuss the properties for the well known (underlined) showers of video observations in Part III of this paper.

MDC	Code	Shower	Ueda	Shigeno	SonotaCo	IMO
1	CAP	Alpha-Capricornids	6	26	122	2283
2	STA	Southern Taurids	46	–	707	8355
3	SIA	Southern iota-Aquariids	–	24	–	–
4	GEM	Geminids	85	242	2510	13193
5	SDA	Southern delta-Aquariids	16	34	324	4716
6	LYR	April Lyrids	11	–	73	1516
7	PER	Perseids	61	142	3524	22169
8	ORI	Orionids	107	37	2733	18249
9	DRA	October Draconids	–	–	–	–
10	QUA	Quadrantis Muralids	–	33	243	3184
11*	EVI	Eta-Virginids	–	–	–	–
12	KCG	Kappa-Cygnids	–	–	213	864
13	LEO	Leonids	38	141	713	9874
14*	(XOR)	Chi-Orionids	–	–	–	–
15	URS	Ursae Minorids (=Ursids)	–	10	28	1100
16	HYD	Sigma-Hydrids	12	6	699	1748
17	NTA	Northern Taurids	30	–	475	3946
18	AND	Andromedids	–	–	18	764
19	MON	(December) Monocerotids	–	11	161	664
20	COM	December Comae Berenicids	–	–	652	435
21*	AVB	Alpha-Virginids	–	–	–	–
22	LMI	Leonis Minorids	–	–	39	550
23*	EGE	Epsilon-Geminids	–	–	–	1134
24*	PEG	Mu-Pegasids	–	–	–	–
25*	NOA	Northern October (Delta-)Arietids	–	–	–	–
26*	NDA	Northern Delta-Aquariids	–	–	–	–
27	KSE	Kappa-Serpentids	–	–	–	–
28*	SOA	Southern October (Delta-)Arietids	–	6	–	–
29*	(DLE)	Delta-Leonids	–	–	–	–
30*	(PSC)	Piscids	–	–	–	–
31	ETA	Eta-Aquariids	17	19	220	1051
32*	DLM	December Leonis Minorids	17	7	–	3181
33	NIA	Northern Iota-Aquariids	–	–	–	–
Number of classified as shower members			446	738	13454	98976
Total number of observed meteors			1521	3668	39208	451282

Meteor Trajectory from Multiple Station Head Echo Doppler Observations

Christian Steyaert [1], *Felix Verbelen* [2], *and the VVS Beacon Observers* [3]

An improved method for determining a meteor's trajectory from its head echo Doppler signature is presented. This methodology is derived from pioneering work from over half a century ago. The new analytical technique employs head echo data that was simultaneously captured by multiple receiving stations located around a low power beacon. In addition to the geometrical data, Monte Carlo simulations of timing errors were generated and reviewed. The method shows great potential, especially if tighter constraints in the inter-station timing can be achieved.

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1 Introduction

Manning (Manning et al., 1949) pioneered Doppler observations of head echoes to determine meteor heights and velocities. With the growing use of pulsed backscatter radar providing more precise data their technique was soon abandoned. Decades later Richardson and Kuneth (1998) revived meteor trajectory determinations using head echo observations. They used both a long base (Richardson) and medium base line (Kuneth) forward scatter reflections from AM modulated video carriers. Their revised method called for additional assumptions including standard range and assumed path geometry of the reflections.

In this article we extend Richardson's and Kuneth's method and apply it to relatively short range observations obtained from the VVS's low powered continuous wave (CW) beacon. We also discuss the limitations of the method as well as possible improvements to the setup and observations.

2 The CW beacon and the receiving stations

The description of the 50 W, CW, beacon at Zillebeke (near Ypres), Belgium is extensively described in (Steyaert, 2006). It has been operating with minimal downtime since April 2005.

The beacon's frequency of 49.990 MHz was consciously chosen to fall just below the six meter ham band to avoid interference during sporadic E and other types of strong propagation band openings. As a result of this frequency choice only specialized, and therefore pricy, receivers can tune to this frequency. Since it was felt the expense of such specialized receivers would limit the number of potential observers, the Working Group Radio Astronomy of the VVS placed a group order for twenty fixed frequency, ready to use, receivers. The receivers, model MRX-50, are produced by AITEC of Japan. The receivers were imported early in 2008. AITEC also manufacturers the HRO receivers used in the Japanese beacon project, AMRO, which is headed by Kimio Maegawa (AMRO, 2010).

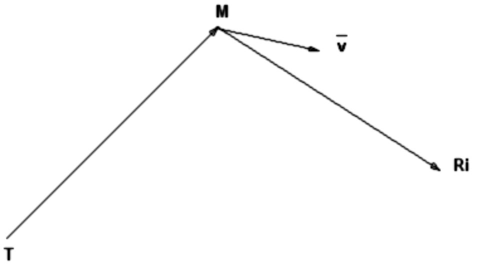

Figure 1 – Head echo geometry.

In addition to the currently operational stations using the VVS's beacon there are several stations still under construction that will use the remaining MRX-50 receivers and others that will use a different receiver.

Typically forward scatter radio meteor observers use software that records spectrograms continuously, although a few stations record only during the periods of the larger streams.

For the head echo study an additional step is required; the audio signal needs to be recorded as well. The recordings are normally in the `.wav` format. The principle and potential yield of head echo observations from several locations was outlined in project 'HADES' (Steyaert & Verbelen, 2006).

3 The Method

Consider the transmitter T, instantaneous meteor head position M with velocity vector $\bar{v}$, and receiver R_i.

The corresponding Cartesian coordinates are:

$$\begin{aligned} TM_x &= (x_M - x_T) \\ TM_y &= (y_M - y_T) \\ TM_z &= (z_M - z_T) \end{aligned} \quad (1)$$

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[3] Janos Barabas, Rik Blondeel, Willy Camps, Johan Coussens, Edwin De Ceuninck, Gaspard De Wilde, Franky Dubois, Pierre Ernotte, Association Jonckheere (test), Volkssterrenwacht Mira (demo), Roland Oeyen, Lucas Pellens, Roger Segers, Chris Steyaert, Dirk Van Hessche, Maarten Vanleenhove, Patrick Vanouplines (TV), Felix Verbelen, John Wardle, Joseph Welkenhuyzen

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IMO bibcode WGN-384-steyaert-trajectory
NASA-ADS bibcode 2010JIMO...38..123S

$$\begin{aligned} R_iM_x &= (x_M - x_{Ri}) \\ R_iM_y &= (y_M - y_{Ri}) \\ R_iM_z &= (z_M - z_{Ri}) \end{aligned} \qquad (2)$$

3.1 Instantaneous Doppler shift

The Doppler shift for receiver ‘i’ is the sum of two parts

$$Doppl_i = Doppl_T + Doppl_{Ri} \qquad (3)$$

with $Doppl_T$ the Doppler shift from the transmitter to the meteor, and $Doppl_{Ri}$ the Doppler shift from the meteor to the receiver ‘i’.

