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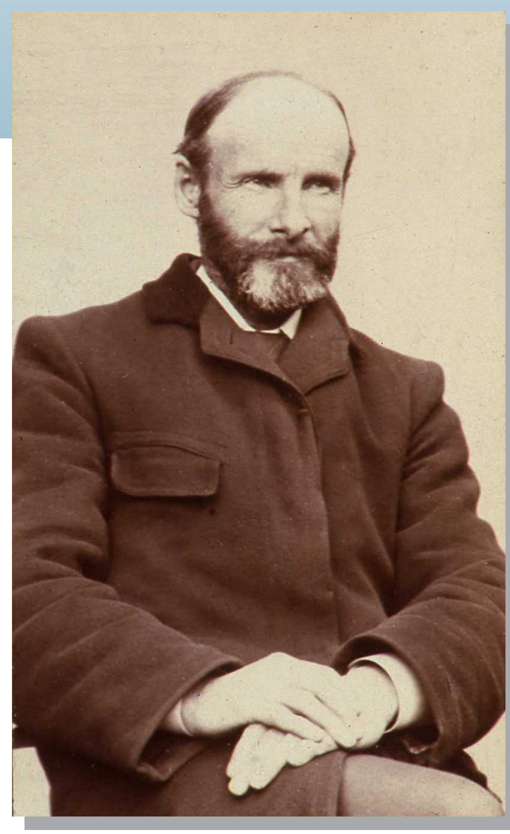

Virtual Meteor Observatory
Video meteor networks
Geminids
William F. Denning

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Administrative

Conferences

Ongoing meteor work

Preliminary results

Front cover photo

Portrait of William Frederick Denning, the doyen of amateur astronomers, by J. Webb of Bristol. More reproductions of photographic images of Denning are presented in M. Beech's article on page 43. Image courtesy: George Spalding.

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

Legal address International Meteor Organization, Mattheessensstraat 60, 2540 Hove, Belgium.

Janus — From the President

Jürgen Rendtel [1]

A new year begun and it is the occasion for a look back to the recent time and also into the future. So, first of all, my best wishes for a peaceful and prosperous 2010. At the same moment, I wish to thank all members of the past IMO Council for their activities over the last years to keep our organization running. During this period we had to solve various problems, which, at the end, led to the introduction of several useful procedures and helped to establish a well running administration. My special thanks go to Marc Gyssens for managing the IMO's finances and providing us regularly with detailed information, and to Chris Trayner as well as Javor Kac for their work as Editors of WGN. Of course, I also very much appreciate the assistance of Jan Verbert (supporting Marc) and Luc Bastiaens for his continuous work on the IMO's web pages. Eventually, I should complete this list mentioning the annual IMO Shower Calendars (Alastair McBeath), the activities of the Commission directors, the delivery of WGN PDFs to the ADS and much more.

With the new year, a newly elected Council started its work — my congratulations to the new and re-elected members. Since our long-term Vice-President Alastair McBeath is no longer member of the Council, we had to elect a successor from the Council. I am happy to announce that Cis Verbeeck volunteered and was elected to this post with one accord. The Secretary-General, Robert Lunsford, and the Treasurer, Marc Gyssens, continue their work also in the new term. We are also happy that Geert Barentsen — known for the IMO live shower analyses — and Detlef Koschny — known for support of "amateur-professional" interaction — joined the Council. Cooperation in the professsional-amateur ranges continued in 2009, for example within the Working Group on Meteor Shower Nomenclature established by the IAU Commission 22.

The past year was another very successful and interesting year for the IMO and for meteor astronomy in general. Numerous results have been published, many of them based on systematic data collection based on different observation methods. Although it sounds like routine, the IMC 2009 in Poreč, Croatia, brought together meteor workers of many countries, allowing to establish contacts and to start new projects. Some first results will certainly be presented at the 2010 IMC at the western edge of Europe in Northern Ireland. We hope that this conference attracts participants from "the other side of the Atlantic" — something we already tried with the IMC/Meteoroids combination in June 2007.

Numerous discussions happened among the IMO Council members, including topics like the IMO support possibilities or the handling of everyday maters. Unfortunately, the number of IMO members actually taking part in voting procedures remained low despite the possibility of electronic vote submission. The votings are important, not primarily because their are requested by the IMO Constitution, but because the Council needs feedback about the decisions.

As described in the December 2008 issue of WGN, the Journal is an essential part of the IMO as it provides the readers with results and allows to send own papers. We learned from the questionnaire and I know that Javor Kac tries to improve our Journal — but please send your own contributions, regardless whether these are short or long. Again, all best wishes for 2010 — hope to hearing about your activities or meeting you at our IMC in September.

Janus *was a Roman god with two faces, one looking to the past and one to the future, called upon at the beginning of any enterprise. Today he is often a symbol of re-appraisal at the start of the year.*

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IMO bibcode WGN-381-rendtel-janus NASA-ADS bibcode 2010JIMO...38....1R

From the Treasurer—How can you support your organization?

Marc Gyssens [1]

1 Supporting members 2009

The following people have paid at least double the normal membership fee for 2009:

Kristin Adgere	Luc Bastiaens	Luis Bellot Rubio	Felix Bettonvil
Marc Gyssens	Trond Erik Hillestad	Klaas Jobse	Choi Yeon Jung
Robert Lunsford	Robert Malmström	Sirko Molau	Dragana Okolić
Alan Pevec	Jean Louis Rault	Tom Roelandts	René Scurbecq
Hans-Georg Schmidt	Fintan Sheerin	Richard Taibi	Cis Verbeeck
Jan Verbert			

Casper ter Kuile provided a substantial gift to the IMO Suport Fund, which in turn helped the IMO to support IMC participants (see Section 2) and Paul Roggemans contributed with a gift membership (see Section 3). Several members also regularly give smaller gifts that are equally appreciated! Thanks to these gifts, we were able to support two Bulgarian and two Romanian meteor workers to attend the 2009 International Meteor Conference in Poreč, who would otherwise not have been able to attend. By doing so, we try to prevent valuable meteor workers having to work in isolation and to ensure that they get integrated in the international network that is at the very basis of our Organization. Notice that subsidies have been granted on the basis of a formal application. These applications were judged by the Council. As the IMO has only limited capabilities to provide support, the Organization of course wishes to ensure that this support is well spent!

To all these people, our sincerest thanks!

As many of you may also want to support the IMO in some way, we will discuss below the most straightforward ways to do so.

2 Supporting membership

Please consider to pay (at least) the double amount of your normal membership fee at the occasion of your next renewal. Plese mention 'supporting membership' as comment with your payment, so we can disambiguate it from a two-year membership!

Currently, most of the support is contributed to the IMO Support Fund, to which prospective IMC participants can turn for help to be able to actually attend. Up to some years ago, the IMO has spent part of the reserves it has built up over the years for this purpose, over and above the gifts it received. Given its noncentral location and the extra travel costs involved for many participants, the IMO will do a similar effort for the 2010 IMC in Armagh, Northern Ireland. However, we obviously cannot do this every year, and, therefore, we appeal to our members to become supporting member if they can, so that we can as a rule balance the support we wish to provide against your gifts!

The Supporting Members of a particular year will be listed either in the last WGN issue of that year or the first issue of the following year.

Also note, as already indicated above, that smaller gifts are of course also welcome as they also contribute to this goal!

3 Gift memberships

Another way to support the meteor community is by providing gift memberships to one or more meteor worker for whom this would otherwise constitute a considerable financial effort. If you want to do this, take the following, easy steps:

1. Inform the meteor workers concerned of your intention, to make sure he or she accepts your kind gift. After all, nobody can be forced to join or rejoin an organization!
2. In case of *new* members, i.e., for those meteor workers concerned that have not been IMO member before, ask them to fill out a membership form on the website. (It is possible to clarify that this concerns a gift membership by adding a comment.) In case of a *renewal*, the person is already in our membership database, and must therefore not take any special action.
3. In the comment accompanying your payment, please mention clearly for whom the membership fees are intended!

[1] Heerbaan 74, B-2530 Boechout, Belgium. E-mail: `marc.gyssens@uhasselt.be`

IMO bibcode WGN-381-gyssens-support NASA-ADS bibcode 2010JIMO...38....2G

Providing gift memberships is another way to ensure that valuable meteor workers do not get isolated by providing them access to the information disseminated by the IMO!

4 Directly donating IMC support

Just as it possible to provide gift memberships, you can also provide gift IMC registrations! This can be done in two ways. Either you add a gift to your payment of your own IMC registration, which will then be added to the IMO Support Fund and thus contribute to our ability to provide IMC support. Alternatively, you may wish to support a particular person, and pay his or her registration fee. In that case, the first thing you must do is checking whether the person involved wants to attend the IMC (after all, going to an IMC involves considerably more costs than just the registration fee!) and accepts your support. Then the person involved should fill in the registration form on the IMO website. (For details, please refer to the article on the 2010 IMC in this issue.) Please mention in the comments that this is a gift registration. Finally, the person donating the registration fee should clearly mention in the comment accompanying the payment for whom the registration fee is intended!

In conclusion, any support, whether general or earmarked for a special purpose, is most welcome and the international meteor community will be grateful for it!

Correction — 2008 Ursid maximum from Croatian Meteor Network video data

Željko Andreić, Damir Šegon and Klaudio Gašparini

We regret that part of Table 4 of (Andreić et al., 2009) contained an error. The second column in the table does not represent the UT time but the Solar longitude of the Ursid orbits.

References

Andreić Ž., Šegon D., and Gašparini K. (2009). “2008 Ursid maximum from Croatian Meteor Network video data”. *WGN, Journal of the IMO*, **37:6**, 177–181.

IMO bibcode WGN-381-andreic-correction NASA-ADS bibcode 2010JIMO...38....3A

Conferences

International Meteor Conference 2010
September 16–19, Armagh, UK

David Asher
on behalf of the IMC 2010 Organizing Committee

Venue

The 2010 International Meteor Conference (IMC) will take place in Armagh from September 16th (Thursday evening) to 19th (Sunday lunchtime). This is your chance to meet meteor enthusiasts from many different countries, exchange ideas and learn about their meteor work. IMC 2009 in Poreč, Croatia, was a great success.

IMCs are known for their relaxed and informal atmosphere. This year, evening social activities, as well as registration and welcome dinner, will take place in the Armagh City Youth Hostel. We have booked the whole youth hostel for the duration of the IMC. Armagh moreover provides many opportunities for educational visits to Irish pubs.

Armagh is a historic and pretty market town of about 15000 inhabitants, with September temperatures around 10–20° C. There are sheep in rural areas (Figure 1) but not generally in the City of Armagh itself.

IMC 2010 is being organized by the Armagh Observatory (Figure 2), a modern astronomical research institute having a rich heritage and a longstanding association with meteor science.

Scientific content

IMC talks (Friday morning till Sunday morning) will be in the Market Place, a modern theatre and conference venue built in Armagh for the millennium. Some participants present their meteor work at the IMC. You are encouraged to contribute a talk or poster about visual, photographic, video or radio observations, fireballs, orbit determination, stream modelling, meteor physics, extraterrestrial meteors, or anything else related to meteors.

Before the IMC (Sept. 15–16) there will be a Fireball Data Workshop (FireWorks) convened by Detlef Koschny; contact us if you are interested. On the Friday evening (Sept. 17) there will be a radio meteor discussion session organized by Jean-Louis Rault and Cis Verbeeck (contact `radio@imo.net`).

Conference logo

Armagh, sometimes referred to as "The Ecclesiastical Capital of Ireland", has two cathedrals, both named Saint Patrick's. These and the logo for IMC 2010 are shown in Figure 3.

Travel information

Armagh is located 60 km south-west of Belfast and 130 km north of Dublin, and is easily reached via Belfast International Airport, Belfast City Airport or Dublin Airport, all of which are served by low cost and other airlines. Bus connections to travel from these airports to Armagh, and further details of different travel options, are given on the conference website `http://www.imo.net/imc2010`. The website also has some notes about possibilities for tourism in Ireland; you may like to plan some extra days before or after the IMC.

Participants requiring a visa should note that Armagh is in Northern Ireland (NI), which is part of the United Kingdom (UK); the rest of the island of Ireland is the Republic of Ireland (ROI), separated from NI by an (invisible) international border. You should be sure to have appropriate travel documents for both countries if you come to Armagh via the ROI (Dublin). If you require a visa, we recommend flying to Belfast (UK) to avoid the need for 2 separate visas. The UK and ROI are not part of the European Schengen Area. If you need a visa to enter the UK, we can send you a formal invitation. Such invitations will be sent only to IMO members and other serious applicants known to the international meteor community.[1]

Registration

The standard registration fee is 155 EUR (170 EUR after Jun. 30). This covers lectures, proceedings, conference excursion, T-shirt, all meals, and youth hostel accommodation for 3 nights. To register, please visit `http://www.imo.net/imc2010` and fill out the registration form. If you register in this way, you will be automatically directed to the page with payment information. Only if you do not have internet access, you can fill out the paper registration form on page 6.

[1] It is the participant's responsibility to obtain all documents required to enter the UK. Failure to do so does not constitute a valid reason for full or partial reimbursement of the registration fee or prepayments thereof.

Figure 1 – Sheep.

Figure 2 – Armagh Observatory.

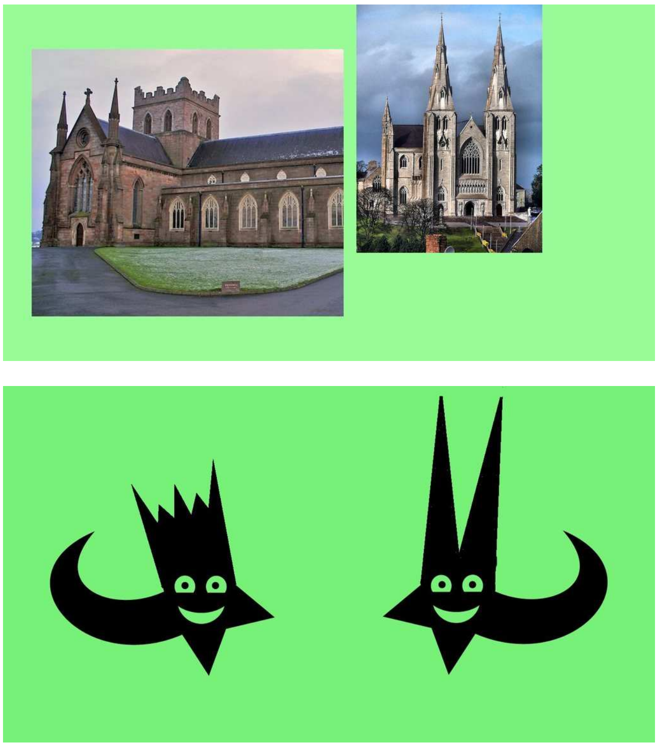

Figure 3 – The two St Patrick's Cathedrals of Armagh, Church of Ireland (left) and Roman Catholic (right), and the IMC 2010 logo (below). Thanks to Nastassia Smeets whose "Immy, the shooting star" was the logo of IMC 2005. Immy was the inspiration for this year's logo.

For your registration to remain valid, the IMO expects to receive either the full sum of 155 EUR (early)/170 EUR (late) or a prepayment of at least 80 EUR **within two weeks after registration**. If you only make a prepayment, you can pay the balance at a later date or at the conference itself.

You will receive automatic confirmation e-mails for both receipt of your registration and receipt of (each) payment. For further questions regarding registration and payment, please contact the IMO Treasurer, Marc Gyssens (`treasurer@imo.net`). UK participants who wish to pay in GBP rather than EUR and save currency exchange costs, please contact the local organizers (`imc2010@arm.ac.uk`).

Just over 60 people can sleep in the youth hostel. We have pre-booked some nearby B&B (bed & breakfast) places and in total can accommodate 80 people for the standard registration fee. If you arrange your own accommodation (e.g., single room, B&B not booked by us, or hotel), we offer a registration fee of 110 EUR (120 EUR after June 30) which covers all conference benefits (in particular, also the lunches and dinners) except accommodation and breakfasts.

You can specify your preference (hostel or shared room in B&B) when you register, although we cannot guarantee B&B availability for the standard registration fee, because we need to ensure the hostel is fully occupied. But the sooner you register, the more likely we can help you stay where you want.

Further information and contact details

For all further information, latest updates, etc., please check the IMC 2010 website:
`http://www.imo.net/imc2010`

You can also contact the organizers via e-mail:
`imc2010@arm.ac.uk`
or post:
IMC 2010 (Dr A.A. Christou), Armagh Observatory, College Hill, Armagh, BT61 9DG, Northern Ireland
or phone:
+44 (0)28 3752 2928 (Armagh Observatory), 3751 2973 (Apostolos Christou) or 3751 2953 (David Asher).

The organizing committee is Apostolos Christou (chairman), David Asher, Geert Barentsen, Miruna Popescu, Mark Bailey, Tom Barclay, Shenghua Yu, Colin Folsom, Naslim Neelamkodan, Tobias Hinse, Aileen McKee and Alison Neve. We look forward to seeing you in Armagh.

IMO bibcode WGN-381-asher-imcann NASA-ADS bibcode 2010JIMO...38....4A

International Meteor Conference
Armagh, 2010 September 16–19
Registration form

Do not use if you have internet access! Please register electronically on `http://www.imo.net/imc2010` if you can. Only if you have **no** internet access, fill out one form for each individual participant and return it to Marc Gyssens, IMO Treasurer, Heerbaan 74, B-2530 Boechout, Belgium, as soon as possible. Registration will be guaranteed only after Marc Gyssens has received either the full registration fee of 155 EUR (up to June 30)/170 EUR (from July 1 onward) or a pre-payment of at least 80 EUR. We expect this payment to arrive within two weeks after the form.

Name: ______________________ Address: ______________________

____

____

Phone: ____________ Fax: ____________ E-mail: ______________

- I wish to register for the IMC 2010 from September 16 to 19.
- I intend to travel by ______, together with ______________________
- I prefer to share a room with ______________________
- I prefer shared room in youth hostel: ____ shared room in bed & breakfast: ____ (if possible)
- T-shirt: Size (S-M-L-XL): ________ Gender: ________ (included in fee)
- Food requirements (e.g., vegetarian, nut allergy): ______________________

For participants wishing to contribute to the program:

Lecture: ______________________________________

Requirements: ______________________________________

Duration: ________ minutes (including a few minutes for questions and discussion)

Workshop: ______________________________________

Poster(s): ______________________________ Space: ________ m^2

Comments:

- I am paying the entire registration fee of 155 EUR (early)/170 EUR (late)
- I am paying the advance (80 EUR) now, the remainder later
- I am arranging my own accommodation and paying a lower registration fee, 110 EUR (early)/120 EUR (late).
- Please send me information about paying in GBP rather than EUR (UK participants only)

The indicated amount should be sent to IMO Treasurer, Marc Gyssens. The following payment options are available:

- **International bank transfer** to the International Meteor Organization, Mattheessensstraat 60, B-2540, Hove, Belgium, IBAN account number: BE30 0014 7327 5911, BIC bank code: GEBABEBB (Fortis Bank, Belgium). This is recommended for people living in the European Union, as it is no more costly than a domestic bank transfer when done correctly.
- **PayPal payment** to `payment@imo.net`. In that case, we must ask you to add the costs involved in the transaction (3.4% of the total sum including costs, plus 0.35 EUR).
- **Other arrangements**. Please contact the IMO Treasurer for information.