The radial velocity component that contributes to the Doppler shift is conveniently obtained by means of the scalar product of the direction vector and the velocity vector:

$$Doppl_T = -\frac{\overline{TM}}{|\overline{TM}|} \cdot \frac{\overline{v}}{c} f \qquad (4)$$

$$Doppl_{R_i} = -\frac{\overline{R_iM}}{|\overline{R_iM}|} \cdot \frac{\overline{v}}{c} f \qquad (5)$$

with the lengths:

$$|\overline{TM}| = \sqrt{TM_x^2 + TM_y^2 + TM_z^2} \qquad (6)$$

$$|\overline{R_iM}| = \sqrt{R_iM_x^2 + R_iM_y^2 + R_iM_z^2} \qquad (7)$$

and c the speed of light, f the frequency.

Expanding (4) and (5) in coordinates gives:

$$Doppl_T = -\frac{(TM_xv_x + TM_yv_y + TM_zv_z)}{\sqrt{TM_x^2 + TM_y^2 + TM_z^2}} \frac{f}{c} \qquad (8)$$

$$Doppl_{Ri} = -\frac{(R_iM_xv_x + R_iM_yv_y + R_iM_zv_z)}{\sqrt{R_iM_x^2 + R_iM_y^2 + R_iM_z^2}} \frac{f}{c} \qquad (9)$$

and for the total $Doppl_i$:

$$\begin{aligned} &Doppl_i = \\ &-\tfrac{f}{c}\left(\tfrac{TM_x}{\sqrt{TM_x^2+TM_y^2+TM_z^2}} + \tfrac{R_iM_x}{\sqrt{R_iM_x^2+R_iM_y^2+R_iM_z^2}}\right) v_x \\ &-\tfrac{f}{c}\left(\tfrac{TM_y}{\sqrt{TM_x^2+TM_y^2+TM_z^2}} + \tfrac{R_iM_y}{\sqrt{R_iM_x^2+R_iM_y^2+R_iM_z^2}}\right) v_y \\ &-\tfrac{f}{c}\left(\tfrac{TM_z}{\sqrt{TM_x^2+TM_y^2+TM_z^2}} + \tfrac{R_iM_z}{\sqrt{R_iM_x^2+R_iM_y^2+R_iM_z^2}}\right) v_z \end{aligned} \qquad (10)$$

this can be rewritten as:

$$Doppl_i = A_iv_x + B_iv_y + C_iv_z \qquad (11)$$

Scalars A_i, B_i, C_i are the only function of the position of the meteor. Hence velocity components v_x, v_y, v_z can be obtained from solving the linear system

$$\begin{bmatrix} \sum\limits_i A_i^2 & \sum\limits_i A_iB_i & \sum\limits_{A_iC_i} \\ \sum\limits_i A_iB_i & \sum\limits_i B_i^2 & \sum\limits_{B_iC_i} \\ \sum\limits_{A_iC_i} & \sum\limits_{B_iC_i} & \sum\limits_i C_i^2 \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \qquad (12)$$

$$= \begin{bmatrix} \sum\limits_i Doppl_{Obsi}A_i \\ \sum\limits_i Doppl_{Obsi}B_i \\ \sum\limits_i Doppl_{Obsi}C_i \end{bmatrix}$$

from the Doppler shift observations of at least three different locations.

Linear system (12) is the solution of the least square form:

$$Min\frac{1}{2}\sum_i (Doppl_{Obsi} - A_iv_x - B_iv_y - C_iv_z)^2 \qquad (13)$$

with respect to the velocity components v_x, v_y, v_z.

3.2 Doppler shift derivative

Similar to the Doppler shift itself, the derivative or slope of the Doppler shift for receiver ‘i’ is the sum of two parts:

$$\frac{\partial Doppl_i}{\partial t} = \frac{\partial Doppl_T}{\partial t} + \frac{\partial Doppl_{R_I}}{\partial t} \qquad (14)$$

Assuming a time independent velocity vector $\overline{v}$

$$\frac{\partial Doppl_T(t)}{\partial t} = -\frac{1}{|\overline{TM}|}\left[v^2 - \frac{(\overline{TM}\cdot\overline{v})^2}{TM^2}\right]\frac{f}{c} \qquad (15)$$

$$\frac{\partial DopplR_i(t)}{\partial t} = -\frac{1}{|\overline{R_iM}|}\left[v^2 - \frac{(\overline{R_iM}\cdot\overline{v})^2}{R_iM^2}\right]\frac{f}{c} \qquad (16)$$

with

$$TM^2 = |\overline{TM}|^2 = TM_x^2 + TM_y^2 + TM_z^2 \qquad (17)$$

$$R_iM^2 = |\overline{R_iM}|^2 = R_iM_x^2 + R_iM_y^2 + R_iM_z^2 \qquad (18)$$

$$v^2 = \overline{v}^2 = \overline{v}.\overline{v} = v_x^2 + v_y^2 + v_z^2 \qquad (19)$$

3.3 Solving the equations

The goal is to find the position, M, and velocity vector, $\overline{v}$, from the observed Doppler shifts and Doppler shift derivatives at a given time.

The six unknowns x_M, y_M, z_M and v_x, v_y, v_z can in principle be obtained from at least three $Doppl_{Obsi}$ and the corresponding $\frac{\partial Doppl_{Obsi}}{\partial t}$. The general procedure is:

- choose M (x_M, y_M, z_M)
- solve (12) for v_x, v_y, v_z
- calculate for each ‘i ‘$\frac{\partial Doppl_i}{\partial t}$ with (12)
- calculate $J = \frac{1}{2}\sum\limits_i \left(\frac{\partial Doppl_i}{\partial t} - \frac{\partial Doppl_{Obsi}}{\partial t}\right)^2$ (20)
- iterate M for minimum value J

In case of a stream meteor, the velocity vector is fairly well known so the following alternative procedure can be used:

- choose M (x_M, y_M, z_M)
- calculate for each ‘i ‘$Doppl_i$ with (10)
- calculate $J' = \frac{1}{2}\sum\limits_i (Doppl_i - Doppl_{Obsi})^2$ (21)
- calculate for each ‘i ‘$\frac{\partial Doppl_i}{\partial t}$ with (12)
- calculate $J = \frac{1}{2}\sum\limits_i \left(\frac{\partial Doppl_i}{\partial t} - \frac{\partial Doppl_{Obsi}}{\partial t}\right)^2$ (20)
- iterate M for minimum value $J + \lambda J'$ (22)

λ is a positive weight factor.

3.4 Measurements at different absolute times

In section 3.3 we stated loosely that the time of all measurements was equal. However this is not a necessary condition. If at time t = 0 the coordinates of the head echo are $x_M; y_M; z_M$, then they are at time t_i :

$$\begin{aligned} x_{Mi} &= x_M + v_x t_i \\ y_{Mi} &= y_M + v_y t_i \\ z_{Mi} &= z_M + v_z t_i \end{aligned} \tag{23}$$

Formulae (1), (2), and (3) should be replaced with:

$$\begin{aligned} TM_{ix} &= (x_{Mi} - x_T) \\ TM_{iy} &= (y_{Mi} - y_T) \\ TM_{iz} &= (z_{Mi} - z_T) \end{aligned} \tag{1'}$$

$$\begin{aligned} R_iM_{ix} &= (x_{Mi} - x_{Ri}) \\ R_iM_{iy} &= (y_{Mi} - y_{Ri}) \\ R_iM_{iz} &= (z_{Mi} - z_{Ri}) \end{aligned} \tag{2'}$$

$$Doppl_i = Doppl_{Ti} + Doppl_{Ri} \tag{3'}$$

In principle it is possible to use several Doppler and Doppler rate measurement of the same observer at different times.

4 A worked out example

During the Geminids 2009, the observers listed in Table 1 were recording `.wav` files, which allow the measurement of head echoes.

Figure 2 is a typical recording made with the Spectrum Lab freeware (DL4YHF, 2010). The descending lines lasting several minutes are mainly reflections caused by high level (10 km) planes within 30 km of the beacon.

The faint horizontal lines (e.g. at 740 and 840 Hz) are local interference. Normally the carrier is not directly detected in this particular setup.

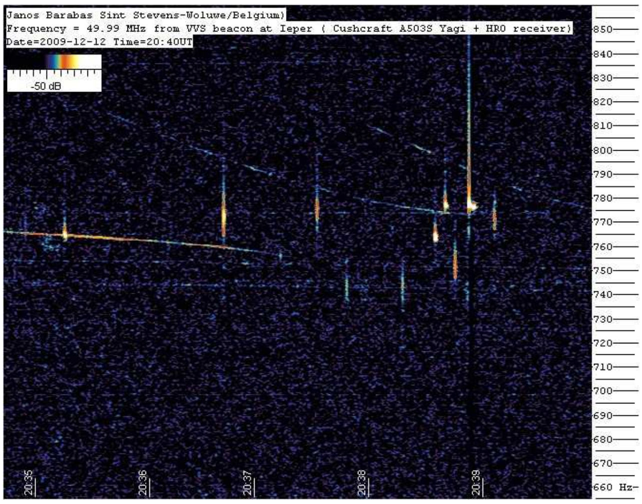

Figure 2 – Spectrumlab 5 minute recording of Janos Barabas during the Geminids 2009 maximum.

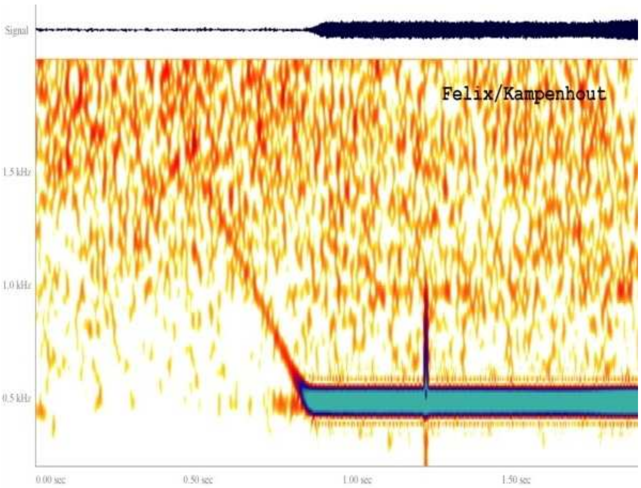

Figure 3 – Head echo of the 2009 December 12, $20^{\mathrm{h}}38^{\mathrm{m}}$ UT Geminid, as recorded by Felix Verbelen.

Twelve meteors are seen as ‘vertical’ streaks, clustering in the 730–800 Hz frequency band. As this recording was made during the maximum of the Geminids, there is a high probability that most of them are Geminids indeed. The sporadic activity during that time of the day (local evening) is normally low.

The Doppler spread is related to the thermal motion of the ions of the trails. The carrier frequency is near the midpoint of the vertical scale, at 770 to 775 Hz.

In the low time resolution Spectrum Lab recording of Figure 2 the trail at $20^{\mathrm{h}}38^{\mathrm{m}}50^{\mathrm{s}}$ extends nearly vertical up to at least 840 Hz. Figure 3 shows the same meteor trail with a much greater time resolution as produced by the freeware program, Spectrogram by R.S. Horn (Electronics Lab, 2010). The increased time resolution of Spectrogram emphasizes the meteor is definitely a head echo swiftly approaching the point of closest approach for that observer’s radio system.

Figure 4 is the compilation of all observed head echoes reduced to the same time and frequency scale. It is remarkable that the observer closest to the beacon (Table 3), Johan Coussens, did not record a sufficiently strong head echo.

Table 1 – Radio observers during the 2009 Geminids contributing to this work.

Name	**Location (Belgium)**	**Longitude (E) dec degrees**	**Latitude (N) dec degrees**	**Antenna Altitude ASL (m)**
VVS beacon at Astrolab-IRIS Zillebeke (Ypres)		2.9100	50.8180	41
Johan Coussens	Harelbeke	3.3293	50.8566	65
Dirk Van Hessche	Ninove	3.9868	50.8249	
Roger Segers	Puurs	4.2835	51.0709	
Roland Oeyen	Lembeek	4.1965	50.7152	63
Janos Barabas	Sint Stevens-Woluwe	4.4560	50.8760	
Felix Verbelen	Kampenhout	4.5944	50.9503	15
Willy Camps	Tessenderlo	5.0922	51.0822	26
Lucas Pellens	Overpelt	5.4324	51.2039	