Financial support for IMC2010 participants

Jürgen Rendtel and Marc Gyssens

As during previous years, *IMO* is making limited funds available to support participation in the *IMC* 2010. To apply for support, please do the following:

1. E-mail your application to *IMO* President Jürgen Rendtel, at `president@imo.net`. Include the word 'Meteor' in the subject line to get round the anti-spam filters. *IMO* cannot be held responsible for applications which are lost or arrive late. The application must be submitted by an *IMO* member, but may also request support for other meteor workers. The proposal must state that all the candidates are committed to attend the *IMC* (except for unforeseen circumstances) if the requested support is granted in full.
2. Complete an *IMC* Registration Form (preferably electronically) for everyone seeking support (unless already done before).
3. Include a brief curriculum vitae of everyone seeking support, focusing on aspects relevant to meteor work. Supported participants are expected to present either a talk or a poster at the *IMC*. (Indicate and detail this on the Registration Form.)
4. The application must explain the motivation for participating in the *IMC* and the importance of this participation to the person or group of persons requesting support.
5. Include a budget for travel costs and registration, and the amount of support requested. Other sources of external support, or their absence, must be mentioned. The proposal must indicate to what extent *IMO* support is essential to attend the *IMC*.
6. The applications should reach the President no later than Friday, 2010 June 11. The decision of the *IMO* Council will be made as soon as possible, probably within two weeks after this deadline. If the support is granted in full, the registration becomes definitive. If the requested support is not granted, or only partially granted, the candidates should inform the President within three weeks after notification of the *IMO* Council's decision if they want to sustain or withdraw their registration. Most likely, the support will consist of waiving registration fees, which will be settled directly between the IMO and the Local Organizers. Any additional support, if granted, will be paid in cash at the *IMC*.

Should the application be turned down, the standard conference fee (i.e., €155, without the surcharge for a late application) will still apply. We strongly encourage all meteor workers who want to attend the *IMC* 2010, but who are prevented from doing so by financial considerations, to apply for support.

IMO bibcode WGN-381-rendtel-imcsupport NASA-ADS bibcode 2010JIMO...38Q...7R

Call for Future IMCs

Jürgen Rendtel and Marc Gyssens

Since last year, the IMO Council sends out regular calls for organizing future IMCs. In this way, the Council wants to avoid the situation that no spontaneous proposals are offered, with as a possible undesirable consequence that we might have a year without IMC.

This is a formal call for organizing the 2011 IMC, which is supposed to take place around the third week of September, from Thursday evening (arrival of the participants) to Sunday lunchtime (departure of the participants). Proposals are due 2010 June 1, and should be sent to the President, `president@imo.net`, preferably in PDF-format.

The IMO Council will decide on the proposal to be accepted in 2010 September, at the IMC in Armagh, Northern Ireland. The Council may take advantage of the intermediate time to ask for clarifications or additional information from the candidates.

From past experience, we know it is often difficult to choose between several proposals. If multiple proposals merit the opportunity to host an IMC, the Council will contact such candidates to ask them to retain their candidacy for the next year. If in the next round the Council must decide between equally worthy proposals, priority will be given to the older one.

There are no forms to solicit for the 2011 IMC, but your proposal should at least contain the following elements:

1. **Who are you?** Who is going to be the local organizers? Which local, regional, or national astronomical organization(s) is/are backing you up? What is your experience with meteor work? Have you been involved in past IMCs, as passive/active participant or as co-organizer? Do you or the organization(s) to which you belong have experience in organizing events that can be compared to an IMC?

2. **Why do you want to do it?** What is your motivation for wanting to organize an IMC?

3. **Where do you want to do it?** At what location do you want to organize an IMC? Why is this a good location? Can it easily be reached by plane, public transportation, and/or car? How many hours is it by public transport from the nearest major international airport? Provide a few pictures of the location, or, a weblink to such pictures.

4. **At what venue are you going to hold the IMC?** Preferably, lectures and accommodation should be under the same roof, but there is no real objection to the lecture room being at a separate location within easy walking distance from the accommodation. Describe the accommodation at your disposal. Preferably, add an offer from the hotel and/or the institution providing additional accommodation to prove that the venue you propose is indeed available and that the price is within the limits of your budget (see below). Provide also a few pictures of the accommodation, or, a weblink to such pictures.

5. **What will it cost?** Draft a preliminary budget for the IMC proposed. Mention all sources of income, in particularly sponsors or subsidies. Take into account that the price per participant should not exceed 150 EUR by much. Of this amount, 10 EUR must be reserved for producing and mailing the (post-)proceedings to the participants. With respect to the expenditures, take into account that the participants must be offered full board from Thursday evening, dinner, up to Sunday, lunch, inclusive. Of course, lecture room facilities should be accounted for, as well as a coffee break in the morning and in the afternoon. Finally, it is also customary to have a half-day excursion, usually on Saturday afternoon.

   Note that, although the IMO provides the service of collecting the registration fees for you, the IMO will in principle *not* cover any negative balance that you might incur, so, please, draft your budget responsibly!

6. **Can it also be done in a later year?** We can only have one IMC every year. It is therefore important for us to know if you can also make this offer in a subsequent year. If there are reasons why the application cannot be postponed, please describe these reasons clearly! It is imperative that you answer the questions honestly. Of course, we understand that you are keen to organize next year's IMC, otherwise you would not have applied, but having a clear picture of the real time constraints of all the candidates is a serious help for the Council to make the best decision possible!

Of course, you may add to your application any information or considerations which you think may influence your candidacy favorably. In general, however, help the Council in seeing the wood for the trees! While it is important that your application is complete and addresses all the issues mentioned above, please do so *concisely*! Avoid beating about the bush with meaningless phrases and be as factual as possible!

If you are interested in applying for the local organization of the 2011 IMC, please email the President as soon as possible that you intend to apply by the due date of 2010 June 1. Even though such a declaration of intent is not a formal commitment, it is an indication for the Council as to how many applications may be expected: based on this information, the Council may actively solicit additional candidacies.

We hope to receive many candidacies!

IMO bibcode WGN-381-rendtel-futureimcs NASA-ADS bibcode 2010JIMO...38R...7R

Wanted: Students interested in meteor research

Peter Brown [1], Margaret Campbell-Brown [2] and Paul Wiegert [3]

The Meteor Physics group at the University of Western Ontario has several openings for graduate students interested in pursuing meteor research. The Western meteor group consists of three full time faculty members, two emeritus faculty, two adjunct faculty, three post-doctoral fellows and half a dozen graduate students along with a number of undergraduates. The group has research interests in meteor observations at all sizes using various technologies, ablation modelling, and orbital dynamics. Students having completed or about to complete undergraduate training in relevant science areas (eg. physics, astronomy, math, geophysics, computer science) are eligible to apply. Available degrees are at the masters (2 year study) or doctoral (4 year study) level in several program areas (Physics, Astronomy, Geology or Geophysics). A collaborative program in planetary science is available in all four of these core graduate program disciplines. If accepted, students are guaranteed a salary during the course of their study program sufficient to comfortably meet tuition and living expenses.

Possible graduate student projects include:

- Search for interstellar meteoroids using radar and optical instruments
- Observational studies of meteor showers using radar, all sky and optical instruments
- Radar measurements and characterization of the sporadic meteor background (velocity distributions, mass distribution)
- Measurement of pre-atmospheric orbits and ablation behaviour of meteorite-producing fireballs through satellite and infrasound measurements
- Computer simulations of comet, asteroid and meteoroid stream dynamics
- Modelling aspects of small meteoroid ablation
- Mass influx of meteoroids at various sizes
- Observation and modelling of Infrasonic airwaves from meteors to measure source characteristics
- Meteorite recovery field expeditions
- Analysis of spacecraft anomalies resulting from meteoroid impacts

Interested students should contact one of the authors by email. More details of the research programs underway can be found at: `http://aquarid.physics.uwo.ca`.

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[2]Email: `Margaret.Campbell@uwo.ca`
[3]Email: `pwiegert@uwo.ca`

IMO bibcode WGN-381-brown-wanted NASA-ADS bibcode 2010JIMO...38....9B

Ongoing meteor work

The VMO file format. I. Reduced camera meteor and orbit data

Geert Barentsen [1], Rainer Arlt, Detlef Koschny, Prakash Atreya, Joachim Flohrer, Tadeusz Jopek, André Knöfel, Pavel Koten, Jonathan Mc Auliffe, Jürgen Oberst, Juraj Tóth, Jeremie Vaubaillon, Robert Weryk, Mariusz Wiśniewski and Przemyslaw Żołądek

We propose a standard XML-based file format for storing and transferring reduced data from photographic and video meteor observations and meteoroid orbits and trajectories. The format is the result of discussions within the Virtual Meteor Observatory (VMO) team, which aims to facilitate collaboration in the meteor science community and increase the scientific impact of combined observational data. The proposed format is extensible and allows meteoroid orbits and trajectories to be traced back to the original observing data and algorithms. We provide a description of the structure of the format and give precise definitions for each data field.

Received 2009 September 30

1 Introduction

The Virtual Meteor Observatory (VMO) project aims to facilitate collaboration between different meteor groups, by giving meteor researchers an easy way to query and retrieve data available to the worldwide community. During the first meeting of the VMO team, it was agreed that a first step towards this goal is to specify a standard file format to store and exchange meteor data (Barentsen et al., 2007; Koschny et al., 2009). The format should store data that has been *reduced* to a form that makes it suitable for scientific use, yet provide sufficient technical details to allow the quality and origin of the observation to be assessed. Such a format would allow existing data archives and software tools to become compatible through single format conversion tools. It would also encourage software to support a standard format and allow observations to be stored in centralized and searchable archives.

The architecture of the VMO was discussed previously and the reader is referred to Koschny et al. (2008) for a description. In this paper, we propose a file format for storing the reduced results from photographic and video-based observations (hereafter collectively referred to as "camera observations"). We also specify how to store meteoroid trajectories and orbits (which may be derived from any observing technique). In a follow-up article in WGN, we will extend the format to visual observations and fireball reports. By then, we will have covered almost all data sections proposed by Koschny et al. (2009), with the exception of observations by forward or backward scatter radio techniques. Formats for forward scatter data are available from Brentjens (2006) and Terrier (2009) and may be incorporated in the future.

The format presented here, "VMO Format 1.0", is also documented on the website of the International Meteor Organization, `http://vmo.imo.net/standards`, where it is accompanied by additional examples and validation tools. We recommend users to check the website for updates.

2 File structure

The VMO file format is based on XML, which is a standard method for storing complex information in simple text files. An XML file is a hierarchical structure of *elements*, which are strings of data enclosed by start- and end-tags. For example, a Perseid meteor of magnitude +2.5 seen on 2009 August 12 may be formatted using XML as follows:

```
<meteor>
  <time>2009-08-12T00:04:13.25</time>
  <shower_code>PER</shower_code>
  <mag>2.5</mag>
</meteor>
```

An example of a well-known XML-based format is XHTML, which is used to define the layout of webpages using elements such as `<title>` and `<img>`. In this paper, we describe the VMO format by defining our own suitable elements. These elements must be used according to the XML syntax rules, which are not given here but can easily be retrieved online[1].

A file in the VMO format starts with the `<vmo>` root element, which appears exactly once and encloses the entire contents of the file. The root element must specify the version number (1.0) and the organization that defined the format (IMO) as follows: `<vmo version="1.0" xmlns="http://www.imo.net">`. The root element may have certain child elements such as `<location>` (defining an observing site) and `<cam_session>` (a camera observing session). These child elements may appear an unlimited number of times in any order. Some of the elements refer to each other, for example a camera observing session refers to an observer and a location as follows:

```
<vmo version="1.0" xmlns="http://www.imo.net">
   <location>
      <location_code>DEPOTS</location_code>
      <name>Potsdam</name>
```

[1] Armagh Observatory, College Hill, Armagh BT61 9DG, UK. Email: `gba@arm.ac.uk`

IMO bibcode WGN-381-barentsen-vmo-camera
NASA-ADS bibcode 2010JIMO...38...10B

[1] `http://www.w3schools.com/xml`

```
      ...
   </location>

   <observer>
      <observer_code>ARLRA</observer_code>
      <first_name>Rainer</first_name>
      <last_name>Arlt</last_name>
      ...
   </observer>

   <cam_session>
      <location_code>DEPOTS</location_code>
      <observer_code>ARLRA</observer_code>
      ...
   </cam_session>
</vmo>
```

A precise definition of the various elements and their relations is given in Tables 1–13. A graph of the structure is shown in Figure 1, an example file is shown in Figure 2.

Note that we introduce sessions which are comprised of smaller observing periods. Such sessions are not necessary for the complete and unambiguous storage of data, but the grouping into sessions makes the handling of data packages far more comfortable. Typical sessions may correspond to nights, but can also correspond to group campaigns or other practical entities. All photographic, video, and later on also visual observations will be grouped in sessions.

The tables and graph show the allowed multiplicity (occurence) of each element. The possible values are "1" if the element is obligatory, "0..1" if the element is optional but should not appear more than once, "0..N" if the element is optional and can appear several times, and "1..N" if the element is obligatory and can appear several times. Elements may appear in any order.

Most elements are intentionally left optional to allow the format to be used even when only minimal data is available. This allows the format to be useful for older data which was created before any standard was defined, or even historical data. However, one should make a reasonable effort to include as many elements as possible.

3 Conventions

In addition to the element definitions given in the tables, a VMO file must adhere to the following conventions:

1. The number of digits used to store a number must always be *at least* 1 or 2 larger than would be called for by the "significant-figures rule". For example, if an eccentricity was determined to be 0.3266, but with an uncertainty of 0.0021, one should retain the precision of $e = 0.3266 \pm 0.0021$ and *not* round to $e = 0.327 \pm 0.002$. The "significant-figures rule" should *not* be used when storing numbers that may be used in further computations, because it introduces rounding errors.

2. Uncertainties must be given as a standard error (σ) or covariance value. These errors must be obtained by propagating the uncertainties of the input data (e.g., the meteor astrometry) to the output data (e.g., the orbital elements). This may be done using analytical propagation formulas or statistical Monte Carlo iterations.

3. All equatorial coordinates must be given in decimal degrees (epoch J2000.0). At least 5 digits behind the decimal sign must be supplied if arcsecond-precision is available.

4. All times must be given in Coordinated Universal Time (UTC). This is the international standard on which civil time is based, with leap seconds added at irregular intervals. Times must be formatted using the ISO 8601 standard (e.g., "2009-08-12T23:14:05").

4 Traceability

During discussions on the VMO format, several meteor scientists emphasized the importance of being able to trace reduced data back to the original observations and processing steps (Koschny et al., 2007). For example, it should be possible to retrieve the original single-station data that was used to compute an orbit. It should also be possible to determine which algorithms and processing steps were used in the computations. The VMO format allows such traceability in the following ways:

1. Orbits and trajectories may be linked to the original single-station data by means of a `<meteor_code>` element (cf. Figure 1). These unique meteor codes may be assigned using the rules given in Table 7.

2. Orbits refer to an `<orbit_pipeline>` element (cf. Table 9), which holds references and descriptions of the various processing steps and algorithms used in the determination of the trajectory and orbit. In addition, the state vector of the meteor can be stored to allow the orbit to be recomputed easily.

3. The format provides a `<file>` element (cf. Table 13), which allows raw and intermediate data to be linked to the reduced data. For example, we may link an original video clip to a meteor as follows:

```
<vmo version="1.0" xmlns="http://www.imo.net">
  ...
  <meteor>
    <shower_code>PER</shower_code>
    <mag>2.5</mag>
    <file>
      <path>videos/met293.avi</path>
      <comments>
        Meteor of 2009 Aug 12, 23:14:05
      </comments>
    </file>
  </meteor>
  ...
</vmo>
```

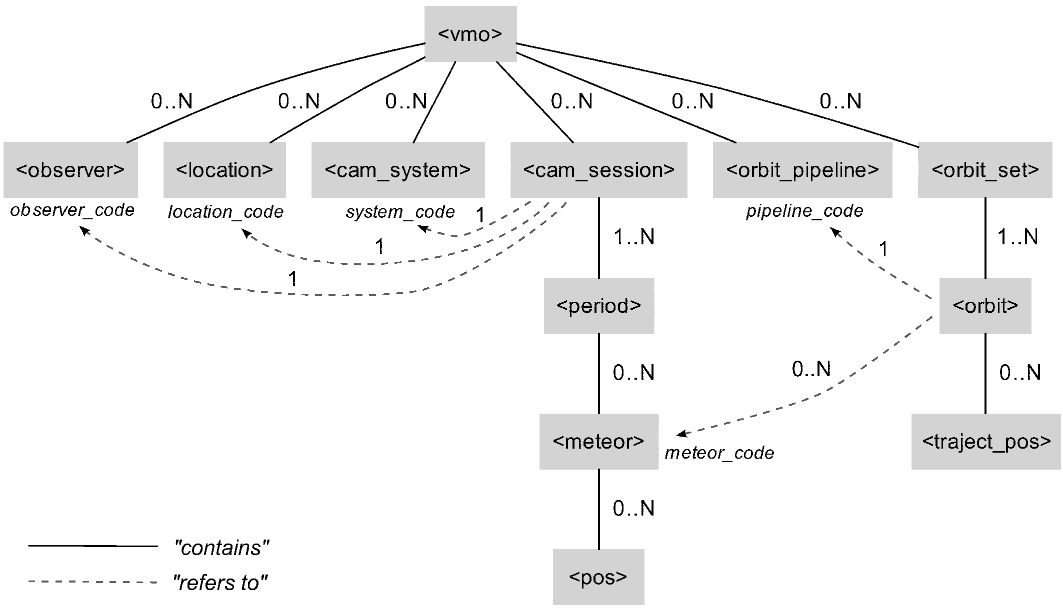

Figure 1 – Structure of the most important elements in the VMO format. Solid lines denote an element containing another element, dashed arrows denote an element referring to another element through a unique code. Numbers next to the arrows denote the minimum and maximum multiplicity of the relation. All the elements are defined in detail in Tables 1–13.

```
<?xml version="1.0" encoding="UTF-8"?>

<!-- VMO Format example for video observation -->
<vmo version="1.0" xmlns="http://www.imo.net">

  <observer>
    <observer_code>KOSDE</observer_code>
    <first_name>Detlef</first_name>
    <last_name>Koschny</last_name>
    <city>Noordwijkerhout</city>
    <country_code>Netherlands</country_code>
    <email>Detlef.Koschny@esa.int</email>
  </observer>

  <location>
    <location_code>NLNOOR</location_code>
    <name>Noordwijkerhout</name>
    <country_code>NL</country_code>
    <lon>4.491112</lon>
    <lat>52.265282</lat>
    <height>55</height>
  </location>

  <cam_system>
    <system_code>TEC1</system_code>
    <name>TEC1 system, ESA/RSSD</name>
    <system_type>VIDEO</system_type>
    <contact_code>KOSDE</contact_code>
  </cam_system>

  <cam_session>
    <system_code>TEC1</system_code>
    <location_code>NLNOOR</location_code>
    <observer_code>KOSDE</observer_code>
    <software_code>METREC_V4.1+</software_code>
    <camera_code>WATEC</camera_code>
    <lens_code>FUJ50_1.2</lens_code>
    <gain>highest setting</gain>

    <period>
      <start>2009-01-30T18:04:40</start>
      <stop>2009-01-31T05:00:00</stop>
      <teff>10.9175</teff>

      <meteor>
        <meteor_code>CAM-20090130-TEC1-M001</meteor_code>
        <time>2009-01-30T18:17:21.69</time>
        <shower_code>SPO</shower_code>
        <speed>14.9</speed>
        <mag>2.04</mag>
        <e_mag>0.42</e_mag>

        <pos>
          <pos_no>1</pos_no>
          <time>2009-01-30T18:17:21.69</time>
          <mag>2.63</mag>
          <pos_ra>110.91751</pos_ra>
          <pos_dec>72.38500</pos_dec>
          <e_mag>0.42</mag>
          <e_pos_ra>0.0321</e_pos_ra>
          <e_pos_dec>0.0321</e_pos_dec>
        </pos>

        <pos>
          <pos_no>2</pos_no>
          <time>2009-01-30T18:17:21.74</time>
          <mag>2.54</mag>
          <pos_ra>110.01901</pos_ra>
          <pos_dec>72.09010</pos_dec>
          <e_mag>0.42</e_mag>
          <e_pos_ra>0.0321</e_pos_ra>
          <e_pos_dec>0.0321</e_pos_dec>
        </pos>

        ...

      </meteor>
    </period>
  </cam_session>
</vmo>
```

Figure 2 – Example of a video meteor in the VMO format. Note that the right column of this figure needs to be stored below the left column in a real file.

This mechanism allows observing software to use the VMO format as the main output format for the reduced data, while keeping the raw and intermediate data in the software-specific formats. Data archives may decide whether or not to store this raw data centrally, depending on the available storage and bandwidth resources. There is a <file> option for most of the tables. The <orbit_pipeline> can be accompanied by actual reference papers or even entire software packages using the <file> element.

5 Extending the format

The VMO format is designed to store reduced data, e.g. astrometric and photometric measurements, which are ready to use for scientific analyses. In addition to these parameters, observations produce a lot of raw and intermediate data. We have chosen not to include most of such data, either because it would make the format needlessly complex or because there is no standard way to store the information.

However, the XML syntax provides a mechanism to include additional data in an existing format by means of adding custom elements. Any user may add his own elements by using a *namespace prefix* in the element names. These elements marked in that way are now outside the namespace of the VMO, `http://www.imo.net`. For example, the Polish Fireball Network (PFN) decided to include the list of astrometric reference stars in the VMO files. This is achieved by adding a prefix, "pfn", in front of their custom elements, and the namespace `http://pfn.pkim.pl`. For example:

```
<vmo version="1.0" xmlns="http://www.imo.net">
  ...
  <pfn:refstar xmlns:pfn="http://pfn.pkim.org">
    <pfn:x>0.2486</pfn:x>
    <pfn:y>0.3654</pfn:y>
    <pfn:ra>12.574894</pfn:ra>
    <pfn:dec>36.542478</pfn:dec>
  </pfn:refstar>
  ...
</vmo>
```

It is likely that the extension to store reference star data will be included in the next version of the VMO format, after some additional discussions in the VMO team. Other future extensions may include support for spectra and moving locations (i.e., describing the path of an aircraft). We invite anyone using extensions to join the VMO team and help improve the standard.

We refer the reader to the XML syntax rules for further details on adding custom elements[2].

6 Conclusion

We presented the first version of an extensible XML-based file format for reduced data from video- and photographic meteor observations and meteoroid orbits and trajectories. An initial database implementation is now available at `http://vmo.imo.net` which brings all these tables (and additional auxiliary ones) together in a relational database with some software tools for data ingestion and analysis. These software tools are also available as services to outside users. Data providers will have to provide ingestion routines which convert the data to the VMO format as described in this paper.

We invite the community to evaluate the format and propose corrections and extensions. Meteor researchers are also invited to contribute with actual datasets to let the VMO grow and to discover possible short-comings of the data model described here. Updated versions of the format will be published on the IMO website.

[2] `http://www.w3schools.com/xml/xml_namespaces.asp`

Acknowledgements

We are grateful to Sirko Molau, SonotaCo and Peter Jenniskens for their valuable comments. We thank the International Space Science Institute in Bern for their generous support in this project. Travel expenses for T. Jopek were covered by the Polish Ministry of Science and High Education, grant No. N N203 302 335.

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This paper has been typeset from a LaTeX file prepared by the authors.

```
<?xml version="1.0" encoding="UTF-8"?>

<!-- Example orbit / trajectory -->
<vmo version="1.0" xmlns="http://www.imo.net">

 <orbit_pipeline>
   <pipeline_code>UF02.21</pipeline_code>
   <name>UFOOrbit 2.21 by SonotaCo</name>
   <astrometry>Uses UFOAnalyzer 2.25 by SonotaCo</astrometry>
   <trajectory>Ceplecha (1987)</trajectory>
   <errors>Uncertainties propagated by Monte-Carlo</errors>
 </orbit_pipeline>

 <orbit_set>
   <set_code>ORB-ARLRA-PER2009</set_code>
   <contact_code>ARLRA</contact_code>
   <version>2009-06-12T18:00:00</version>

   <orbit>
     <pipeline_code>UF02.21</pipeline_code>
     <orbit_type>VIDEO</orbit_type>
     <time>2007-08-13T00:16:06.015</time>
     <shower_code>PER</shower_code>
     <iau_no>0007</iau_no>

     <!-- Orbital elements -->
     <q>0.959751</q>
     <aph>15.732</aph>
     <a>8.346</a>
     <e>0.8850</e>
     <i>112.997</i>
     <omega>152.542</omega>
     <asc_node>139.803842714</asc_node>
     <t0>240220518.531</t0>
     <m0>0.801</m0>

     <!-- State vector from which orbit can be computed -->
     <state>
       2007-08-13T00:16:06.015,6786436.2,
       356741.9,123474.3,35425.6,12325.4,23747.2
     </state>

     <!-- Brightness, mass, velocity, radiant -->
     <mag_abs>1.21</mag_abs>
     <mass>0.0821</mass>
     <vel_geo>58.505</vel_geo>
     <vel_helio>40.573</vel_helio>
     <rad_obs_ra>45.1926</rad_obs_ra>
     <rad_obs_dec>57.7185</rad_obs_dec>
     <rad_geo_ra>45.8621</rad_geo_ra>
     <rad_geo_dec>57.6263</rad_geo_dec>

     <!-- Uncertainties -->
     <e_q>0.0041</e_q>
     <e_a>1.61</e_a>
     <e_e>0.021</e_e>
     <e_i>0.21</e_i>
     <e_omega>1.02</e_omega>
     <e_asc_node>0.00000049</e_asc_node>
     <e_t0>59.2</e_t0>
     <e_m0>0.24</e_m0>
     <e_mag_abs>0.73</e_mag_abs>
     <e_mass>0.11</e_mass>
     <e_vel_geo>0.22</e_vel_geo>
     <e_vel_helio>0.23</e_vel_helio>
     <e_rad_obs_ra>0.44</e_rad_obs_ra>
     <e_rad_obs_dec>0.10</e_rad_obs_dec>
     <cov_rad_obs>0.00023</cov_rad_obs>
     <e_rad_geo_ra>0.75</e_rad_geo_ra>
     <e_rad_geo_dec>0.50</e_rad_geo_dec>
     <cov_rad_geo>0.00041</cov_rad_geo>
     <e_state>
       0.10,12474.3,14964.5,13142.7,3.12,6.34,7.44,
       0.145,0.574,0.134,0.136,0.245,0.244
     </e_state>

     <!-- Reference to single-station data -->
     <meteors>2</meteors>
     <meteor_code>CAM-20070812-ICC2-M061</meteor_code>
     <meteor_code>CAM-20070812-LCC3-M008</meteor_code>

     <!-- Trajectory information -->
     <traject_pos>
       <pos_no>1</pos_no>
       <time>2007-08-13T00:16:05.68123</time>
       <lon>13.822943</lon>
       <lat>47.084535</lat>
       <height>115.372</height>
       <mag_abs>3.182</mag_abs>
       <e_time>0.00071</e_time>
       <e_lon>0.00062</e_lon>
       <e_lat>0.00042</e_lat>
       <e_height>0.12</e_height>
       <e_mag_abs>0.76</e_mag_abs>
     </traject_pos>
     <traject_pos>
       <pos_no>2</pos_no>
       <time>2007-08-13T00:16:05.69872</time>
       <lon>13.816761</lon>
       <lat>47.080943</lat>
       <height>114.636</height>
       <mag_abs>2.871</mag_abs>
       <e_time>0.00071</e_time>
       <e_lon>0.00037</e_lon>
       <e_lat>0.00043</e_lat>
       <e_height>0.10</e_height>
       <e_mag_abs>0.68</e_mag_abs>
     </traject_pos>

     ...

   </orbit>

 </orbit_set>

</vmo>
```

Figure 3 – Example of a meteoroid orbit in the VMO format. Note that the right column of this figure needs to be stored below the left column in a real file. The line-breaks and whitespaces inside <state> and <e_state> are not allowed, but have been added for readability.

Table 1 – <**vmo**> element: the root element which must appear exactly once in each VMO file and encloses all the data.

Name	#	Description	Example(s)	Type
observer	0..N	A person observing or researching meteors, see Table 2.		<observer>
location	0..N	An observing site, see Table 3.		<location>
cam_system	0..N	Video or photographic equipment, see Table 4.		<cam_system>
cam_session	0..N	Video or photographic observing session, see Table 5.		<cam_session>
orbit_pipeline	0..N	Orbit determination procedure details, see Table 9.		<orbit_pipeline>
orbit_set	0..N	A set of computed meteoroid orbits and trajectories, see Table 10. These sets are similarly motivated like the camera sessions as to group data into packages for more convenient handling.		<orbit_set>
visual	0..N	Visual observing session. To be defined in the follow-up WGN paper.		<visual>
fireball	0..N	Fireball report. To be defined in the follow-up WGN paper.		<fireball>

Table 2 – <**observer**> element: contact information for a person, such as a visual observer or the operator of a video station. Each observer is uniquely identified by the *observer_code*, which is used by other elements to refer to an observer.

Name	#	Description	Example(s)	Type
observer_code	1	Unique alphanumeric identification code for the person, in uppercase. This code has to be unique within each file, and should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'ARLRA'	string
first_name	1	Given names and optionally also the middle name. All characters from the extended latin alphabet may be used. For other alphabets, use the English transcription. Avoid nicknames.	'Rainer'	string
last_name	1	Last name(s). Again, only characters from the extended latin alphabet should be used.	'Arlt'	string
address1	0..1	Address line 1.		string
address2	0..1	Address line 2.		string
address3	0..1	Address line 3.		string
postal_code	0..1	Postal code.		string
city	0..1	City of residence.	'Berlin'	string
country_code	1	Two-letter ISO 3166 country code of residence.	'DE'	string
birth_year	0..1	Year of birth. Note that this field is optional.	'1991'	integer
email	0..1	E-mail address.	'visual@imo.net'	string
url	0..1	Personal or institute web site.	'www.rainerarlt.de'	string
affiliation	0..1	Institute, club or association. Enter more than one if needed.	'AKM'	string
comments	0..1	A comment field allowing free text.		string
file	0..N	Attach one or more files, for example a photo of the observer. See Table 13.		<file>

Table 3 – <**location**> element: information on an observing site. Each location is uniquely identified by the *location_ code*, which is used by other elements to refer to a location.

Name	#	Description	Example(s)	Unit	Type
location_code	1	Unique alphanumeric identification code for the location, in uppercase. This code has to be unique within each file, and should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'DEPOTS'		string
name	1	Administrative name of the town or village, optionally followed by a more specific name of the site.	'Potsdam, Astrophysical Institute'		string
country_code	1	Two-letter ISO 3166 country code.	'DE'		string
lon	1	Geographic longitude in decimal degrees. The longitude should be a signed value between −180 and +180. A negative value means 'WEST', a positive value means 'EAST'. The WGS84 coordinate system should be used, which is also the basis for the GPS system and tools such as Google Earth. Give 5 or more digits behind the decimal sign if meter-accuracy is required.	13.102355	deg	decimal
lat	1	Geographic latitude of the location in decimal degrees. The latitude should be a signed value between −90 and +90. A negative value means 'SOUTH', a positive value means 'NORTH'. The WGS84 coordinate system should be used. Give 5 or more digits behind the decimal sign if meter-accuracy is required.	52.404186	deg	decimal
height	0..1	Height of the location in meters according to the WGS84 coordinate system.	24.3	m	decimal
uncertainty	0..1	Estimated error of the coordinates in meters.	20	m	decimal
comments	0..1	A comment field allowing free text.			string
file	0..N	Attach one or more files, for example a photo of the observing site. See Table 13.			<file>

Table 4 – <**cam_system**> element: information on a video or photographic observing system. Each system is uniquely identified by the *system_ code*, which is used by other elements to refer to a system. The actual technical details of the system have to be given in each <cam_session> element, since most components may change frequently and should be specified for each session to ensure correct information.

Name	#	Description	Example(s)	Type
system_code	1	Unique alphanumeric identification code for the system, in uppercase. This code should preferably be registered centrally at http://vmo.imo.net to avoid conflicts.	'ICC3'	string
name	1	Long name of the system.	'ESA/RSSD Intensified CCD Camera #3'	string
system_type	0..1	Type of the system. Should be either 'STILL' (typically one exposure per meteor) or 'VIDEO' (multiple exposures per meteor).	'VIDEO'	string
contact_code	0..1	Contact person for the system, identified by the observer code. The <observer> element for this person should preferably, but not obligatory, be given in the same file.	'KOSDE'	string
comments	0..1	Free text field for comments.	'Built in 1998.'	string
file	0..N	Attach one or more files, for example system documentation. See Table 13.		<file>

Table 5 – **<cam_session>** element: observing session performed using a camera system. A session is an arbitrary collection of observing periods and meteors, typically recorded during a single night. A session also holds the technical details and configuration of the camera system.

Name	#	Description	Example(s)	Type
system_code	1	System identified by the unique code. The corresponding <cam_system> element should preferably, but not obligatory, be given in the same file.	'ICC3'	string
location_code	1	Location of the session, identified by the unique location code. It is compulsory to give the <location> element for this location in the same file.	'NLNOOR'	string
observer_code	1	The contact person for this session, identified by the observer code. It is compulsory to give the <observer> element for this person in the same file.	'KOSDE'	string
version	0..1	Time of last update (used as version identifier).	2009-06-12T18:00:00	datetime
software_code	0..1	Code of the software used to process the data.	'METREC_V3.6'	string
shower_cat_code	0..1	Code of the shower catalog used to identify shower meteors, if shower designations are given in <meteor>.	'IMO2009'	string
camera_code	0..1	Camera body or chip used.	'MINTRON_12v1'	string
prism_code	0..1	Prism or grating used (if any).		string
lens_code	0..1	Lens used.	'FUJINON_12'	string
intensifier_code	0..1	Intensifier used (if any).	'DEP_42'	string
relay_lens_code	0..1	Lens that filmed the output of the intensifier (if any).	'RELAY_1'	string
digitizer_code	0..1	Device used to digitize the exposures.	'MATROX_METEOR2'	string
gain	0..1	Free description of the gain setting.	'Highest gain'	string
storage	0..1	Description of any intermediate storage (e.g., VCR tape, analog film, MPEG-compressed digital file).	'KODAK_400_ASA'	string
interlaced_flag	0..1	Does the camera use the interlaced video format? Leavy empty for a still camera.	true, false	boolean
interlaced_order	0..1	Order of the interlaced fields: 'ODD' or 'EVEN'.	'ODD', 'EVEN'	string
exposure_time	0..1	Length of each exposure in decimal seconds. If interlaced fields are used, give the exposure time for each field. If the exposure time varied, leave empty.	0.02, 0.1, 36000.0	decimal
sampling_interval	0..1	Interval between the beginnings of exposures in decimal seconds. If interlaced fields are used, give the interval between 2 fields.	0.02	decimal
shutter_flag	0..1	Did the system have a rotating shutter to make breaks in the meteor trail?	true, false	boolean
shutter_frequency	0..1	Frequency of the shutter, use breaks per second.	8.64	decimal
shutter_description	0..1	Precise description of the shutter shape. Attach a drawing if necessary.	'The equal-sized blades interrupt the light 8.64 times per second.'	string
fov_vertical	0..1	Vertical size of the field of view in degrees.	40	decimal
image_scale	0..1	Approximate image scale in degrees per pixel.	0.001	decimal
effective_x	0..1	Effective number of pixels in the x (horizontal) direction, taking into account all components of the system. If interlaced fields are used, give the resolution of a single field.	320	integer
effective_y	0..1	Effective number of pixels in the y (vertical) direction, taking into account all components of the system. If interlaced fields are used, give the resolution of a single field.	240	integer
depth	0..1	The number of brightness steps the system can distinguish, taking into account all components.	256	integer
saturation_value	0..1	Saturation value of the pixels.	255	string
color_flag	0..1	Does the system record color?	true, false	boolean
e_time	0..1	Uncertainty (σ) of the clock, use decimal seconds.	2.05	decimal
e_astrometry	0..1	Uncertainty (σ) of the astrometric model, use decimal degrees.	0.051	decimal
comments	0..1	Free text field for comments.		string
period	1..N	One or more observing periods, as specified in Table 6.		<period>
file	0..N	Attach one or more files, for example the session log file. See Table 13.		<file>

Table 6 – <**period**> element: describes the observing conditions and observed meteors in a given interval.

Name	**#**	**Description**	**Example(s)**	**Unit**	**Type**
start	0..1	Time when the observation started. Leave empty if unknown (do not just enter the time of the first meteor). Use the ISO 8601 format in Universal Time (UTC).	2007-08-11T23:46:27		datetime
stop	0..1	Time when the observation ended. Leave empty if unknown (do not just enter the time of the last meteor). Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:47:54		datetime
teff	0..1	Effective observing time for activity analysis. Leave empty if unknown.	0.975	h	decimal
lm	0..1	Average limiting stellar magnitude during the period.	6.52	mag	decimal
fov_alt	0..1	Measured altitude of the center of the field of view above the horizon in the middle of the period.	32.66	deg	decimal
fov_az	0..1	Measured azimuth of the center of the field of view in the middle of the period. North is 0, east is 90, and so forth.	241.34	deg	decimal
fov_rotation	0..1	Rotation of the field of view in counter-clockwise direction in the middle of the period. Measured as the angle between y-axis and the direction to zenith.	5	deg	decimal
fov_guided_flag	0..1	Is the camera guided, i.e. do the equatorial coordinates of the field of view remain constant throughout the period?	true, false		boolean
fov_obstruction	0..1	Average percentage of the field of view that is obstructed by clouds, trees, buildings, etc. during the period. This should be a number between 0 and 100.	20.5	%	decimal
e_teff	0..1	Uncertainty (σ) of teff.	0.050	h	decimal
e_lm	0..1	Uncertainty (σ) of lm.	0.25	mag	decimal
e_fov_obstruction	0..1	Uncertainty (σ) of fov_obstruction.	5.0	%	decimal
meteor	0..N	Observed meteors, as specified in Table 7.			<meteor>
file	0..N	Attach one or more files, for example the period log file. See Table 13.			<file>

Table 7 – <**meteor**> element: describes a meteor observed by a camera.