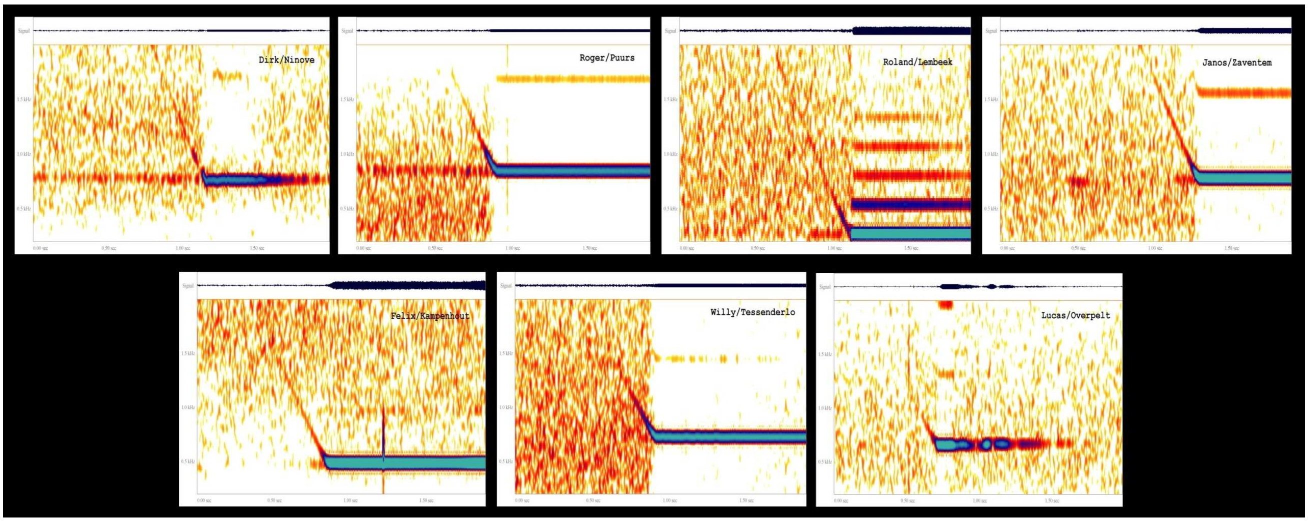

Figure 4 – Impression of the head echo of 2009 December 12, $20^{\mathrm{h}}38^{\mathrm{m}}$ UT by all observers.

Table 2 – Basic head echo data of the 2009 December 12, $20^{\mathrm{h}}38^{\mathrm{m}}$ UT Geminid, measured from observer's records.

head echo	200912122038							
Observer	location/Belgium	*t1*	*freq1*	*t2*	*freq2*	*zero-freq*	*slope* (Hz/sec)	*t_0-freq*
Johan Coussens	Harelbeke	no HE						
Dirk Van Hessche	Ninove	954	1449	1147	806	762	-3332	1160
Roger Segers	Puurs	694	1490	874	910	851	-3222	892
Roland Oeyen	Lembeek	648	1819	1062	414	274	-3394	1103
Janos Barabas	Zaventem	1074	1464	1236	932	780	-3284	1282
Felix Verbelen	Kampenhout	586	1290	810	614	488	-3018	852
Willy Camps	Tessenderlo	746	1165	876	814	729	-2700	907
Lucas Pellens	Overpelt	615	921	684	732	658	-2739	711

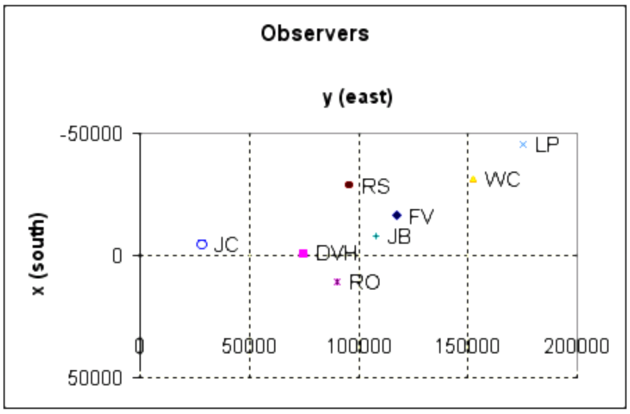

Figure 5 – Location of the observers with respect to the transmitter in the origin.

Two points, $t1$ and $t2$, in Table 2 are measured as far apart as possible on the trail. The values are in milliseconds. Times are NTP synchronized every hour with a tool such as Dimension 4 (Thinking Man Software, 2010).

The base line frequency *zero-freq* and the corresponding time *t_0-freq* are also measured, but are not used in the following calculations.

The slope of the head echo Doppler is simply calculated as the chord between the two points:

$$slope = \frac{freq1 - freq2}{t1 - t2} \tag{24}$$

This is the best approximation for the slope at the mid of the interval $[t1, t2]$, or $(t1 + t2)/2$.

All formulae (1) to (23) are for a general Cartesian system. We choose now a more specific coordinate system that allows easier interpretation of the resulting positions and velocities:

- the transmitter is at the origin of the coordinate system,
- the x-axis is oriented to the local south of the transmitter (tangent to the Earth ellipsoid),
- the y-axis is oriented to the local east of the transmitter (tangent to the Earth ellipsoid),
- the z-axis complements the right handed system, and therefore is pointing to the local zenith.

The resulting Cartesian coordinates are found in Table 3, and the plot on the tangent (x, y) plane in Figure 5. Most observers are located in a sector north east to south east of the transmitter.

For our Geminid example we follow the 'alternative procedure' for stream meteors using formulae (20)–(22).

The position of the standard Geminids radiant $\alpha = 113°$, $\delta = +32°$ in horizontal coordinates at the location of the beacon is: azimuth $Az = 257°$, elevation $h = 34°$, and the components v_x, v_y, v_z of the velocity vector for meteor speed $v = 34400$ m/s:

$$\begin{aligned} v_x &= -\cos(Az)\cos(h)v \\ v_y &= \sin(Az)\cos(h)v \\ v_z &= -\sin(h)v \end{aligned} \tag{25}$$

giving numerical values:

$$\overline{v} = (6415.4, -27788.0, -19236.2) \tag{26}$$

A logical starting value for (x_M, y_M, z_M) is $(0, 0, 90000)$, or 90 km above the beacon. The downhill simplex method minimizing $J + \lambda J'$ (22) finds an optimal point (rounded to the whole km) at $(-22000, 9000, 960000)$. The weight factor λ in (22) was chosen to be 0.2.

We choose $(x_M, y_M, z_M) = (-16000, 18000, 96000)$, for which following detailed calculations are performed.

This is the position along the trail at time t = 0. This is well before the start of the observed head echo.

The corresponding x_{Mi}, y_{Mi}, z_{Mi} for the mid point of the measured head echoes are according to (23):

Observer	ti	x	y	z
Verbelen	0.698	−17522	−10396	82573
Van Hessche	1.051	−15261	−20191	75792
Camps	0.811	−16797	−13536	80399
Pellens	0.650	−17833	−9048	83506
Oeyen	0.855	−16515	−14759	79553
Segers	0.784	−16970	−12786	80919
Barabas	1.155	−14590	−23095	73782

The z-values at these midpoints of the head echo are realistic.