Name	#	Description	Example(s)	Unit	Type
meteor_code	0..1	Unique alphanumeric identification code for the meteor. Use the format '`CAM-YYYYMMDD-SYSTEM-M999`' (all uppercase), where `YYYYMMDD` refers to the date on which the session started, `SYSTEM` refers to the unique code of the camera system, and `999` refers to the relative number of the meteor in the session. For example, the first meteor observed by system `ICC3` in the session that started on 2007 August 11 should be called '`CAM-20070811-ICC3-M001`'. In case a multiple sessions have started on the same date, append '`-N`' after the date, where `N` is the number of the session. For example, the first meteor of the second session is '`CAM-20070811-2-ICC3-M001`'. In case more than 999 meteors are seen in a session, add extra digits to the meteor number, e.g., '`CAM-20070811-ICC3-M1000`'.	'CAM-20070811-ICC3-M001'		string
time	0..1	Time when the meteor was first detected. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:34.45		datetime
shower_code	0..1	The shower designation for the meteor. Initially this is the shower or sporadic source as designated by the observing software, but this value may be recomputed and updated at any point in time afterwards according to an updated standard radiant catalog. 'SPO' is also valid.	'PER'		string
exposures	0..1	Number of exposures in which the meteor was recorded (1 if the observation was photographic).	8		integer
duration	0..1	Duration of the meteor.	1.64	s	decimal
mag	0..1	Brightest instrumental magnitude. The magnitude is "instrumental" because it depends on the spectral response curve of the camera, which may differ from a visual observer.	3.52	mag	decimal
speed	0..1	Average angular speed.	20.30	deg/s	decimal
in_fov	0..1	Denotes whether the meteor entered or left the field of view. '00' = started and ended outside the field of view, '10' = started inside but ended outside, '01' = started outside but ended inside, '11' = both start and end are inside the field of view.	'11'		string
begin_ra	0..1	Right Ascension (J2000.0) of the begin point. The value may have been corrected, e.g. using a linear fit through the meteor or by manual measurement.	20.8753	deg	decimal
begin_dec	0..1	Declination (J2000.0) of the above.	45.4875	deg	decimal
end_ra	0..1	Right Ascension (J2000.0) of the end point. The value may have been corrected, e.g. using a linear fit through the meteor or by manual measurement.	12.8754	deg	decimal
end_dec	0..1	Declination (J2000.0) of the above.	49.7851	deg	decimal
comments	0..1	Free text field for comments.			string
e_duration	0..1	Uncertainty (σ) of duration.	0.13	s	decimal
e_mag	0..1	Uncertainty (σ) of mag.	0.21	mag	decimal
e_speed	0..1	Uncertainty (σ) of speed.	0.54	deg/s	decimal
e_begin_ra	0..1	Uncertainty (σ) of begin_ra.	0.0031	deg	decimal
e_begin_dec	0..1	Uncertainty (σ) of begin_dec.	0.0025	deg	decimal
cov_begin	0..1	Covariance of begin_ra and begin_dec.	0.000035	deg^2	decimal
e_end_ra	0..1	Uncertainty (σ) of end_ra.	0.0022	deg	decimal
e_end_dec	0..1	Uncertainty (σ) of end_dec.	0.0015	deg	decimal
cov_end	0..1	Covariance of end_ra and end_dec.	0.000081	deg^2	decimal
pos	0..N	Optional instanteneous astrometric or photometric measurements, as specified in Table 8.			<pos>
file	0..N	Attach one or more files, for example the meteor sum image. See Table 13.			<file>

Table 8 – <**pos**> element: describes the astrometric and photometric measurements of a meteor frame.

Name	**#**	**Description**	**Example(s)**	**Unit**	**Type**
pos_no	1	Number of the position, counted relative to each meteor starting at 1.	1, 2, 3, 4, 5, ...		integer
time	0..1	Time of the position, accurate to the time interval between exposures or shutter breaks. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:34.45		datetime
mag	0..1	The instrumental brightness of the meteor at the given position.	3.64	mag	decimal
pos_x	0..1	The horizontal position (x) of the meteor within the exposure. This should be a relative value between 0 and 1. The left edge is 0, the right edge is 1.	0.231		decimal
pos_y	0..1	The vertical position (y) of the meteor within the exposure. This should be a relative value between 0 and 1. The bottom edge is 0, the top edge is 1.	0.454		decimal
pos_ra	0..1	Right Ascension (J2000.0) of the meteor position.	32.9785	deg	decimal
pos_dec	0..1	Declination (J2000.0) of the meteor position.	130.4845	deg	decimal
correction_flag	0..1	Was the position corrected afterwards, for example by a manual re-measurement?	true, false		boolean
outlier_flag	0..1	Are the given coordinates outliers relative to the other positions for this meteor?	true, false		boolean
saturation_flag	0..1	Was the camera saturated? This means the measurement is less accurate.	true, false		boolean
e_time	0..1	Uncertainty (σ) of time.	0.062	s	decimal
e_mag	0..1	Uncertainty (σ) of mag.	0.23	mag	decimal
e_pos_x	0..1	Uncertainty (σ) of pos_x.	0.017		decimal
e_pos_y	0..1	Uncertainty (σ) of pos_y.	0.018		decimal
e_pos_ra	0..1	Uncertainty (σ) of pos_ra.	0.0035	deg	decimal
e_pos_dec	0..1	Uncertainty (σ) of pos_dec.	0.0028	deg	decimal
cov_ra_dec	0..1	Covariance of pos_ra and pos_dec.	0.000042	deg^2	decimal
file	0..N	Attach one or more files, for example the frame image. See Table 13.			<file>

Table 9 – <**orbit_pipeline**> element: describes a pipeline of software and methods used to determine orbits. This is important as meteor scientists prefer to know the exact methods and tools used in the computation of an orbit. Note that the examples shown in this table are kept very short for formatting reasons; in reality one should attempt to give much more details.

Name	**#**	**Description**	**Example(s)**	**Type**
pipeline_code	1	Unique code of the orbit determination pipeline.	'UFO2.21'	string
contact_code	1	The contact person, identified by the observer code refering to the <observer>... </observer> element.	'SONOTACO'	string
name	1	Long name of the pipeline (typically the full name of a software package, including the version number and author name).	'UFOOrbit 2.21 by SonotaCo'	string
description	1	General description of the methods and software used to determine the orbit.	'Uses the UFO tools available from http://www.sonotaco.com.'	string
astrometry	0..1	Describe how astrometry was obtained from raw images. If astrometry from an existing database was used, note it here. Provide references if possible. Leave empty for radar orbits.	'Uses UFOAnalyzer 2.25 by SonotaCo. Described in detail in Sonotaco et al (2008), WGN.'	string
trajectory	1	Describe the trajectory determination algorithm. Provide references if possible.	'Ceplecha (1987).'	string
errors	1	Describe how the uncertainties in the astrometry, trajectory and orbit are estimated.	'Uncertainties were propagated from the astrometry to the orbit using Monte-Carlo (1000 iterations).'	string
mass	0..1	Describe how the mass was computed, and specify if the mass is photometric or dynamical. Provide references if possible.	'Photometric mass. ReVelle & Ceplecha (2002), ESA SP-500'	string
comments	0..1	Free text field to provide additional documentation and comments.	'If this was a real example, there should be much more text!'	string
file	0..N	Attach one or more files, for example pipeline documentation or reference papers. See Table 13.		<file>

Table 10 – <**orbit_set**> element: groups a set of orbits/trajectories.

Name	**#**	**Description**	**Example(s)**	**Type**
set_code	1	Code for this collection of orbits. Use '`ORB-OBSERVERCODE-NAME`' in uppercase characters, where `OBSERVERCODE` is the unique observer code of the author/contact person, and `NAME` is an arbitrary name of the set (using alphanumeric characters without spaces). For example, Perseid 2009 orbits computed by Rainer Arlt could be called '`ORB-ARLRA-PER2009`'.	'ORB-ARLRA-PER2009'	string
contact_code	1	The author or contact for this set of orbits, identified by the unique observer code refering to the <observer>... </observer> element.	'ARLRA'	string
version	0..1	Time of last update (used as version identifier).	2009-06-12T18:00:00	datetime
comments	0..1	Free text field to provide comments.		string
orbit	1..N	One or more heliocentric meteoroid orbits. See Table 11.		<orbit>
file	0..N	Attach one or more files, for example a documentation for this specific set of orbits. See Table 13.		<file>

Table 11 – <**orbit**> element: a meteoroid trajectory/orbit computed from two or more camera stations (or one radar station). The orbital elements must be given in the heliocentric reference frame J2000.

Name	#	Description	Example(s)	Unit	Type
pipeline_code	0..1	Code of the orbit computation pipeline used. A corresponding <orbit_pipeline> element should be present in the file, describing in detail how the orbit was computed.	'UFO2.21'		string
orbit_type	1	Type of observations used to determine the orbit. Should be either 'VISUAL', 'STILL', 'VIDEO', 'RADAR' or 'HYBRID'. If 'STILL' and 'VIDEO' data is combined, use 'VIDEO'. For any other combination, use 'HYBRID' and explain in comments.	'VIDEO'		string
time	1	Reference time for the meteor; when the meteoroid was at 100 km height. Use the ISO 8601 format in UTC.	1993-04-21T23:20:24		datetime
t0	0..1	Epoch (seconds since J2000.0) for which the orbital elements are given. The epoch is not necessarily the same as the meteor reference time, because the orbital elements may be given for an earlier point in time.	−211248000.3	s	decimal
q	0..1	Perihelion distance (small q).	0.9381	AU	decimal
a	0..1	Semimajor axis.	6.36	AU	decimal
e	0..1	Eccentricity.	0.8537		decimal
i	0..1	Inclination.	80.3717	deg	decimal
omega	0..1	Argument of periapsis.	211.3147	deg	decimal
asc_node	0..1	Ascending node (J2000.0).	31.9439467	deg	decimal
m0	0..1	Mean anomaly at epoch t0.	69.4212	deg	decimal
shower_code	0..1	Code of the meteoroid stream that fits the orbital elements (if any).	'LYR'		string
iau_no	0..1	IAU number of the meteoroid stream that fits the orbital elements (if any).	'0006'		string
mag_abs	0..1	Absolute maximum brightness in the visual spectral range expressed as a magnitude. This is the brightness that would be recorded if the meteor was at a height of 100 km in the zenith of a visual observer.	−3.27	mag	decimal
mass	0..1	Meteoroid mass in grams.	1734	g	decimal
vel_obs	0..1	Observed velocity *without any correction* for atmospheric deceleration, diurnal abberation or zenith attraction.	47.60	km/s	decimal
vel_inf	0..1	Velocity just before atmospheric entry (= vel_obs corrected for atmospheric deceleration and diurnal aberration).	47.70	km/s	decimal
vel_geo	0..1	Geocentric velocity (= vel_inf corrected for zenith attraction).	46.15	km/s	decimal
vel_helio	0..1	Heliocentric velocity (= vel_geo converted to the heliocentric reference frame).	40.32	km/s	decimal
height_begin	0..1	Height at meteor begin point (leave empty if the begin point was not observed).	103.44	km	decimal
height_max	0..1	Height at the point of brightest absolute magnitude.	79.23	km	decimal
height_end	0..1	Height at meteor end point (leave empty if the end point was not observed).	77.02	km	decimal
rad_obs_ra	0..1	Right Ascension (J2000.0) of the observed radiant. This is the radiant *without any correction* for atmospheric deceleration, diurnal abberation or zenith attraction.	274.1984	deg	decimal
rad_obs_dec	0..1	Declination (J2000.0) of the above.	33.5586	deg	decimal
rad_geo_ra	0..1	Right Ascension (J2000.0) of the geocentric radiant. This is the radiant corrected for atmospheric deceleration, diurnal aberation and zenith attraction.	274.7741	deg	decimal
rad_geo_dec	0..1	Declination (J2000.0) of the above.	33.2541	deg	decimal
z_avg	0..1	Average zenith distance of the observed radiant from the different stations.	51.41	deg	decimal
meteors	0..1	Total number of single-station meteor observations used to compute the orbit.	2,3...		integer
meteor_code	0..N	Codes of the meteors used to determine the orbit. The corresponding <meteor> elements (cf. Table 7) should preferably be given in the same file or be available in a central archive.			string
complete	0..1	Could the meteor trajectory be reconstructed completely from the available data? '11' = yes; '01' = begin is missing; '10' = end is missing; '00' = begin and end are missing.	'11'		string

Table 11 – <**orbit**> element (continued).

Name	#	Description	Example	Unit	Type
conv_best	0..1	Best (closest to 90°) convergence angle. This is the angle between the apparent great circles of meteor motion as seen from any two observing stations; indicating the quality of the observing geometry. Leave empty for radar orbits.	64.5	deg	decimal
state	0..1	7-element state vector $(t, x, y, z, v_x, v_y, v_z)$ of the meteoroid while producing the meteor; t is the ISO 8601 timestamp in UTC, x, y, z are the rectangular Geocentric coordinates in the Earth-fixed reference frame (the X-axis points towards 0 degrees longitude/latitude, the Z-axis points North along the axis of rotation of the Earth, and the Y-axis is the cross product of X and Z), and v_x, v_y, v_z are the velocities in the same reference frame. The state vector should be corrected for atmospheric deceleration and diurnal aberration, but not for zenith attraction. This vector allows for the easy recomputation of orbital elements using different algorithms and reference epochs. It is strongly advised to provide this field.	1993-04-21 T23:20:24, 5268456.3, 2799969.6, 2516762.2, 31826.2, −24824.2, 41340.3	time, m, m, m, m/s, m/s, m/s	vector
e_state	0..1	Uncertainty variances and covariances of the state vector. Use the following format: $(\sigma_t^2, \sigma_x^2, \sigma_y^2, \sigma_z^2, \sigma_{v_x}^2, \sigma_{v_y}^2, \sigma_{v_z}^2, \mathrm{cov}(x,y),$ $\mathrm{cov}(x,z), \mathrm{cov}(y,z), \mathrm{cov}(v_x,v_y), \mathrm{cov}(v_x,v_z), \mathrm{cov}(v_y,v_z))$	0.001, 1328.3, 1447.5, 1396.7, 12.5, 69.1, 32.4, 0.145, 0.574, 0.134, 0.136, 0.245, 0.244	s^2, m^2, m^2, m^2, m^2/s^2, m^2/s^2, m^2/s^2, m^2, m^2, m^2, m^2/s^2, m^2/s^2, m^2/s^2	vector
e_time	0..1	Uncertainty (σ) of time.	1.3	s	decimal
e_t0	0..1	Uncertainty (σ) of t0.	1.3	s	decimal
e_q	0..1	Uncertainty (σ) of q.	0.0052	AU	decimal
e_a_inv	0..1	Uncertainty (σ) of 1/a. The error of the *inverse* of the semi-major axis is asked because this quantity follows a normal distribution. The error distribution of the semi-major axis itself is heavily skewed.	1.89	AU	decimal
e_e	0..1	Uncertainty (σ) of e.	0.040	AU	decimal
e_i	0..1	Uncertainty (σ) of i.	0.64	deg	decimal
e_omega	0..1	Uncertainty (σ) of omega.	1.42	deg	decimal
e_asc_node	0..1	Uncertainty (σ) of asc_node.	0.000012	deg	decimal
e_m0	0..1	Uncertainty (σ) of m0.	0.023	deg	decimal
e_mag_abs	0..1	Uncertainty (σ) of mag_abs.	0.54	mag	decimal
e_mass	0..1	Uncertainty (σ) of mass.	102	g	decimal
e_vel_obs	0..1	Uncertainty (σ) of vel_obs.	0.58	km/s	decimal
e_vel_inf	0..1	Uncertainty (σ) of vel_inf.	0.58	km/s	decimal
e_vel_geo	0..1	Uncertainty (σ) of vel_geo.	0.47	km/s	decimal
e_vel_helio	0..1	Uncertainty (σ) of vel_helio.	0.42	km/s	decimal
e_height_begin	0..1	Uncertainty (σ) of height_begin.	2.33	km	decimal
e_height_max	0..1	Uncertainty (σ) of height_max.	1.87	km	decimal
e_height_end	0..1	Uncertainty (σ) of height_end.	1.56	km	decimal
e_rad_obs_ra	0..1	Uncertainty (σ) of rad_obs_ra.	0.075	deg	decimal
e_rad_obs_dec	0..1	Uncertainty (σ) of rad_obs_dec.	0.050	deg	decimal
cov_rad_obs	0..1	Covariance of rad_obs_ra and rad_obs_dec.	0.00023	deg^2	decimal
e_rad_geo_ra	0..1	Uncertainty (σ) of rad_geo_ra.	0.075	deg	decimal
e_rad_geo_dec	0..1	Uncertainty (σ) of rad_geo_dec.	0.050	deg	decimal
cov_rad_geo	0..1	Covariance of rad_geo_ra and rad_geo_dec.	0.00041	deg^2	decimal
comments	0..1	Free text field for comments.			string
traject_pos	0..N	Optional instantaneous position along the trajectory of the meteoroid as specified in Table 12			<traject_pos>
file	0..N	Attach one or more files, for example an orbit graph. See Table 13.			<file>

Table 12 – <**traject_pos**> element: describes a point on the trajectory of the meteor. This element may be used multiple times inside <orbit> to describe the atmospheric trajectory of a meteoroid in geographic coordinates.

Name	**#**	**Description**	**Example(s)**	**Unit**	**Type**
pos_no	1	Number of the point, counted relative to each trajectory starting at 1.	1, 2, 3, 4, 5...		integer
time	0..1	Time when the meteoroid was at the given position. Use the ISO 8601 format in Universal Time (UTC).	2007-08-12T00:12:35.24		datetime
lon	0..1	Geographic longitude in decimal degrees. The longitude should be a signed value between −180 and +180. A negative value means 'WEST', a positive value means 'EAST'. The WGS84 coordinate system should be used, which is also the basis for the GPS system.	13.148752	deg	decimal
lat	0..1	Geographic latitude in decimal degrees. The latitude should be a signed value between −90 and +90. A negative value means 'SOUTH', a positive value means 'NORTH'. The WGS84 coordinate system should be used.	52.516435	deg	decimal
height	0..1	Geographic height above zero in kilometer, relative to WGS84.	87.1549	km	decimal
mag_abs	0..1	Absolute brightness in the visual spectral range expressed as a magnitude. This is the brightness that would be recorded if the meteor was in a visual observer's zenith at a height of 100 km.	−2.4	mag	decimal
vel	0..1	Velocity between this and the following <traject_pos>.	46.53	km/s	decimal
e_time	0..1	Uncertainty (σ) of time.	0.14	s	decimal
e_lon	0..1	Uncertainty (σ) of lon.	0.00045	deg	decimal
e_lat	0..1	Uncertainty (σ) of lat.	0.00071	deg	decimal
e_height	0..1	Uncertainty (σ) of height.	0.0041	km	decimal
cov_lon_lat	0..1	Covariance of lon and lat.	0.00056	deg^2	decimal
cov_lon_height	0..1	Covariance of lon and height.	0.00024	deg·km	decimal
cov_lat_height	0..1	Covariance of lat and height.	0.00083	deg·km	decimal
e_mag_abs	0..1	Uncertainty (σ) of mag_abs.	0.42	mag	decimal
e_vel	0..1	Uncertainty (σ) of vel.	1.3	km/s	decimal

Table 13 – <**file**> element: allows files in custom formats to be attached.

Name	**#**	**Description**	**Example(s)**	**Type**
path	1	Location of the file relative to the location of the XML document. Can also be a remote URL.	'videos/vid287.avi'	string
comments	0..1	A comment field allowing free text.		string

Development of an All-Sky Video Meteor Network in Southern Ontario, Canada : The ASGARD System

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An automated all sky camera network has been constructed in Southern Ontario, Canada as one instrumental component of the Southern Ontario Meteor Network. The design strategy for the network as well as hardware and software which have been developed are described. The metric precision of our reductions are typically $\sim$ few hundred meters and photometry precise to 0.5 mag for meteors fainter than -6. Early results of the network are presented.

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1 Introduction

The utility of well-spaced photographic stations for meteor work has been recognized for as long as instrumental observations of meteors have occurred (cf. Whipple, 1954). Expansion of this early concept to multiple stations and later to all-sky observations was driven in part by the serendipitous observation of the Příbram meteorite fireball in 1959 from an early camera network established in the former Czechoslovakia (Ceplecha & Rajchl, 1965). It was recognized that such camera networks could prove valuable in recording the pre-atmospheric orbit for recovered meteorites (cf. Halliday, 1973). From this early recognition, and the need for solid data concerning the origin of meteorites in the solar system, at least three substantial camera networks arose: the European Network in Eastern Europe (early 1960's – present), the Prairie Network in the United States (1963–1975) and the Meteorite Observation and Recovery Project (MORP) in Canada (1971–1985). All of these networks had as their main design goal the recovery of meteorites from photographically observed fireballs. In total four meteorites were recovered by these dedicated networks Příbram and Neuschwanstein (EN), Lost City (PN) and Innisfree (MORP). The data from these meteorite-orbits proved valuable in many respects but the low recovery rates made support for these large operations problematic — only the EN survives to the present. The wealth of experience gathered by the EN operations has lead to modern versions of these observing systems (Spurný et al., 2006) and the establishment of the Desert Fireball Network (DFN) in Australia (situated where terrain is ideal for meteorite recovery) already proving more productive than earlier camera networks.

These networks have been setup with meteorite recovery as the main driver, though they have proven highly useful for many diverse studies (cf. Oberst et al., 1998; Halliday et al., 1996). As such they have tended to focus on detection and reduction of fireballs most likely to produce meteorites, though often are sensitive to smaller fireballs as well. More recently, entirely automated or semi-automated multi-station networks have also been set up using CCDs and/or image intensifiers to record somewhat fainter meteors (cf. Trigo-Rodriguez et al., 2008; Olech et al., 2006).

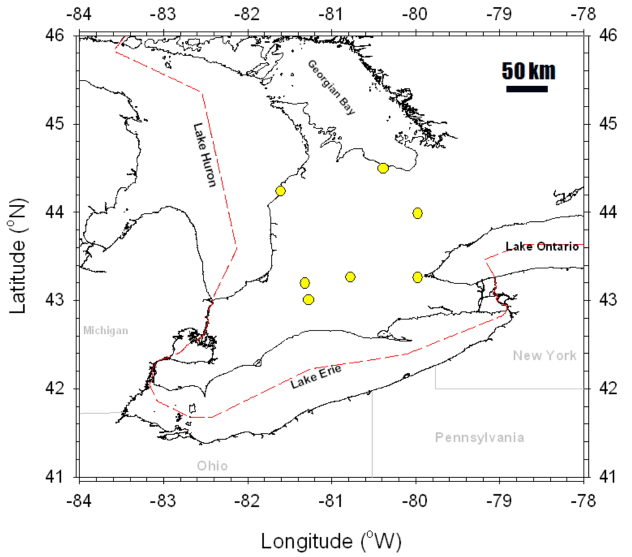

Figure 1 – Location of seven ASGARD cameras (circles) in Southern Ontario.

There are many reasons to study smaller, centimetre-sized meteoroids, a size range generally not recorded by all-sky photographic cameras (except at very high velocities). Meteoroids in this size regime are a major mass-loss mechanism for comets (Sykes & Walker, 1992), and as such meteor showers tend to be most detectable at such sizes, making statistical studies possible. In particular, meteoroids in this range (which produce meteors at or just below the threshold of the fireball category, depending on speed) are bright enough to be amenable to multi-instrument observations. This means that many events can be recorded in detail to provide constraints for numerical entry models. It is this latter application which was the main design driver for the development of an all-sky camera network as part of the multi-instrumental Southern Ontario Meteor Network (SOMN).

2 Instrumentation and Software Design

The all-sky video network component of the SOMN was developed originally from hardware and software supplied by Sandia National Labs as part of their Sentinel

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Figure 2 – Video camera and enclosure.

camera network. Our intent was to use a dense array of all-sky cameras (with spacing of order 50–100 km) to record many meteors from multiple stations. At present the network consists of seven cameras (Figure 1). As will be shown later, a typical event has astrometric residuals of order 100–200 m (depending on geometry) which for our purposes is sufficient for multi-instrumental studies. The intent is to use the moderate precision metric data for comparison with other instrumental recordings of the same event and to act as a "trigger" for other instruments. Here we sacrifice precision in favour of semi-automation in reduction. Improvements in these residuals would be possible with fully manual reductions, but only with enormous labour given the large number of events recorded.

2.1 Camera Hardware

The cameras used for each station are HiCam HB-710E SONY Ex-view HAD (1/2″ size) CCD cameras equipped with a Rainbow L163VDC4 1.6–3.4 mm f/1.4 lens (Figure 2). The cameras are housed inside a simple enclosure with a clear acrylic dome. The enclosure has a thermostat for heating during winter and a fan system to circulate air and prevent dewing of lenses or the dome. A photosensor is attached to each camera which shuts off the unit during the day. The acrylic domes have a useful lifetime of only $\sim$ 6 months and are entirely replaced on a regular basis. The video signal from the camera (NTSC, 29.97 frames per second) in a 640×480 format is captured by a Brooktree 878A frame-grabber card in a PC, processed, and then streamed to disk. Timing information (based on the system time when a hardware interrupt from the capture card occurs) is calibrated against a US GlobalSat BU-353 USB GPS

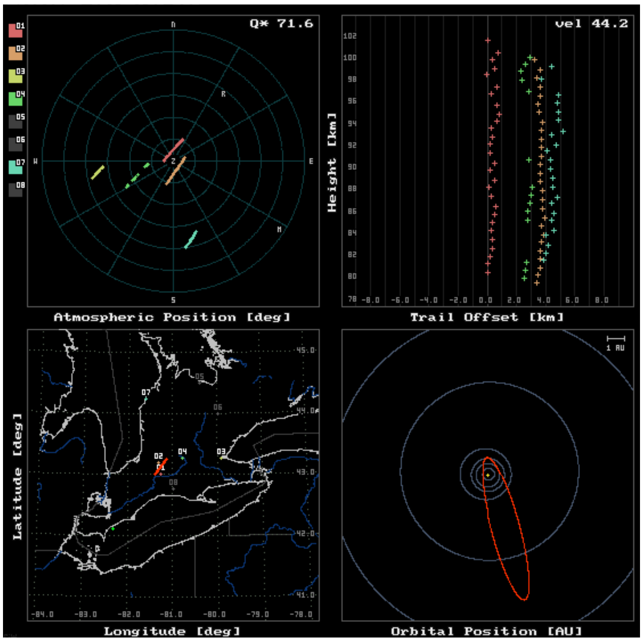

Figure 3 – Automated output showing apparent azimuth and altitude of detected points from all stations; observed — (upper right) theoretical height along trail using a mean velocity of 44.2 km/s (as a means to check for deceleration; (lower left) map showing apparent ground track and projected terminal ground point and (lower right) approximate orbital diagram. Note that camera 4 has some dropped frames for this event.

receiver using the Network Time Protocol (NTP) software. Instead of simply correcting the system clock periodically (which allows it to drift between updates), NTP will adjust the clock rate to ensure the clock is always accurate to better than one frame time. When extreme accuracy is desired, NTP can use a pulse per second (PPS) signal to obtain times accurate to $\sim$ 10 microseconds.

2.2 Software Design

To record events with these video systems, the All Sky and Guided Automatic Real-time Detection (ASGARD) software was developed by one of us (RJW) (Weryk et al., 2008). An early version of the detection software and our reduction procedures was first described by Weryk et al. (2008), however many changes and improvements have been made since that time. The software detects meteors in real-time, and can acquire video data from a range of video sources, including analog video camera interfaces, pre-recorded video, and digital camera interfaces using the high-speed CameraLink interface. The software is run under the Debian GNU/Linux operating system, and ideally requires at least a 1 GHz processor, 256 MB of memory, and a 40 GB hard drive. However, a modern 3 GHz processor could run 8+ cameras simultaneously. This would be beneficial if each camera had a longer focal length lens, which would give effective all-sky coverage while at the same time being sensitive to fainter meteors. The software is in theory scalable to cameras that produce 125+ MB/s data streams; however this has not been tested.

The key design philosophy with ASGARD was the

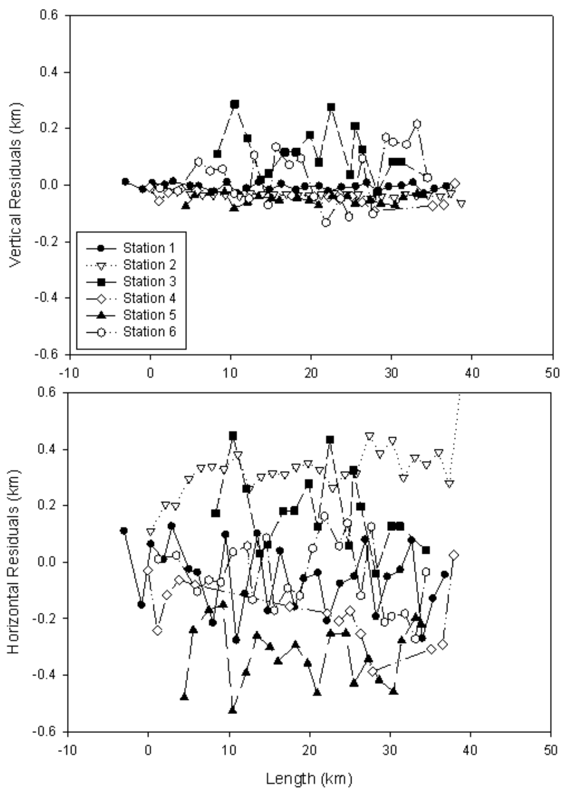

Figure 4 – Line of sight residuals (vertical and horizontal) between the best fit trajectory solution and the observed sightlines

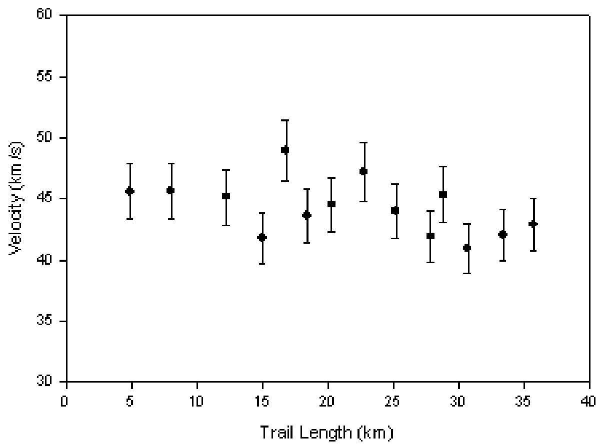

Figure 5 – Average velocity measured from all cameras along the length of the trajectory.

use of software plugins for the detection algorithm. This allows the software to be tuned to specific requirements, such as using intensified vs. non-intensified imagery, or tuned to the amount of available computing power. The detection plugin used by the SOMN all-sky cameras is based on pixel thresholds. For each video frame, the number of neighbouring pixels that have increased by a given intensity from a previous frame (typically from one second before) is computed. The threshold value is currently set to a constant which limits our faintest detectable meteors around magnitude -1; however this results in higher SNR values which are more useful when comparing the video data against other instruments, such as infrasonic records.

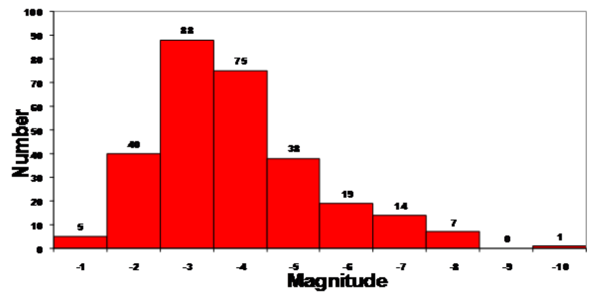

Figure 6 – Peak absolute panchromatic magnitude of 287 manually reduced events between 2008-2009.

We find that for our current network of seven cameras, regular multi-station detections become common only around magnitude -3. It is quite straightforward to dynamically adapt the threshold parameter to image noise, and this is planned for the future. Regions prone to false alarms (such as smoke chimneys or tree branches) are masked to not contribute to the pixel sum. When the sum has exceeded a set limit, event detection is started. Detection ends when there has not been a trigger pixel for a few seconds, and the detection is saved to disk only when the number of triggered frames passes a configured limit. The software is also capable of detecting simultaneous events which is beneficial for highly active meteor showers, or when aircraft are present. Because of this, it is more efficient to stream the raw video frames to disk (with the detection software recording a list of frame number, pixel centroid, brightness, and related information) and have a separate program produce video, image, and text summary files. On the SOMN cameras, the streaming video consumes 33 GB per hour of video and the local disk drives store 20+ hours of video in a rolling buffer to allow for later re-analysis of bright meteors that had entered a masked region, or for events that occurred near sunset when the background sky brightness was too high for optimal detection.

Another feature of the software is its heuristic event rejection filters. Events such as high-altitude aircraft, excessive noise triggers, specular reflections from satellites, clouds passing in front of the Moon, and other false triggers can be eliminated in the summary generator. Further false triggers can be eliminated by only considering events that are visible on multiple stations.

2.3 Basic Analysis

Astrometric positions are calibrated based on the equations provided in Borovička et al. (1995) and use either the Bright Star Catalogue (Hoffeit & Jaschek, 1982) or the SKY2000v4 catalogue (Myers et al., 2002) for reference stellar positions. Each camera records a calibration image every 15 minutes and these basic data are used to construct plates for each site. Positions are calibrated against local zenith and azimuth angles rather than against celestial equatorial coordinates. The plate constants also include the effects of any lens distortion. We find that at most sites our cameras remain precise to within one pixel over timescales of the order of weeks.

While each event is different, typically SOMN camera hardware has 0.2 degree precision which allows for trajectory solutions on the order of $\sim$ 250 m precision. With a relatively dense network it is common to have many cameras available for any one event and this allows reduction of the residuals through judicious choice of the closest cameras (high apparent event elevations) and good plate fits allowing even better residuals in some cases.

For photometric measurements, the instrumental magnitude scale is calibrated against the same catalogue. We also use bright planets and the moon for calibration. For stars, a circular disc is defined around a star as to contain all light. A ring is also defined around the star (with no overlap with the disc), and the median pixel value is used to estimate the background brightness. This value is subtracted from each pixel in the disc and then all pixel values in the disc are summed. The resulting sum is converted into a magnitude measurement (using the standard astronomical magnitude scale), and this instrumental magnitude scale is found to relate linearly to each of the UVBRI scales used in the Johnson-Cousins magnitude system, with red having the highest correlation due to the spectral response of the HAD CCD chip. The photometric offset (slope is fixed at unity) is computed using linear regression. Meteors are then measured using an aperture mask that covers all light in a given frame, however the background pixel values are determined by median combining images that preceded the meteor, and the stellar calibration offset is applied. The calibration is quite good (better than $\sim$ 0.5 instrumental magnitude) for objects fainter than -6; thereafter saturation becomes increasingly a problem. However, less than 10% of all our events are bright enough for this to be an issue.

In order to compare any photometric results against other authors, we transform our calibrated instrumental magnitude scale to the panchromatic band-pass through application of synthetic photometry to a series of published meteor spectra to compute a mean color correction term. Details of this process are presented in Weryk et al. (2008). Our photometric measurements have much less dynamic range than film making photometry of very bright events highly uncertain. However, as most of our events are only moderately above our detection threshold (where our calibration is best) this is not a significant limitation. A separate high speed photometry system for brighter events is currently being tested to overcome this limitation.

2.4 Automated Analysis

Events are synchronised to a central server where they are correlated based on the time of observation. For each multistation event, the atmospheric trajectory solution is computed using the program MILIG (Borovička, 1990) and heliocentric orbits are computed with the program MORB (Ceplecha, 1987). A preliminary summary list is automatically produced at this stage (see example in Table 1).

Based on the quality of the initial solution, some

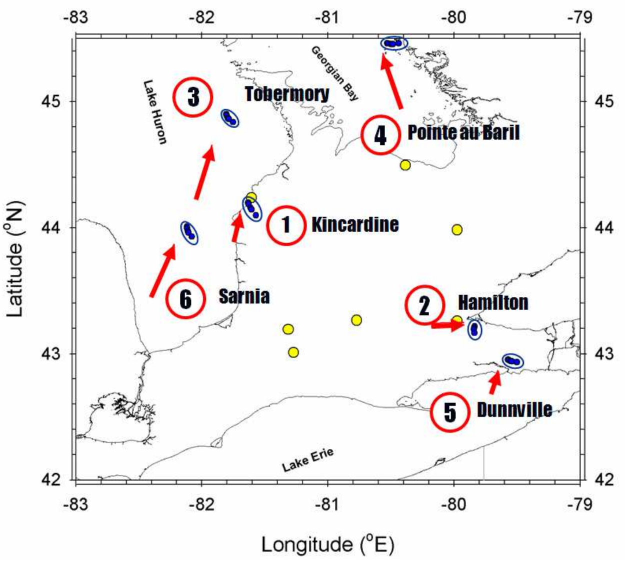

Figure 7 – Ground tracks (red arrows) and estimated fall zones for meteorites (blue circles) for events listed in Table 2.

events are found to have acceptable solutions directly from this automated pipeline and stored in a master database. All events are checked manually for quality and position picks or other errors. We find that relying entirely on the automated solutions is not possible as typically more than half of all events need some form of manual improvement to the selections (including more points not detected by the automated algorithm or refined picks in some cases). This includes checks for good convergence angles (the exact limits we find depend on the number of cameras in a solution, ranges to the event and its duration), internal checks on the solution consistency (similar beginning heights etc.) and small overall dispersion in measured velocity from multiple stations.

3 Results and Early Analysis

A completely reduced example event detected by the ASGARD camera network is shown in Figures 3–5. We examine each event for detectable deceleration (notable in 25% of all reduced cases to date) and correct to out-of-atmosphere velocity by using the average velocity from the earliest 1/2 to 1/3 of the trail (depending on total trail length and internal consistency between multiple stations) and then take a global average. Note also that we do not reject trails on the basis of duration alone; this would have the effect of biasing our overall sample away from cometary meteoroids. However, for some analyses, short duration events are removed at a later analyses stage as these tend to be the least accurate given their typically small number of measured points.

Figure 6 shows the magnitude distribution of a selection of fully reduced events during 2008–2009 manually reduced to mid-2009. Our effective apparent magnitude cutoff for multi-station events is near -3. More than 90% of all our events have pre-atmospheric masses between 0.1 – 10 g.

Despite the network having not been designed for meteorite-fireball recovery observations, over the last three years at least six events have been detected which had a non-negligible end mass. Table 2 summarizes these potential meteorite-producing events. Unfortunately, given the network's location near the Great Lakes, many of these objects have endpoints over the lakes and hence are not recoverable. Figure 7 shows the ground paths and probable fall areas for these potential small meteorite-producing fireballs.

4 Future Work

The bulk of the analysis work for the all sky network is focused on cross-comparisons with other sensor suites. Some initial comparisons between radar and infrasonically observed meteor events have already begun, but more detailed analysis together with entry model predictions are now underway. We also expect to use the growing database to examine the relationship between the apparent strength of ablating meteoroids and their orbital characteristics — a topic which has received much better attention at larger sizes. Finally, with routine monitoring we hope to be able to document future shower outbursts rich in brighter meteors, such as the 2009 Perseids where over 200 multi-station orbits were automatically recorded on the night of Aug 13, 2009 alone.

Acknowledgements

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Table 1 – An example of automated output from the ASGARD system.

```
      date     time :                       :  vel   beg   end : src
 -------------------+-----------------------+------------------+------
+ 20080801 04:22:20 : -- -- -- 04 05 06 07 : 24.0  90.0  77.9 : CAP
+ 20080801 04:39:47 : -- -- -- 04 -- -- 07 : 53.5  98.7  93.4 : ...
+ 20080801 04:46:48 : -- -- 03 -- 05 -- -- : 66.5  95.7  87.9 : ...
+ 20080801 04:58:14 : -- -- 03 -- 05 06 -- : 56.2  99.8  87.1 : ...
+ 20080801 05:53:39 : -- 02 -- 04 05 06 07 : 46.6  85.2  76.1 : ...
+ 20080801 06:09:32 : -- 02 -- 04 05 06 07 : .... ..... ..... : ...
+ 20080801 06:18:50 : -- -- -- -- 05 06 07 : 53.2 102.3  83.0 : ...
+ 20080801 06:25:06 : -- -- 03 04 05 06 -- : 34.1  92.9  82.2 : ...
+ 20080801 06:28:03 : -- -- -- 04 05 -- 07 : 16.8 147.8  75.4 : ...
+ 20080801 06:43:08 : -- -- -- -- 05 06 07 : 41.4  91.0  85.7 : SDA
+ 20080801 06:54:30 : -- -- -- 04 05 06 07 : .... ..... ..... : ...
+ 20080801 08:05:27 : -- -- -- -- 05 06 -- : 60.3 104.5  98.8 : PER
+ 20080801 08:19:30 : 01 02 03 04 05 06 07 : 67.8 109.0  82.0 : ...
+ 20080801 08:21:58 : -- 02 -- 04 -- -- -- : .... ..... ..... : ...
+ 20080801 08:23:06 : -- 02 -- 04 05 06 07 : 37.4  91.5  83.5 : ...
+ 20080801 08:50:39 : -- 02 03 04 -- 06 -- : 66.7 107.5  98.6 : ...

     CAP : alpha_Capricornids
     SDA : Southern_Delta_Aquariids
     PER : Perseids
```

Table 2 – Details for six probable meteorite falls from 2006 – 2009. The initial velocity, peak magnitude, photometric mass, end height, duration and dynamic mass at the end height are given. The estimated PE value and fireball type are also shown.