The resulting errors are according to (20) and (21):

Observer	(O − C)dD/dt	(O − C)*Doppl*
Verbelen	−125.2	−191.2
Van Hessche	309.9	−227.5
Camps	6.2	499.8
Pellens	−307.4	277.5
Oeyen	−86.0	−151.2
Segers	−57.2	−407.1
Barabas	41.7	956.8

These errors are on the high side, especially the Doppler differences. This was only the initial step for a chosen x_M, y_M, z_M. The errors can still be reduced with the iterative procedure yet they remain rather high, mainly due to timing errors. A small timing error has a large impact on the instantaneous Doppler due to the high Doppler rate.

As there is only limited redundancy in the measurements we did not try to identify an outlier. Instead we made Monte Carlo simulations for the timing errors. Each timing instance was subjected to a 5 ms standard deviation.

The resulting horizontal plane scatter graph (Figure 6) shows a large spread in the north-south direction. The large spread is the result of the direction of the meteor in combination with the location of the observers.

The height scatter turns out to be much more limited, and there is only a slight dependency between z and both x and y.

It is unclear why Johan Coussens did not record the head echo. Probably the signal was too weak compared to the strong directly received carrier. Another possibility is that there is a selectivity effect at play.

General procedure (20), which determines both the meteor position and velocity, was tried with insufficient

Table 3 – Cartesian coordinates of the observers with respect to the transmitter.

	x	y	z	r
Beacon	0.0	0.0	0.0	0.0
Johan Coussens (JC)	−4148.1	28822.7	−1.3	29119.6
Dirk Van Hessche (DVH)	−1085.3	75164.5	−427.1	75173.6
Roger Segers (RS)	−28793.4	95559.9	−779.5	99806.6
Roland Oeyen (RO)	10882.3	90146.5	−582.1	90802.8
Janos Barabas (JB)	−7353.0	108098.2	−918.5	108351.9
Felix Verbelen (FV)	−15831.4	117647.7	−1087.6	118713.1
Willy Camps (WC)	−31405.6	152178.5	−1863.4	155396.5
Lucas Pellens (LP)	−45689.6	175533.6	−2574.8	181400.7

results for this example. The subject will be pursued when more accurate data are available.

5 Conclusion / future

The full theory for determining meteor trajectories from multiple Doppler head echo observations has been established.

Numerical results are encouraging, but will only be truly valuable if the timing accuracy of the recordings is improved to a few milliseconds.

Additional observing stations spread around the transmitter would improve the geometry and contribute to better results.

Several simultaneous head echoes are recorded per day. The identification, measurements and calculations of head echoes are currently done manually therefore the analysis procedure is very time intensive. A method to automate the analysis is needed to cope with the high volume of data.

Acknowledgments

We wish to thank:

- Astrolab IRIS for hosting the beacon and the VVS sponsoring the project and yearly license,
- Jeff Brower for greatly improving this text,
- Eddy Jespers (Eclips) for importing the MRX-50 receivers,
- Enric Algeciras for organizing the CE compliance tests of the MRX-50 receivers,
- Belgian Institute for Postal Services and Telecommunications (BIPT) for allocating the beacon frequency,
- Masa-Yuki Yamamoto for his invaluable liaison role with AITEC,
- David Entwistle for the interesting discussions about the Monte Carlo method and sensitivity analysis, and thoroughly checking the calculations.

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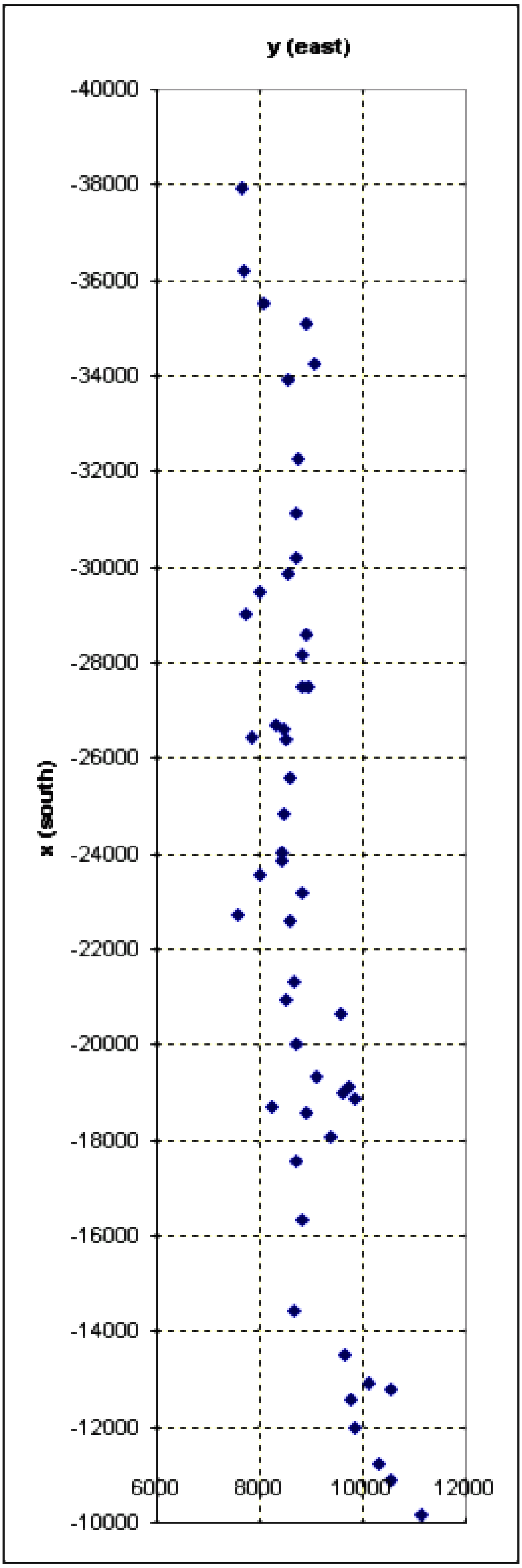

Figure 6 – Scatter on the results for the Monte Carlo simulation: horizontal plane.

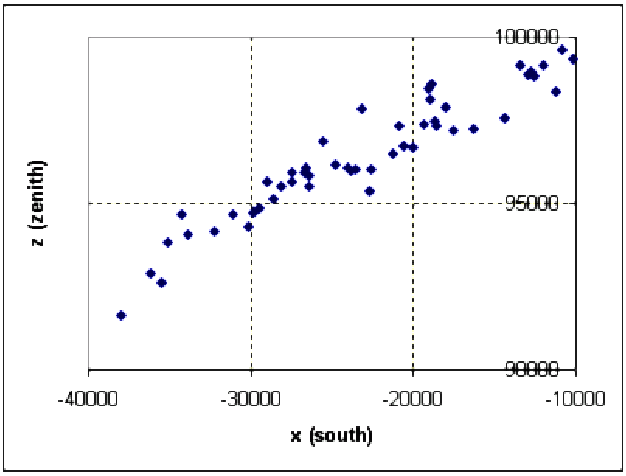

Figure 7 – Scatter on the results for the Monte Carlo simulation: north-south vertical plane.

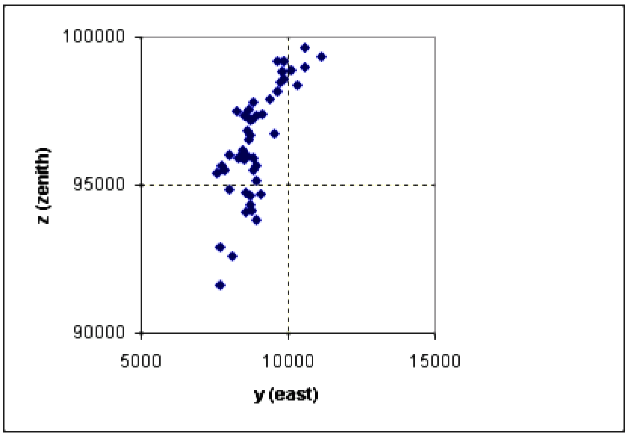

Figure 8 – Scatter on the results for the Monte Carlo simulation: east-west vertical plane.

Results of the IMO Video Meteor Network — May 2010

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

The results of the IMO Video Meteor Network in 2010 May are presented. Almost 6 000 meteors were recorded in about 1 600 hours of observing by 39 cameras. The activity profiles of the η-Aquariids and η-Lyrids in 2010 are presented.

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1 Introduction

In May, we experienced once more strong differences between individual observing sites. Observers in the region of the Alps suffered strongest from the poor weather. Hardly any observer in southern Germany, Slovenia or northern Italy obtained more than 10 observing nights. At other observing sites, the weather was more cooperative, and Carl Hergenrother did not miss even a single night once more. With 1 600 observing hours, the monthly total was smaller than in the years before (Table 1 and Figure 1). Still, the number of almost 6 000 meteors was clearly higher, mainly thanks to our Australian observer Steve Kerr. He did not only enjoy longer nights thanks to the southern hemisphere winter season, but with the η-Aquariids also the strongest southern meteor shower.

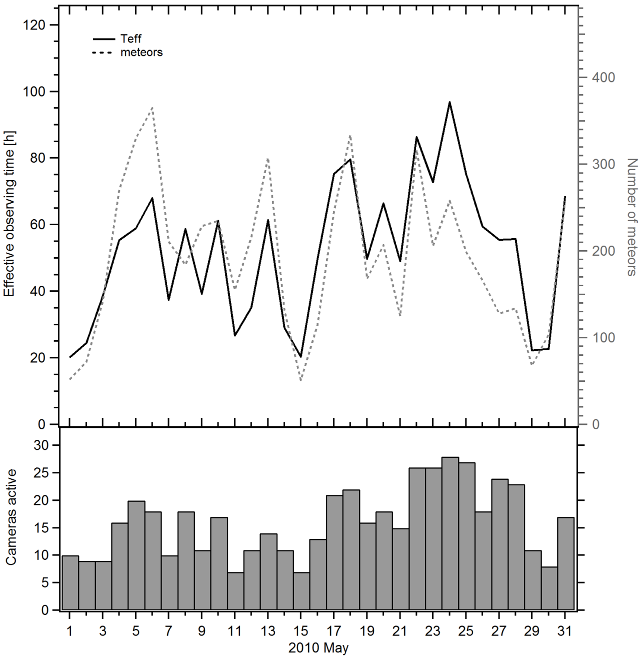

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 May.

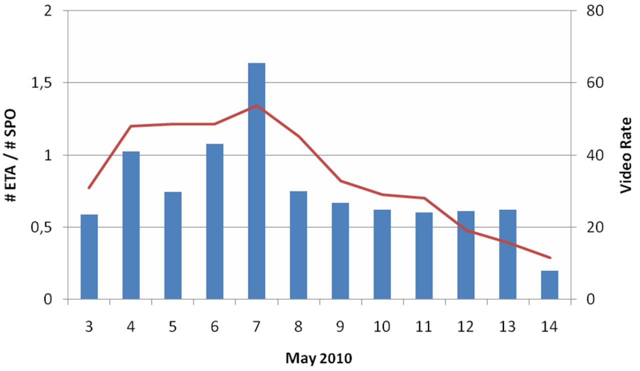

Figure 2 – Activity profile of the η-Aquariids, obtained from data of the Australian camera GOCAM1 (bars) in May 2010. The long-term video rate profile from IMO network data till 2009 (Molau & Rendtel, 2009) is plotted for comparison (line).

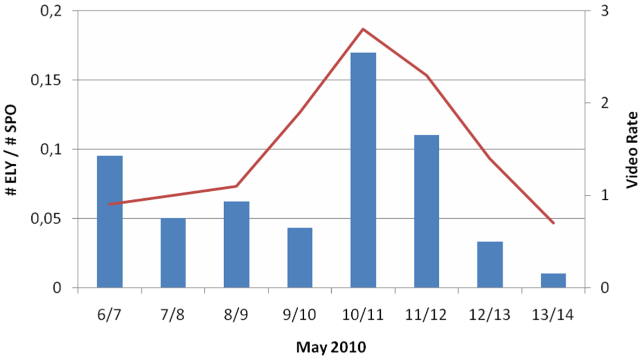

Figure 3 – Activity profile of the η-Lyrids, obtained from data of all IMO network cameras in May 2010 (bars). The long-term video rate profile from data till 2009 (Molau & Rendtel, 2009) is plotted for comparison (line).

2 Eta Aquariids

Over many days, the η-Aquariids (ETA) were the dominating shower from "down under" as can be seen from the following analysis (Figure 2). Based on the data from GOCAM1, the number of shower meteors (439 in total) was divided by the number of sporadics (585 in total) and plotted on a daily basis (bars). For comparison, the long-term video rate profile from the 2009 meteor shower analysis (Molau & Rendtel, 2009) was overlaid (line). The time of maximum (47° solar longitude) matched very well to the long-term average ($\lambda_\odot = 46\overset{\circ}{.}8$), but the peak was clearly narrower.