SOMN#	V_∞	M_{max}	$Mass_P$	H_{END}	Dur	$Mass_D$	PE	Type
yyyymmdd	km/s	P.mag.	kg	km	sec	kg		
20060305	18.65	-9.7	11.6	35.5	2.90	0.3	-4.75	H
20060405	15.18	-6.9	6.8	28.2	3.77	—	-4.32	I*
20061123	23.36	< -13.7	> 146	< 39.9	> 2.83	—	—	—
20080306	19.66	-11.2	75	24.5	5.00	0.6	-4.37	I
20080314	19.9	-8.6	> 4.4	< 34.5	> 2.72	0.8	-4.62	H
20080325	13.82	-7.9	14.8	32.4	5.67	1.0	-4.77	H

Geminids ZHR activity profiles as a function of magnitude

Shigeo Uchiyama [1]

The activity profiles of ZHRs per magnitude class of the Geminids were derived from the Visual Meteor Database (VMDB) of the IMO. The maximum solar longitude, $L_{\max}$, depends on the magnitude class m, according to the equation $L_{\max} = 262.^\circ328(\pm 0.^\circ033) - 0.^\circ055(\pm 0.^\circ014)m$ (eq. J2000.0). The profile widths of the brighter classes are narrower. The relationship between the FWHM and magnitude class is $\mathrm{FWHM} = 1.347(\pm 0.046) + 0.119(\pm 0.018)m$ (in units of degrees). Then the profile of the population index was obtained from these equations.

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1 Introduction

The Poynting–Robertson effect (hereafter P–R effect) causes the orbital speeds and semi-major axes of the dust grains to decrease with time (Wyatt & Whipple, 1950). Since smaller dust grains are more affected by the P–R effect than larger grains, many small dust grains will be perturbed onto orbits interior to the shower while large grains remain outside. The P–R effect strongly affects dust grains which have a small perihelion distance q and small revolution period P. Since the orbit of the Geminids has a small perihelion distance ($q \sim 0.14$ AU) and short period ($P \sim 1.6$ yr), the P–R effect has significantly influenced the Geminids. The Earth approaches the Geminids from the inside boundary of the shower orbit and continues through to the outside. Thus the population index of the Geminids varies from large to small at near maximum activity (Rendtel, 2004). This paper presents the calculated ZHRs per magnitude class, ZHR_m, of the Geminids from the IMO's Visual Meteor Database (VMDB), and as well as the dependences of the maximum solar longitude and activity width on the meteor magnitude.

2 ZHRs per magnitude classes, ZHR_m

ZHRs per magnitude class, ZHR_m, are calculated for each magnitude class by IMO standard formula except for the limiting magnitude correction.

$$\mathrm{ZHR} = \frac{\sum n_{m,i} + 1}{\sum C_i}$$
$$C = \frac{T_{\mathrm{eff}} \sin(h_{\mathrm{R}})}{P_m F}$$

The P_m is a limiting magnitude correction derived by comparing observations at a dark site and at a site affected by light pollution. At both locations very bright meteor numbers are almost the same though faint meteor numbers are very different. Therefore, the P_m varies with meteor magnitude and limiting magnitude. Perception coefficients (Koschack and Rendtel, 1990a; Koschack and Rendtel, 1990b) are used for the limiting magnitude corrections. The perception coefficients are determined for different values of the difference between meteor and limiting magnitudes (Figure 1). Limiting magnitude correction P_m is determined by

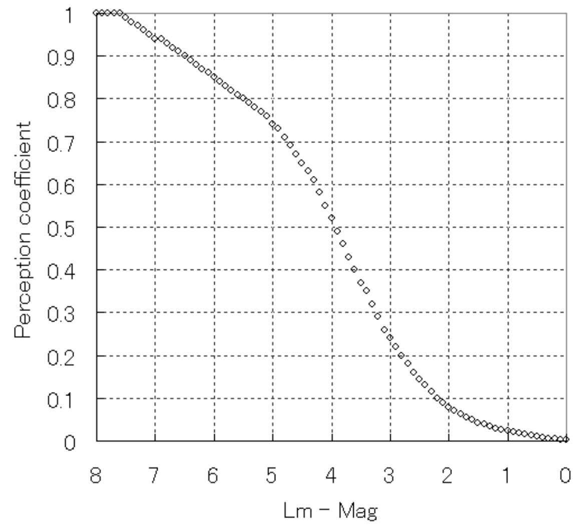

Figure 1 – Perception coefficients as a function of the difference between meteor magnitude and mean limiting magnitude.

$$P_m = \frac{P_{6.5,m}}{P_{\mathrm{Lm},m}}$$

Where $P_{6.5,m}$ and $P_{\mathrm{Lm},m}$ are perception coefficients of meteor magnitude m under the limiting magnitude 6.5 and Lm, respectively. For example, when the limiting magnitude is 5.8 and the meteor magnitude is 3, the perception coefficient is 0.20. When the limiting magnitude is 6.5, perception coefficient of magnitude 3 is 0.37. Since ZHR is at limiting magnitude 6.5, the correction factor P_m for the limiting magnitude correction is $0.37/0.20 = 1.85$.

3 Data

The VMDB on the IMO Web page (`www.imo.net`) contains a large number of visual meteor observation data with rates and magnitude distributions. Magnitude data were used to derive ZHR_m. The magnitude data in the VMDB does not contain the effective observation time T_{eff} and the field obstruction factor F, although they are needed to calculate the ZHR_m. Rate data were compared with the magnitude data, and added the T_{eff} and the F to the magnitude data. I selected the data to derive ZHR_m of the Geminids with following criteria; 1) Moon light pollution was small, i.e., 1993, 1996, 1998, 1999, 2001, 2002, 2004, 2007; 2) the limiting magnitude was fainter than 5.0; 3) the field obstruction factor F

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NASA-ADS bibcode 2010JIMO...38...31U

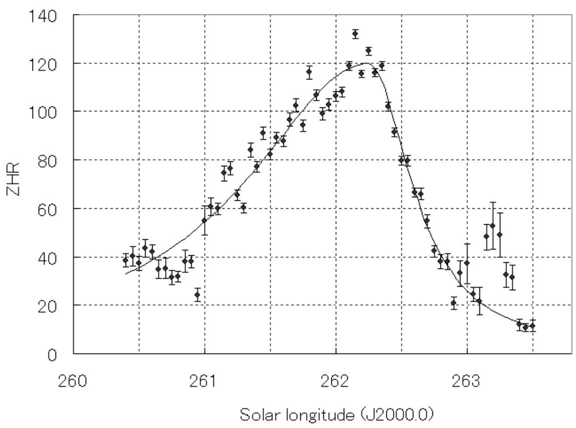

Figure 2 – ZHR profile of the Geminids. The ZHRs were calculated with assumed population index $r = 2.0$, and were used as standard numbers to derive personal coefficients.

was less than 1.4; 4) the radiant height was over 25 degrees; and 5) the observation period, from the begin to end, was less than 2 hours. The total number of Geminid meteors analyzed were 72 421 in 1244.2 hours of total effective observation time.

4 Analysis

4.1 Personal Coefficient

Each observer has a personal coefficient. When analysis is done without personal coefficients, the result may be skewed due to different perceptions of each observer. Therefore, we need to obtain personal coefficients for the observers. Standard meteor numbers are needed to derive personal coefficients. Although sporadic meteor numbers are used as the standard meteor numbers in many cases, sporadic meteor numbers are small and have poorer statistics. The Geminid ZHR profile was used as standard meteor numbers to calculate personal coefficients in this work. Thus the Geminid ZHR profile was derived first. The calculation formula to obtain ZHRs is the IMO standard procedure with assumed population index $r = 2.0$. Figure 2 shows the profile.

Jenniskens et al. (2000) showed that a Lorentz profile fits 1999 Leonids storm profile. The formula of a Lorentz profile is:

$$\mathrm{ZHR} = \mathrm{ZHR}_{\max}\frac{(W/2)^2}{(T - T_{\max})^2 + (W/2)^2}$$

Since a Lorentz profile is symmetric and the Geminid profile is asymmetric, the half-width $W/2$ was translated into two values, W_a for ascending branches and W_d for descending branches. The Lorentz profile fitted to the Geminid profile was obtained by a weighted least square method, and is also shown in Figure 2. The weighting was proportional to the inverse error. Using the Lorentz profile as the standard number at the solar longitude, the personal coefficients were calculated as corrections of the limiting magnitude dLm for all observers ($r = 2.0$ was assumed). For observers who recorded many observations, the personal coefficients of all observations were averaged. Observations by observers whose absolute personal coefficients |dLm| are greater than magnitude 1.0 were omitted.

4.2 Analysis Steps

Although one may think that the data should be analyzed in each year, all eight years of data were analyzed together. The reasons are that; 1) a large amount of data are needed to calculate ZHRs per magnitude class since observed meteor numbers are divided into each magnitude class; and 2) observation gaps exist in any one years data due to longitude distribution of observation sites and weather conditions. I have analyzed some meteor showers from Japanese observations since 2002, and the Geminid activities have shown small scatter from year to year in comparison with the Perseids or the Quadrantids. Therefore, the analysis from all years data is acceptable. The solar longitude bin size adopted was 0.05 degree (around 1.25 hours). Since bright meteor numbers are small and statistically insufficient in 0.05 degree steps, a bin size of 0.1 degree was adopted for magnitude -1 or brighter. When a bin of data was insufficient, nearby data was added to have sufficient data.

5 Result

The calculated ZHR_m are shown in Figure 3. The Lorentz profiles for the ZHR_m were derived by a least square method, and are also shown for the profiles in Figure 3. Generally the descending branches are steeper than the ascending branches. The descending branches are very steep for very bright meteors. The total ZHR maximum corresponds to the maximums of magnitude 2 or 3 meteors. The maximums of very bright meteors show delays of about half a day from the total ZHR maximum. When the ZHR maximum occurs in daytime, you can see about one fireball per hour the following night. When the ZHR maximum occurs during the nighttime you can see few fireballs the next night. ZHR_m of magnitude 4 and 5 show similar activity levels from solar longitude $261.^\circ5$ to $262.^\circ2$.

By fitting Lorentz profiles, it is possible to obtain the maximum solar longitude $L_{\max}$, ascending branch W_a, descending branch W_d, full-width at half-maximum FWHM, and the maximum ZHR_m, $\mathrm{ZHR}_{m,\max}$, for any magnitude. The relation between the meteor magnitude class m and the maximum solar longitudes is shown in Figure 4, and the relations between the meteor magnitude class and the ascending branches W_a, descending branches W_d, full-width at half maximum FWHM are shown in Figure 5. The figures show that the brighter meteors have later maximum solar longitudes and narrower activity widths. The derived relations between them, assuming a linear relationship, are as followed;

$$L_{\max} = 262.^\circ328(\pm 0.^\circ033) - 0.^\circ055(\pm 0.^\circ014)m \quad (1)$$

$$W_\mathrm{a} = 0.^\circ956(\pm 0.^\circ045) + 0.^\circ088(\pm 0.^\circ016)m \quad (2)$$

$$W_\mathrm{d} = 0.^\circ390(\pm 0.^\circ030) + 0.^\circ029(\pm 0.^\circ013)m \quad (3)$$

$$\mathrm{FWHM} = 1.^\circ347(\pm 0.^\circ046) + 0.^\circ119(\pm 0.^\circ018)m \quad (4)$$

The units of these values are degrees except for m which is magnitude. The solar longitude is in J2000.0. With

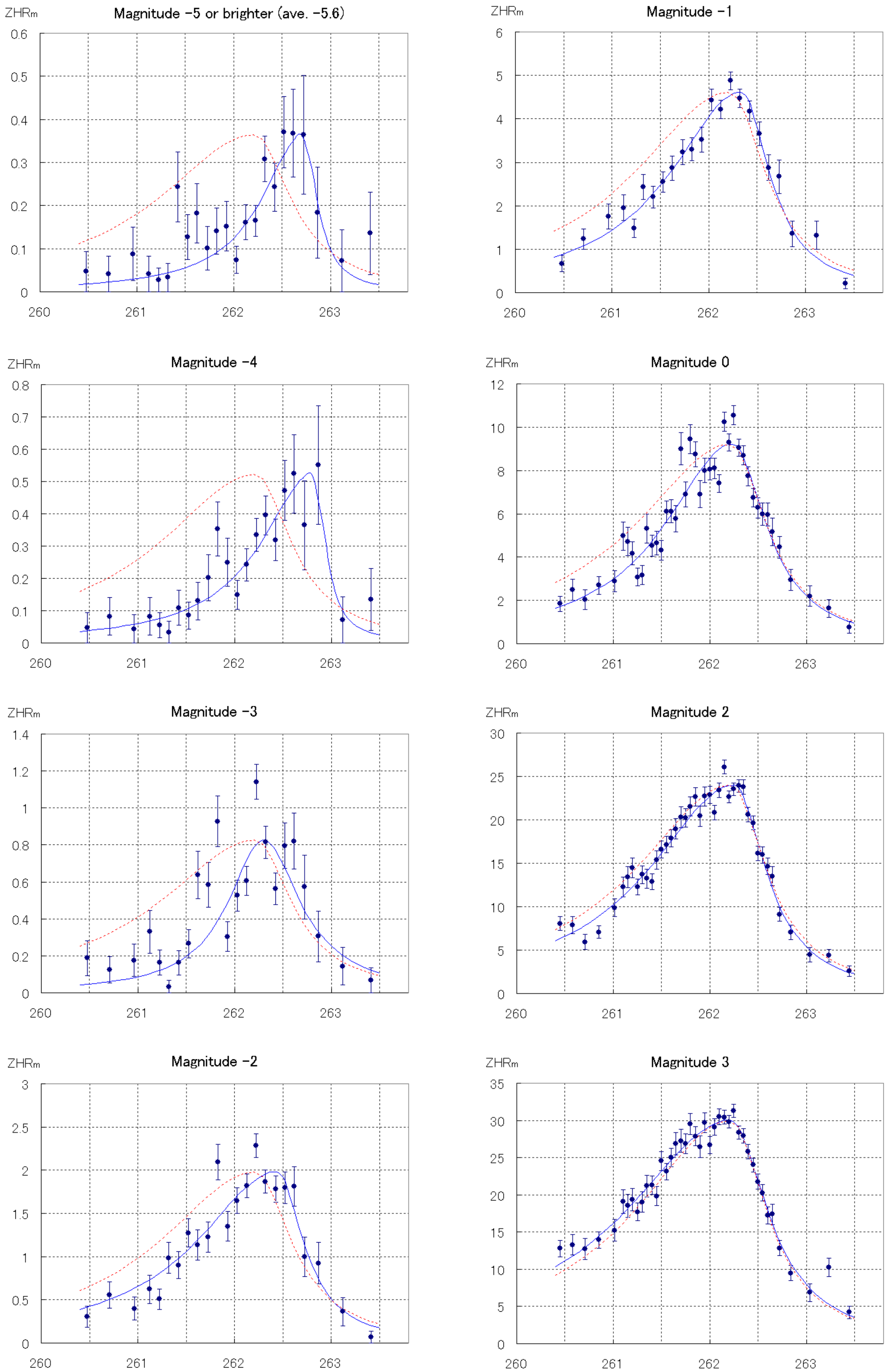

Figure 3 – ZHRs per magnitude class ZHR_m of the Geminids. The solid lines show fitted Lorentz profiles. The dotted lines show ZHR shapes with conversion ZHR maximum to the ZHR_m maximum for comparison with shapes of ZHR_m. The horizontal axes are solar longitude (J2000.0).

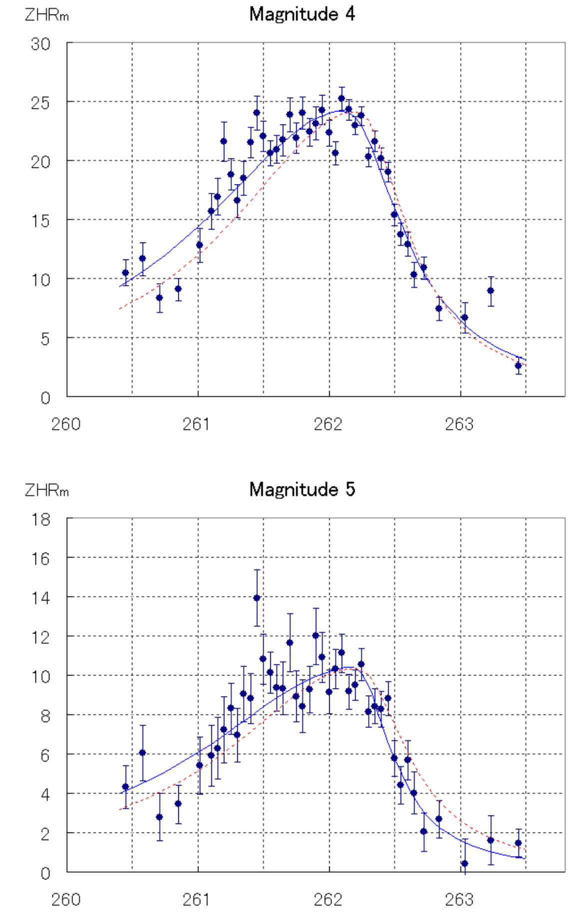

Figure 3 – Continued.

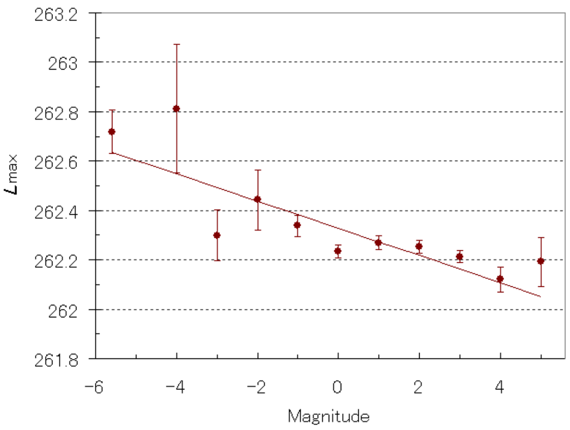

Figure 4 – Maximum solar longitude $L_{\max}$ versus meteor magnitude.

perception coefficients and $\mathrm{ZHR}_{m,\max}$, the true meteor number $\mathrm{ZHR}_{\max}$ of magnitude classes $\mathrm{ZHR}_{t,m,\max}$ were calculated. They fit a regression line well (Figure 6). The derived relation between m and $\mathrm{ZHR}_{t,m,\max}$ is

$$\mathrm{ZHR}_{t,m,\max} = 8.96(\pm 0.40) \times 2.084(\pm 0.045)^m \qquad (5)$$

6 The profile of the population index

Using equations (1) to (5), $\mathrm{ZHR}_{t,m}$ at any solar longitude can be calculated. Then the population indices

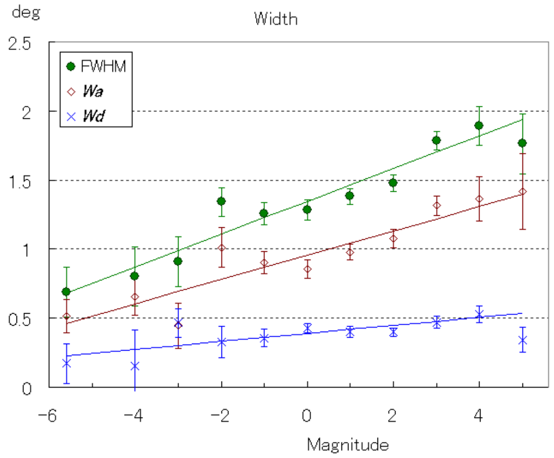

Figure 5 – Width versus meteor magnitude. FWHM are Full Width at Half Maximum, W_{a} and W_{d} are half width of ascending branches and descending branches respectively.