3 Eta Lyrids

The η-Lyrids, which have been included in the IMO working list not too long ago (Arlt & Rendtel, 2006),

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IMO bibcode WGN-384-molau-vidmay
NASA-ADS bibcode 2010JIMO...38..130M

Table 1 – Observers contributing to 2010 May 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	12	14.5	42
			TIMES5 (0.95/50)	⊘ 10°	3 mag	7	7.4	19
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	18	48.7	120
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	19	39.6	90
			BMH2 (0.8/6)	⊘ 55°	3 mag	18	42.7	121
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	17	44.5	123
			STG38 (0.8/3.8)	⊘ 80°	3 mag	19	56.9	121
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	10	35.7	85
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	23	122.5	417
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	23	87.6	236
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	16	45.6	104
HERCA	Hergenrother	Tucson	SALSA2 (1.2/4)	⊘ 80°	3 mag	31	119.1	302
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	4	10.9	24
IGAAN	Igaz	Budapest	HUPOL (0.8/3.8)	⊘ 80°	3 mag	18	27.1	62
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	11	55.9	327
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	5	12.4	31
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	12	19.3	43
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	9	32.0	108
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	8	21.6	58
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	16	145.6	1575
KOSDE	Koschny	Noordwijkerhout	LIC4 (1.4/50)	⊘ 60°	6 mag	14	62.7	269
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	15	49.1	193
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	5	12.7	80
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	12	29.9	70
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	13	17.5	43
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	4	12.5	27
MORJO	Morvai	Fülöpszallas	HUFUL (0.8/3.8)	⊘ 80°	3 mag	21	42.0	93
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	15	52.5	109
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	15	42.6	109
ROTEC	Rothenberg	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	12	23.3	66
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	15	22.0	53
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	8	17.1	26
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	15	77.8	261
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	15	72.2	225
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	16	72.6	247
STORO	Stork	Ondřejov	OND1 (1.4/50)	⊘ 55°	6 mag	1	2.2	22
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	11	19.6	50
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	11	28.0	85
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	8	16.0	40
					Overall	31	1 619.9	5 983

are active in the first half of May as well. They were analyzed with the same method (Figure 3), whereby this time the data of all cameras from the IMO network between May 6/7 and 13/14 were used (59 ELY, 1012 SPO). In this case, not only the time of maximum (50° solar longitude) agrees perfectly with the long-term value (Molau & Rendtel, 2009), but also the shape of the activity profile is very similar. Note that the absolute rate is by an order of magnitude smaller than for the η-Aquariids.

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Handling Editor: Javor Kac

Results of the IMO Video Meteor Network — June 2010

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

The IMO Video Meteor Network results from 2010 June are presented. More than 1 700 hours of observing time and over 6 000 meteors were collected by 32 cameras. The outburst of June Boötids on June 23/24 as reported by the visual observers was confirmed. The long term activity profile in 2010 and a detailed profile from June 23/24 are presented. The presence of two recently detected minor showers was also checked. While some meteors could be assigned to δ-Piscids and f-Ophiuchids, none of the showers stood out from the sporadic background.

Received 2010 July 29

1 Introduction

June was another highlight for most observers of the IMO network. If we forget about a short rainy period right before midsummer, most observers enjoyed perfect conditions through all of June. Twelve cameras recorded meteors in twenty and more nights, and even though the data from five cameras are still missing at this point, we managed to obtain another all-time high for June with more than 1 700 hours of effective observing time and 6 000 meteors (Table 1 and Figure 1). June is among the months with the least observations in the IMO Video Meteor Network database. In soccer we would say, that the relegation spots are held by February (24 558 meteors), May (24 395 meteors) and June (24 362 meteors). When the currently missing data are added, June will probably pass the other two months. Once more, that is in particular thanks to Steve Kerr, who took full advantage of the high meteor activity and long nights in the southern hemisphere.

2 June Boötids

On June 24, Javor Kac reported enhanced June Boötid activity to the IMO-News Mailing List (Kac, 2010), which Slovenian observers had noted during a comet observing session between 00^h and 01^h UT. Also his own camera Orion1 had recorded more JBO than SPO this night. He alerted other observers to give this shower special attention, but there were no further positive reports. Some visual observers even noted that they had observed nothing special on June 23/24. So was that just a false alarm?

To answer this question, the video data between June 21/22 and 29/30 were analysed in detail. At first, we calculated the ratio between the number of June Boötids and Sporadics over all cameras for each night. The result, which is based on a total of 1889 SPO and 141 JBO, is given in Figure 2. The observation of Javor is clearly confirmed: Whereas the June Boötids were virtually absent all of the time, we recorded over a hundred shower meteors on June 23/24 alone, which is about one third of the sporadic count of that night. The ratio of Antihelion to sporadic meteors is plotted for comparison. As expected, the Antihelion rate was almost constant in that time interval. Whereas the regular June Boötid maximum was predicted for June 27, we observed an early outburst of this shower similar to 2004. Only the ZHR stayed probably below 10 this time.

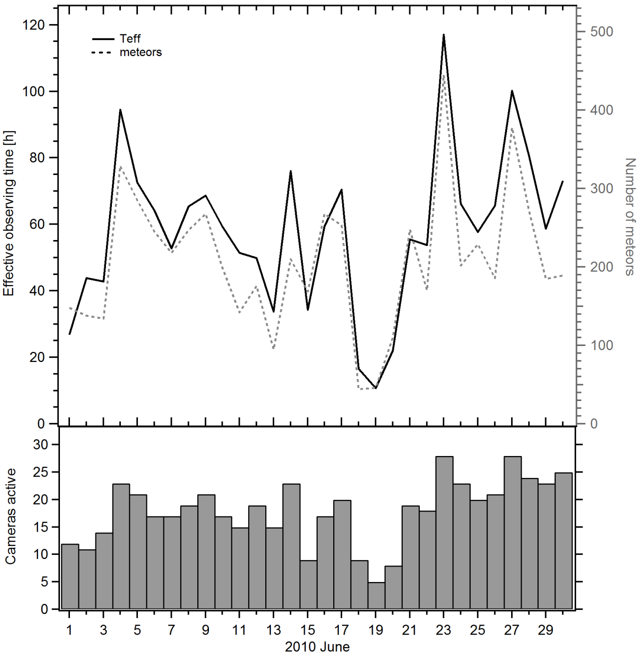

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 June.

Next, we analysed whether the activity on June

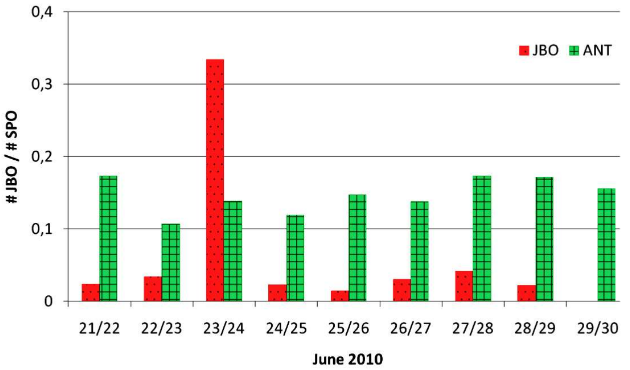

Figure 2 – Activity profile of the June Boötids in the last third of June 2010 (dotted bars). The enhanced JBO rate of June 23/24 is clearly visible. For comparison, the activity profile of the Antihelion source in given as well (square pattern bars).

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IMO bibcode WGN-384-molau-vidjun
NASA-ADS bibcode 2010JIMO...38..132M

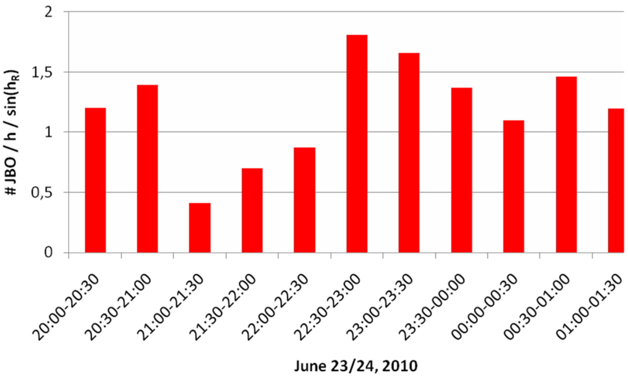

Figure 3 – JBO activity on June 23/24. Here, the average hourly number of June Boötids, corrected by the radiant altitude, is given.

23/24 was constant, or whether there were strong variations as suggested by some observers. Fortunately just that night was the best June night ever (for the first time we collected more than 100 hours effective observing time), so that we could analyze the number of June Boötids in half hour intervals and correct the counts for the radiant altitude. The resulting profile is given in Figure 3. There might be a dip in activity between 21^h00^m and 22^h30^m UT, but overall the JBO activity was clearly enhanced all night long.

Finally, we derived the radiant position of the June Boötids from the observation of that single night. With $\alpha = 224°$, $\delta = 48°$ and $v_{\text{inf}} = 17$ km/s we obtained values that match almost perfectly to the values given in the IMO shower calendar (McBeath, 2009). Reports from observers who noted the radiant about 10 degrees farther south in previous years could not be confirmed for 2010.

3 June minor showers

Away from the JBO and ANT, there are just two other showers in June. Both, the δ-Piscids (410 DPI) and f-Ophiuchids (412 FOP) were detected in our shower analysis last year (Molau & Rendtel, 2009), which is why we wanted to check if they were traceable in 2010 as well. We extended the shower list by these showers and recomputed the meteor shower assignment for all observations starting from June 19. Between June 19 and 26, a total of 48 meteors were assigned to the δ-Piscids. The activity was so low that the shower did not stand out of the sporadic background. Only on June 21/22 we recorded a slightly larger number of δ-Piscids (16 meteors). With only 31 meteors fitting to the radiant, the f-Ophiuchids remained below the detection threshold all the time between June 26 and 30.

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Figure 4 – This sporadic fireball of about magnitude −4 was captured on 2010 June 11 at $01^h24^m29^s$ UT by the IMO Video Meteor Network camera Orion1 from Ljubljana, Slovenia. Photo courtesy: Javor Kac / Orion Astronomical Society.

Figure 5 – A magnitude 0 sporadic meteor, captured on 2010 June 13 at $20^h58^m04^s$ UT by the IMO Video Meteor Network camera Orion2 from Središče ob Dravi, Slovenia. Photo courtesy: Mitja Govedič / Orion Astronomical Society.

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Molau S. and Rendtel J. (2009). "A comprehensive list of meteor showers obtained from 10 years of observations with the IMO video meteor network". *WGN, Journal of the International Meteor Organization*, **37:4**, 98–121.

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Table 1 – Observers contributing to 2010 June 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	17	28.1	81
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	24	84.2	216
CASFL	Castellani	Monte Baldo	BMH2 (0.8/6)	⊘ 55°	3 mag	20	32.5	95
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	21	73.4	244
			STG38 (0.8/3.8)	⊘ 80°	3 mag	24	67.1	189
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	13	39.5	87
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	13	62.5	207
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	20	55.8	146
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	18	71.1	209
HERCA	Hergenrother	Tucson	SALSA2 (1.2/4)	⊘ 80°	3 mag	28	102.0	250
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	7	26.1	55
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	14	40.6	259
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	9	18.2	44
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	21	47.4	139
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	9	41.3	193
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	11	40.1	126
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	23	178.4	1352
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	14	42.6	231
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	20	65.9	203
MORJO	Morvai	Fülöpszallas	HUFUL (0.8/3.8)	⊘ 80°	3 mag	7	19.3	44
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	18	48.2	89
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	17	45.7	124
ROTEC	Rothenberg	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	23	66.9	185
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	22	39.0	91
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	16	48.5	86
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	17	73.9	257
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	19	81.8	279
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	17	71.8	265
STORO	Stork	Ondřejov	OND1 (1.4/50)	⊘ 55°	6 mag	2	6.1	84
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	20	35.9	93
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	18	45.4	133
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	19	44.1	171
					Overall	30	1 743.8	6 227

The International Meteor Organization

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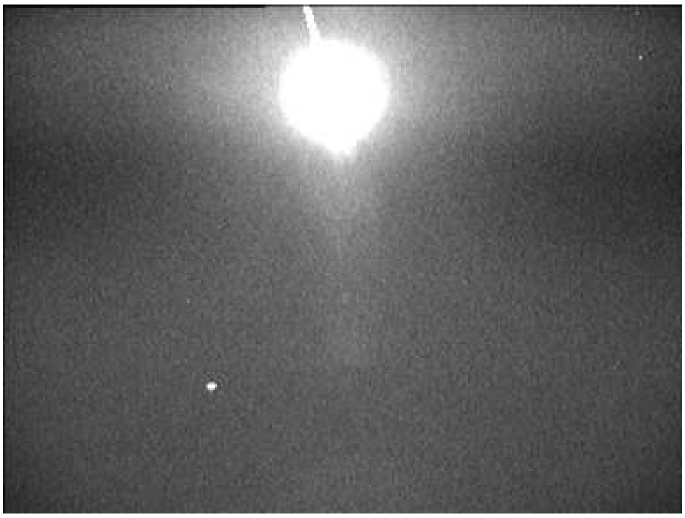
Perseids 2010 from Croatia

A bright Perseid fireball was captured by a number of Croatian meteor network cameras on 2010 August 9 at $02^{h}17^{m}08^{s}$ UT. Its brightness was estimated between about −8 and −12 magnitude, depending on the location.



Pula_A.

Merenje.

Mali Lošinj.

Šibenik.

Stack of meteor detections from 2010 August 11/12 and 13/14 by the CMN camera Pula_C, stationed at Observatory of the Astronomical Society “Istra” in Pula.