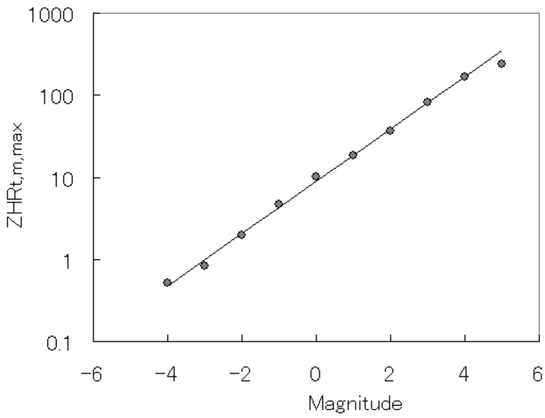

Figure 6 – True meteor number ZHR per magnitude class at maximum $\mathrm{ZHR}_{t,m,\max}$ versus meteor magnitude. They fit a regression line well.

were obtained by regression method. The profile is shown in Figure 7 (filled circles). The minimum of the population index is 1.92±0.04 at solar longitude 262.°6. This coincides with the maximum of magnitude −5. Since bright meteor activities fall steeply after their maximum, the population index goes up again after the minimum. The population index profile in Rendtel (2004) is also shown in Figure 7 (open triangles). He derived the profile from moonless returns of the Geminids between 1988 and 1997. The profile corresponds to the one in this work well.

If the P–R effect had no affect on the Geminids, all magnitude meteors would have same maximum time. In that case, the population index at the ZHR maximum would be 2.08±0.05 from equation (5). Since brighter meteors show shorter profile widths, the total numbers of meteoroids per magnitude classes of the shower are not proportional to the $\mathrm{ZHR}_{t,m,\max}$, but are proportional to the FWHM times the $\mathrm{ZHR}_{t,m,\max}$. The averaged population index of the Geminids during the whole activity period can be calculated as 2.28.

Table 1 – Comparison with other work's maximum solar longitude $L_{\max}$ that are expressed by equations $L_{\max} = L_0 + Am + Bm^2$. Here m means meteor magnitude. Solar longitudes are converted in J2000.0.

	method	L_0	A	B
McIntosh & Šimek (1980)	radar	$262\overset{\circ}{.}0$	$-0\overset{\circ}{.}135$	
Šimek et al. (1982)	radar	$261\overset{\circ}{.}99$	$-0\overset{\circ}{.}118$	
Šimek & McIntosh (1989)	radar	$262\overset{\circ}{.}04$	$-0\overset{\circ}{.}11$	
Pecina & Šimek (1999)	radar	$262\overset{\circ}{.}15 \pm 0\overset{\circ}{.}07$	$-0\overset{\circ}{.}15 \pm 0\overset{\circ}{.}07$	$-0\overset{\circ}{.}04 \pm 0\overset{\circ}{.}02$
Spalding (1984)	visual	$262\overset{\circ}{.}25 \pm 0\overset{\circ}{.}05$	$-0\overset{\circ}{.}078 \pm 0\overset{\circ}{.}025$	
This work	visual	$262\overset{\circ}{.}328 \pm 0\overset{\circ}{.}033$	$-0\overset{\circ}{.}055 \pm 0\overset{\circ}{.}014$	

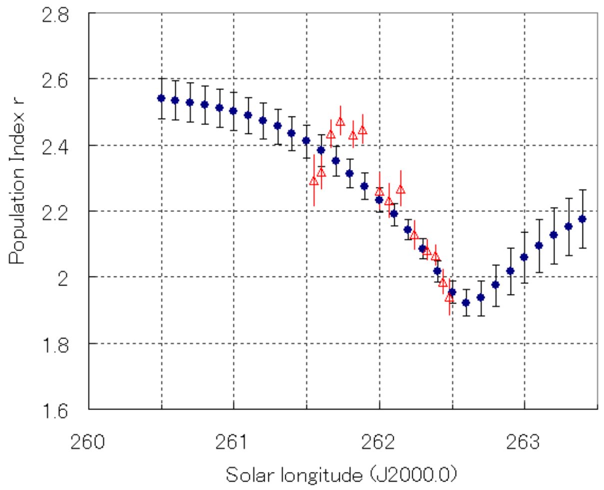

Figure 7 – Profile of the population index of the Geminids. The profile was obtained using the equations (1) to (5) (filled circles). Open triangles show population index by Rendtel (2004). He derived the profile from moonless returns of the Geminids between 1988 and 1997.

7 Comparison with other works

Several studies concerning the maximum times and the activity widths as a function of dust grain sizes of the Geminids have been conducted by radar and visual observations (Tables 1 and 2). They showed that larger meteoroids have later maximum times even though the published times show some scatter. In comparison with these radar observations, the visual observations show that the L_0 (maximum solar longitude of magnitude 0) are late and the A (change rates with magnitude) are small. Although the W_0 (FWHM of magnitude 0) of radar observations correspond to that of visual, the C (change rate with magnitude) of radar observations is large. These radar data used radio magnitude M_r. These results indicate that the radio magnitude do not correspond to visual magnitude well.

8 Conclusion

ZHRs per magnitude class ZHR_m of the Geminids were derived from VMDB available at the IMO website. The profiles show that brighter meteors have later maximum and narrower width. The relations are

$$L_{\max} = 262\overset{\circ}{.}328(\pm 0\overset{\circ}{.}033) - 0\overset{\circ}{.}055(\pm 0\overset{\circ}{.}014)m \quad (6)$$

$$\mathrm{FWHM} = 1\overset{\circ}{.}347(\pm 0\overset{\circ}{.}046) + 0\overset{\circ}{.}119(\pm 0\overset{\circ}{.}018)m \quad (7)$$

The units of these values are degrees except for m which is magnitude. The solar longitude is in J2000.0. The profile of the population index was also obtained and shows a minimum of 1.92±0.04 at solar longitude $262\overset{\circ}{.}6$.

Table 2 – Comparison with other work's FWHM that are expressed by equations FWHM$=W_0 + Cm$.

	method	W_0	C
Šimek & McIntosh (1989)	radar	$1\overset{\circ}{.}36$	$+0\overset{\circ}{.}42$
This work	visual	$1\overset{\circ}{.}347 \pm 0\overset{\circ}{.}046$	$+0\overset{\circ}{.}119$

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Handling Editor: John Correira

Preliminary results

Results of the IMO Video Meteor Network — November 2009

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

Despite the poor weather, 23 observers operating 38 video cameras could cover all nights of November 2009 with video meteor observations. About 2 200 hours of video observations were made in which more than 10 000 meteors were recorded. The Leonids were covered well despite unfavorable timing of the outburst. The activity profile of the Leonids is presented, with a detailed analysis of the descending branch profile. The appearance of apparently slow meteors from radiants close to the Apex area, appearing around Solar longitudes 235° to 236° is also discussed.

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1 Introduction

The observing conditions deteriorated significantly in November after the weather had been highly cooperative for three months in a row. In particular south European observing sites, which where privileged so far, enjoyed only a few clear nights, whereas the weather was still acceptable at the more northern locations. Beside the two American observers who enjoyed perfect conditions again, there were only three cameras with twenty or more observing nights. In particular, the first part of the month was poor. Weather improved in the second ten days of the month just in time for the Leonids, but towards the end of the month the situation became worse again. Thanks to the large number of cameras, we still collected over 2 200 hours of effective observing time and 10 000 meteors (Table 1 and Figure 1).

2 Leonids

The Leonids were once more the highlight of November. The predictions from different researchers promised ZHRs beyond 150 in the night of November 17/18 (McBeath, 2009; Vaubaillon, 2009; Maslov, 2009; Lyytinen & Nissinen, 2009). The peak was confirmed by the preliminary IMO analysis of visual observations (International Meteor Organization, 2009). A ZHR of almost 100 was reached at 20^{h} UT on November 17 — too early for the European video observers. The rate dropped to 40 until midnight with two minor peaks at 23^{h} and 01^{h} UT.

Figure 2 gives the complete Leonid activity profile from our November video data. For each night, the number of Leonids was divided by the number of sporadic meteors and averaged over all cameras. First Leonid activity occurred on November 10. As expected, peak activity was detected in the night of November 17/18 — the only night when more Leonids were recorded than sporadics. Thereafter, the activity declined rapidly and around November 22 the shower was essentially gone.

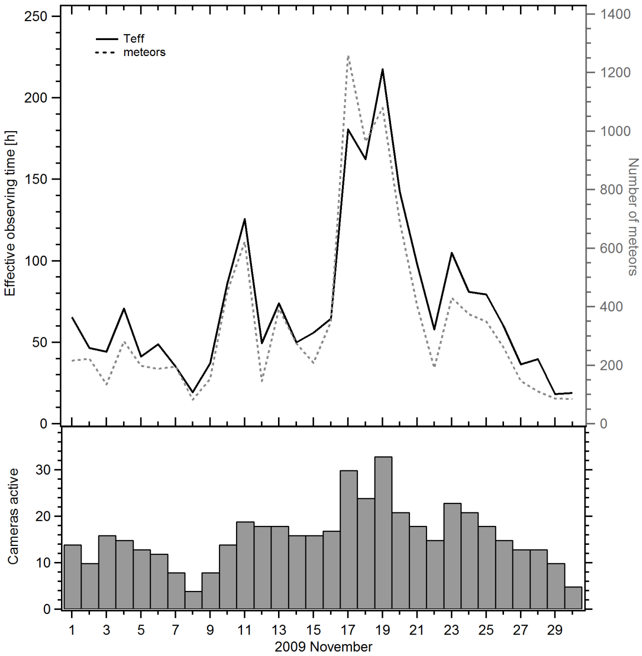

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2009 November.

Figure 3 shows the detailed profile from the morning of November 18. Here, a subset of 17 cameras was selected that enjoyed clear skies for a longer period of time. The number of Leonids was counted in half hour intervals and corrected for the radiant altitude. Unfortunately, only the time interval $00^{\mathrm{h}}30^{\mathrm{m}}$–$05^{\mathrm{h}}00^{\mathrm{m}}$ UT could be reasonably covered, i.e. after the peak. During that time, the Leonid activity drops slowly. For comparison, the preliminary visual profile is overlayed, which shows the same trend. That is about all we can read out of the video data.

3 Slowish meteors around Apex

Finally, we would like to discuss an interesting phenomenon. When reading our recent meteor shower analysis (Molau & Rendtel, 2009), the Japanese video observer SonotaCo stumbled over two strange points in the radiant plot. The figure that shows the difference between the ecliptical longitude of the radiant and the

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IMO bibcode WGN-381-molau-vidnov
NASA-ADS bibcode 2010JIMO...38...36M

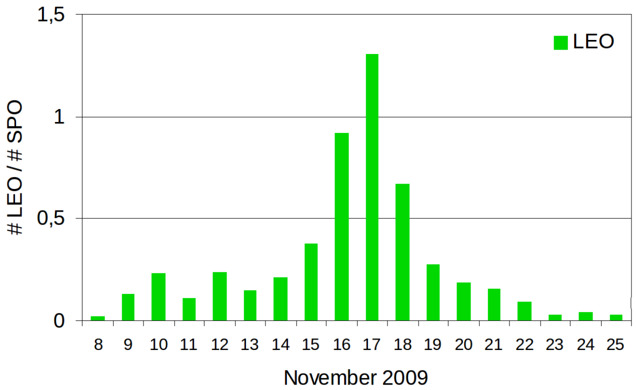

Figure 2 – Activity profile of the Leonids in 2009 November.

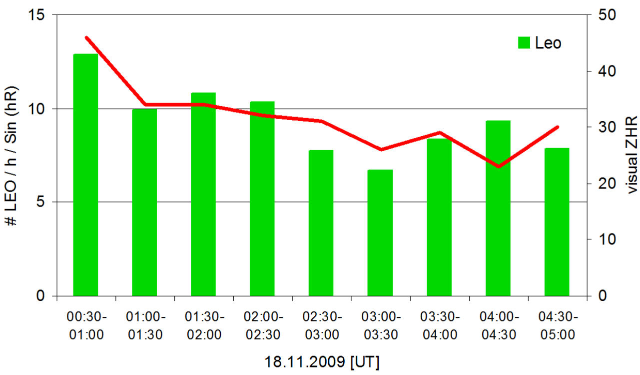

Figure 3 – Detailed activity profile of the Leonids from the morning of 2009 November 18 (bars). The preliminary visual ZHR profile of IMO is shown as a line.

solar longitude against the ecliptical latitude (Figure 4), has a concentration of Apex radiants at about 270 degrees. For geometric reasons they are of high velocity, which is why they are mainly plotted in purple. However, there are also two single yellow dots (Figure 5), i.e. two relatively strong radiants with a significantly lower velocity.

A detailed analysis revealed that these two radiants occurred at solar longitudes 236° and 237° with a position of $\alpha = 161°$, $\delta = 16°–17°$ and a velocity of 52 km/s. The radiant was the third strongest source in both intervals (1 200 meteors in total) comparable to the Northern and Southern Taurids. The temporal proximity and the position only a few degrees away from the Leonid radiant suggested these to be artifacts from the Leonids. But how should they arise?

Our first suspicion was, that one camera was incorrectly calibrated during the Leonid storms.

Spot checks revealed, however, that the meteors belonging to these radiants were recorded in different years by different cameras. Remarkably, many of them came from image-intensified cameras (no wonder given that these provided the majority of data from the Leonid storms) and occurred near the edges of field of view. Larger position and velocity errors are expected there, because the image distortion of intensifiers is much stronger at the edges. But why should these meteors form a distinct pseudo radiant instead of random scatter around the Leonid radiant? A few meteors occurred

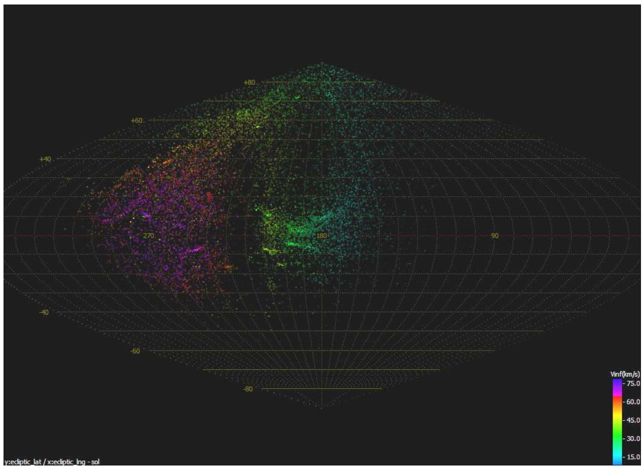

Figure 4 – Radiant plot from the comprehensive IMO meteor shower analysis (Molau & Rendtel, 2009). The x-axis represents the difference between the ecliptical radiant longitude and the solar longitude, the y-axis the ecliptical latitude of the radiant. The radiant velocity is coded by color and the strength by intensity.

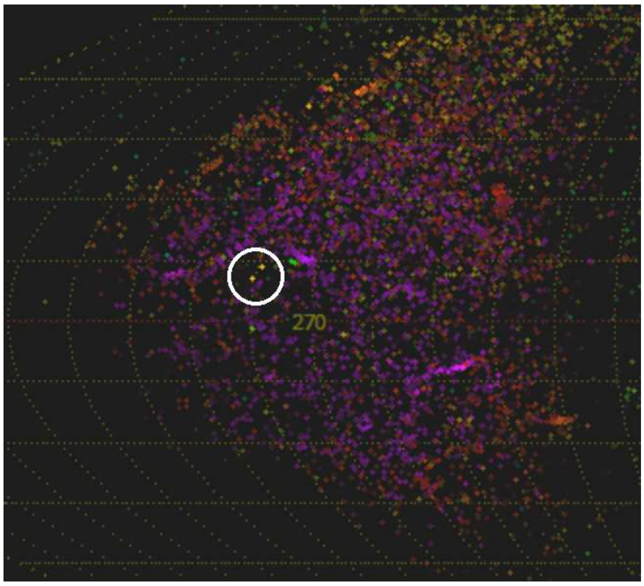

Figure 5 – Magnification from Figure 4 with two unusual radiants in the Apex region.

in line with the original and the "pseudo" Leonid radiant, but there were also high quality meteors (near the center of field of view, many frames, good astrometry) showing a clear velocity deviation (about 10% relative) compared to the Leonids.

Thus, given the current state of affairs, these two spots are most likely a Leonid artifact, but we have no explanation for their origin.

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Table 1 – Observers contributing to November 2009 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	33.5	116
			TIMES5 (0.95/50)	⊘ 10°	3 mag	19	37.2	96
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	19	53.4	327
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	16	94.8	296
			BMH2 (0.8/6)	⊘ 55°	3 mag	15	100.7	392
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	14	102.8	537
			STG38 (0.8/3.8)	⊘ 80°	3 mag	12	18.5	34
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	5	23.9	83
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	9	31.3	141
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	15	50.8	199
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	14	85.0	457
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	26	127.7	439
			SALSA2 (1.2/4)	⊘ 80°	3 mag	25	155.1	643
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	13	73.0	348
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	12	47.3	294
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	10	65.8	616
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	10	67.9	231
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	13	43.0	105
		Kamnik	STEFKA (0.8/3.8)	⊘ 80°	3 mag	5	13.2	38
KOSDE	Koschny	Noord-wijkerhout	TEC1 (1.4/12)	⊘ 30°	4 mag	8	30.6	81
			TRON1 (1.4/12.5)	⊘ 30°	3 mag	3	6.2	13
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	23	166.9	1 019
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	11	68.0	793
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	22	134.3	655
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	20	70.8	325
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	16	66.2	296
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	16	89.1	363
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	22	68.8	272
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	10	63.2	292
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	8	43.4	229
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	9	30.6	112
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	8	40.3	227
STORO	Stork	Ondrejov	OND1 (1.4/50)	⊘ 55°	6 mag	1	3.2	34
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	13	27.5	107
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	4	7.2	21
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	8	26.0	144
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	6	23.9	93
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	5	20.7	78
					Overall	30	2 211.8	10 546

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Handling Editor: Javor Kac

Results of the IMO Video Meteor Network — December 2009

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

The weather in 2009 December was poor again. Nonetheless, 23 observers operating 38 video cameras covered all nights. The Network's cameras operated for more than 2 300 hours and recorded almost 14 000 meteors. The Geminids activity profile is presented, as well as a high-resolution profile from December 13/14. The annual overview of the IMO Video Meteor Network's statistics for 2009 is also presented.

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1 Introduction

In December 2009 the weather was little co-operative with the observers. Towards the middle of the month, skies cleared at many sites and allowed a few Geminids to be caught, but before and after that many observers waited unsuccessfully for clear skies. Particularly poor was the situation at the end of the month. On December 21, 29 and 31 we collected less than 10 observing hours and 20 meteors. Our break-free observing series that started in mid 2007 came almost to an end. Still, we collected over 2 300 hours of effective observing time and almost 14 000 meteors (Figure 1 and Table 4).

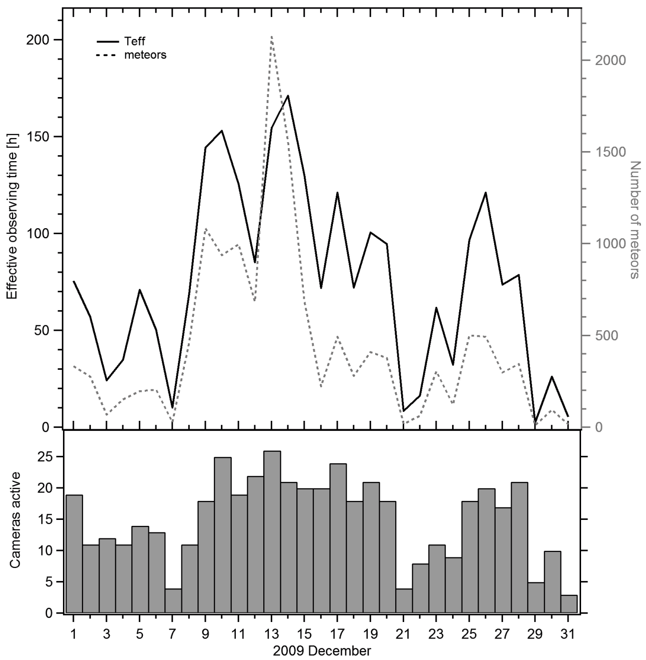

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2009 December.

2 Geminids

A closer look at the Geminds activity (Figure 2) shows the long-term activity profile between December 4 and 16. As usual, the number of shower meteors was divided by the number of sporadics per night and averaged over all cameras. The well-known fact that the Geminid activity profile has a soft slope towards the maximum, but a steep decrease thereafter, was confirmed again.

Highest activity was reported in the night of December 13/14. Five cameras, (Albiano, Doraemon, Finexcam, Templar1 and Templar2) enjoyed almost cloud-free skies that night. In the detailed analysis (Figure 3), the number of Geminids was determined in half-hour intervals, corrected by the radiant altitude, and averaged over all five cameras. The resulting profile is non-obvious: The activity rises in the early evening, then remains at a high level with significant dips at 21^{h}, 23^{h} and 03^{h} UT. The preliminary IMO ZHR profile from visual observations (International Meteor Organization, 2010) is plotted for comparison. In the visual activity prodile, the overall rate remains at a high level as well. Similarly to the video profile, the early hours show a rise in activity and a dip around 03^{h} UT. Dips at

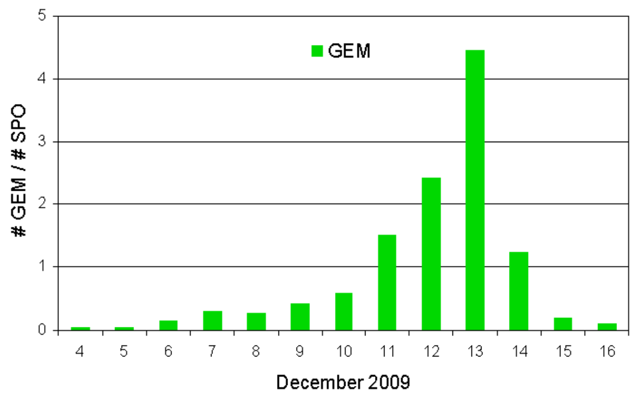

Figure 2 – Activity profile of the Geminids in 2009 December.

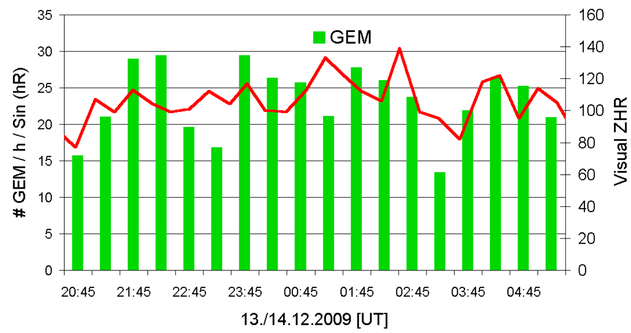

Figure 3 – Detailed activity profile of the Geminids on 2009 December 13/14 (bars). The preliminary visual ZHR profile from the IMO (2010) is shown as a line.

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NASA-ADS bibcode 2010JIMO...38...39M

21^h, 23^h present in the video results are not confirmed by the visual data.

3 2009 statistics

Finally the overall statistics of 2009: Thanks to the continuing growth of the IMO Video Meteor Network and three months with particularly good observing conditions (August–October), we achieved several observing records as reported earlier (Molau & Kac, 2009a; Molau & Kac, 2009d; Molau & Kac, 2009c). The overall result was also better that in any other year before. In the course of 2009, 24 observers (2008: 24) from 10 countries (2008: 10) contributed with a total of 43 camera systems (2008: 37) to the IMO network. Most cameras are located in Central Europe as before, but there are also three systems in the USA. Almost all cameras are automated by now. There was hardly any observer who contributed data in only selected nights, and each observer recorded at least a thousand meteors.

As in the previous year (Molau & Kac, 2009b), we managed to record meteors in any given night. The effective observing time increased by 40% to over 32 000 hours (2008: 23 000) and the number of meteors by even 50% to over 138 000 (2008: 92 000). Hence, the efficiency of the camera systems also increased slightly to an average of 4.3 meteors per hour (2008: 4.0). The Italian observers had a particular share in those results, as will be reported later.

Looking at the distribution of observations over the year, the months August to October are particularly present with 3 900 to 4 500 observing hours. From July on, we recorded more than 10 000 meteors in all months; the absolute maximum was reached in August with more than 30 000 meteors. Least observations were obtained in February and June. Table 1 lists the distribution of observations over the individual months.

The number of observers with 200 and more observing nights almost doubled in 2009 to 11 (2008: 6). Once more, Sirko Molau was on top of the list with 324 nights, 8 less than in the year before. Carl Hergenrother barely missed the 300 nights, and he was followed by Stefano Crivello, Rui Goncalves and Bernd Brinkmann. Enrico Stomeo ranked "only" seventh with 231 nights, but he almost made it to the top with respect to the number of recorded meteors. In the end, he fell just 6% or 1 300 meteors short of Sirko Molau, who has been leading the statistics since 2003. That is in particular surprising given that Enrico operated one camera less and all of his cameras run without an image intensifier. The secret of his success are the perfect weather conditions and the amazing sensitivity of his Mintron cameras. Min38 and Sco38 yielded an average of 5.8 and 6.8 meteors per hour, respectively, which is not too distant from the most sensitive intensified camera systems Avis2 (11.5) and Betsy2 (8.4). Stefano Crivello got an incredible yield with his camera C3P8 as well. The details for the individual observers are given in Table 2.

The TOP 10 of the camera systems has changed significantly last year (Table 3). Thanks to the perfect observing conditions in Tucson, Carl Hergenrother's Salsa ranked first in 2009. The previously best camera Remo2 near Berlin is only in fourth place behind C3P8 in Valbrevenna. This camera collected most observing hours of all and missed the meteor count of the best intensified camera (Avis2: 8471 meteors) by just 200.

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Figure 4 – This bright Geminid fireball (maximum magnitude about −8) was captured on 2009 December 14 at 21^h10^m UT by the IMO Video Meteor Network camera Min38 from Scorze (near Venice), Italy.
Photo courtesy: Enrico Stomeo.

Table 1 – Monthly observing statistics for the IMO Video Meteor Network in 2009.

Month	# Observing Nights	Eff. Observing Time [h]	# Meteors	Meteors / Hour
January	31	2 559.8	9 425	3.7
February	28	1 745.4	3 585	2.1
March	31	2 126.8	4 185	2.0
April	30	2 290.9	5 638	2.5
May	31	2 015.0	4 771	2.4
June	30	1 488.6	3 795	2.5
July	31	2 788.1	13 795	4.9
August	31	4 523.8	30 717	6.8
September	30	4 080.3	15 490	3.8
October	31	3 895.4	22 002	5.6
November	30	2 290.4	10 895	4.8
December	31	2 339.4	13 853	5.9
Overall	365	32 143.9	138 151	4.3

Table 2 – Individual observer's statistics for the IMO Video Meteor Network in 2009. The number of cameras and stations refer to the main part of the year.

Observer	Country	# Observing Nights	Eff. Observing Time [h]	# Meteors	Meteors / Hour	Cameras (Stations)
Sirko Molau	Germany	324	3 974.4	20 454	5.1	4 (2)
Carl Hergenrother	USA	295	2 276.7	5 956	2.6	2 (1)
Stefano Crivello	Italy	278	2 292.7	11 357	5.0	2 (1)
Rui Goncalves	Portugal	252	2 998.3	11 807	3.9	2 (1)
Bernd Brinkmann	Germany	247	1 033.4	4 387	4.2	1 (1)
Javor Kac	Slovenia	240	2 380.0	6 806	2.9	4 (3)
Enrico Stomeo	Italy	231	3 268.8	19 187	5.9	3 (1)
Paolo Ochner	Italy	229	1 236.7	4 128	3.3	1 (1)
Jörg Strunk	Germany	220	1 850.4	6 837	3.7	3 (1)
Flavio Castellani	Italy	212	2 206.5	6 563	3.0	2 (1)
Robert Lunsford	USA	201	1 277.9	6 750	5.3	1 (1)
David Przewozny	Germany	167	692.6	2 478	3.6	1 (1)
Mitja Govedič	Slovenia	158	812.9	3 781	4.7	1 (1)
Stane Slavec	Slovenia	149	535.0	1 195	2.2	1 (1)
Wolfgang Hinz	Germany	144	731.8	3 012	4.1	1 (1)
Ilkka Yrjölä	Finland	129	750.5	3 420	4.6	1 (1)
Maurizio Eltri	Italy	123	749.4	3 317	4.4	1 (1)
Klaas Jobse	Netherlands	123	722.0	6 104	8.5	1 (1)
Antal Igaz	Hungary	113	662.6	2 450	3.7	1 (1)
Hans Schremmer	Germany	108	498.1	2 204	4.4	1 (1)
Detlef Koschny	Netherlands	102	384.8	1 537	4.0	2 (1)
Orlando Benitez-Sanchez	Spain	95	430.7	1 271	3.0	2 (1)
Istvan Tepliczky	Hungary	49	300.2	1 183	3.9	1 (1)
Rosta Stork	Czech Republic	10	77.5	1 967	25.4	2 (2)

Table 3 – TOP 10 camera systems of the IMO Video Meteor Network in 2009.

Camera	Observing Site	Observer	# Observing Nights	Eff. Observing Time [h]	# Meteors	Meteors / Hour
SALSA	Tucson (US)	Carl Hergenrother	287	1 501.2	3 253	2.2
C3P8	Valbrevenna (IT)	Stefano Crivello	264	1 626.0	8 260	5.1
REMO1	Ketzür (DE)	Sirko Molau	258	1 108.5	3 506	3.2
REMO2	Ketzür (DE)	Sirko Molau	258	1 085.5	4 459	4.1
HERMINE	Herne (DE)	Bernd Brinkmann	247	1 033.4	4 387	4.2
TEMPLAR2	Tomar (PT)	Rui Goncalves	246	1 432.8	4 642	3.2
MINCAM1	Seysdorf (DE)	Sirko Molau	242	1 046.1	4 018	3.8
ALBIANO	Albiano (IT)	Paolo Ochner	229	1 236.7	4 128	3.3
TEMPLAR1	Tomar (PT)	Rui Goncalves	225	1 565.5	7 165	4.6
MIN38	Scorce (IT)	Enrico Stomeo	217	1 356.1	7 862	5.8

Table 4 – Observers contributing to December 2009 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	41.0	301
			TIMES5 (0.95/50)	⊘ 10°	3 mag	7	11.2	38
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	18	85.6	445
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	23	142.0	524
			BMH2 (0.8/6)	⊘ 55°	3 mag	21	145.5	699
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	19	149.9	1435
			STG38 (0.8/3.8)	⊘ 80°	3 mag	12	54.9	224
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	6	32.9	194
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	8	62.2	545
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	14	75.0	646
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	18	54.8	193
HERCA	Hergenrother	Tucson	SALSA (1.2/4)	⊘ 80°	3 mag	27	127.3	364
			SALSA2 (1.2/4)	⊘ 80°	3 mag	12	74.1	298
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	2	16.3	104
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	13	16.6	55
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	10	66.5	695
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	1	8.0	20
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	10	16.2	42
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	6	31.1	150
		Kamnik	STEFKA (0.8/3.8)	⊘ 80°	3 mag	5	29.8	141
KOSDE	Koschny	Noord-wijkerhout	TEC1 (1.4/12)	⊘ 30°	4 mag	10	36.8	185
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	18	127.3	590
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	7	29.6	345
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	21	67.5	379
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	17	41.3	108
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	13	22.6	112
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	25	166.3	817
PRZDA	Przewozny	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	15	51.9	251
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	22	96.2	601
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	8	25.6	92
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	16	102.5	854
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	1	2.7	9
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	17	127.0	1 166
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	15	35.5	124
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	6	12.4	47
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	10	35.7	149
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	3	21.4	70
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	10	96.2	841
					Overall	31	2 339.4	13 853

On the Likeness of Denning

Martin Beech [1]

Reproductions of the six known photographic images of W. F. Denning are presented and their circumstances described. A caricature cartoon relating to Denning's discovery of Comet C/1892 F1 is also presented, and the emergence of Denning as a popular, even iconic public figure is briefly discussed.

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1 Introduction

William Frederick Denning (1848–1931) figures prominently in the history of late nineteenth-century meteor astronomy. He was an amateur observer of international renown, and later in life was celebrated with many prestigious awards (Beech, 1998a). His preeminence among meteor observers dates from the late 1890s through to the 1920s and was fueled by an indefatigable approach to observing, a massive correspondence of letters, and the publication of numerous notes and articles in all of the scientific journals and magazines of the day (Beech, 1991). Much has been written about Denning as one of the Grand Amateurs of late Victorian England (Beech, 1998a; Chapman, 1999), and he is remembered not just for his meteor work, but for the discovery of several comets, a new nova in Cygnus, the charting of many faint nebulae, and his long-running series of planetary observations and transit time recordings (Beech, 1998a; Beech, 1998b; Beech, 1993). For all his fame, however, very little is known about Denning's private life and early childhood. Indeed, hardly anything is known about how he lived and how he made a living. The very first entry for the accounting firm of *Denning, Smith and Co.* is contained in the Bristol Registry for 1856, and it must have been at about this time that the Denning family, a young, 8-year old William in tow, moved

Figure 1 – The earliest known formal portrait of Denning. The picture was taken by photographer J. Webb of Bristol in 1896.

Figure 2 – A dapper looking Denning portrayed at his telescope. This photograph has an uncertain date, but was probably taken circa 1885. Denning is shown with the 10-inch With-Browning telescope that he had purchased in 1871.

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Figure 3 – Denning is shown in this image with the celestial globe and meteor wand that he used to record meteor paths with. The celestial globe was constructed by the company of John and William Cary and is currently housed at Burlington House, forming part of the archive of the Royal Astronomical Society. The Carys were preeminent among British globe makers at the turn of the 18th century, and the globe would have been one of Denning's prized possessions. The image is signed and dated April 1926. The globe was donated to the RAS by Mary Willetts (Denning's younger sister Mary Eveline Poyntz Denning—born 1856) in 1942.

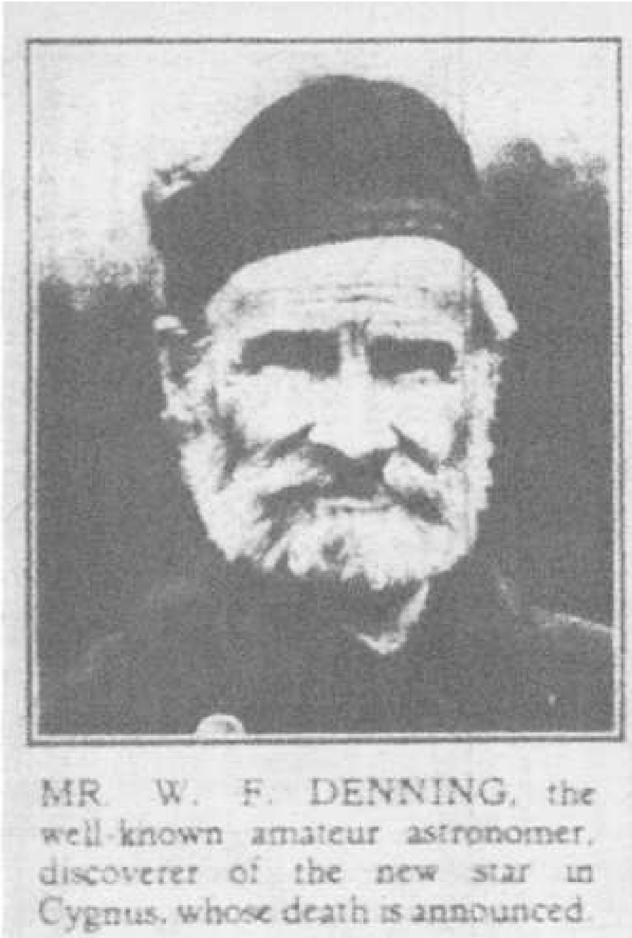

Figure 4 – Image published in the *Times of London* newspaper for Thursday, June 11th, 1931. The felt hat and facial features appear similar to those seen in Figure 3, and the photograph may well have been taken at the same time as that image.

away from the village of Wellow (near Radstock in Somerset) to the City of Bristol. It was at this time that Denning's father, Isaac Poyntz Denning, set up in partnership as an accountant. After this move, we find no recorded trace of Denning's life and activities until 1868, at which time he would have been 20-years old, and when he published, in the *Astronomical Register* (the journal of the short-lived Observational Astronomical Society) his very first research letter relating to observations of Jupiter's satellites.

Denning, as a person, is a shadowy figure. We know when and what he published and how many medals and awards he received in later life, but we know little of what he looked like and his everyday existence. Pictures of Denning do survive, however, but most were taken in his mid-life to twilight years.

2 A gentleman observer

To the author's knowledge, only six pictures of Denning survive. There are probably more photographs within various newspapers and magazines, but they have yet to be unearthed and identified. The earliest known portrait photograph of Denning with a well-recorded date is shown in Figure 1. The image is attributed to the photographer J. Webb of Bristol, and was taken in 1896—when Denning was 48 years old. The image was reproduced on the inside dust-cover of Denning's book *The Great Meteoric Shower of November*, published in 1897, and the portrait may well have been taken to illustrate this text. Denning sent a copy of this picture to his long-time correspondent Alexander Herschel, who wrote to Denning on June 14, 1896, thanking him for the receipt of the "very agreeable portrait of yourself" (Beech, 1991). The picture was also used to illustrate Hector Macpherson Jr.'s biographical account of Denning published in 1905 (Macpherson, 1905).

What is probably the earliest image of Denning is reproduced in Figure 2. This undated "action shot" was most likely taken circa 1885, when Denning would have been in his late thirties. The latest possible date for the image is circa 1906, since Denning announced at that time he was no longer going to pursue his telescopic work (Beech, 1990). The very earliest time that the image could have been taken was 1871, when Denning purchased the telescope shown and at which time he would have been 23 years old. The figure at the telescope, however, appears much older than someone

Figure 5 – Participants attending the plaque unveiling ceremony at 44 Egerton Road, Bristol, on December 18th, 1931. To the right is Dr. Henry Knox-Shaw of the Radcliffe Observatory, Oxford, and the then President of the Royal Astronomical Society. To the left (checking his notes) is Mr. Norman Langley Denning. Closest to the window, in a rain coat, is Professor Lennard-Jones of Bristol University, and next to him is Christine Gravely (daughter of Denning's older sister Ellen Louisa Denning). The gentleman still wearing his hat is probably Frederick Denning (Denning's younger brother, born 1850). The gentleman to the far left facing the camera is Ernst Edward Denning, and the woman facing the camera is possibly Mary Willetts.

in his early 20s and hence my estimate for circa 1885. It is not clear where the photograph was taken, other than in the Bristol area. In the 1880 Bristol Directory, Denning is listed as living at Tyndale House in Ashley Down (a northern suburb of Bristol). Ten years later, he is listed as living at Hanley Villa, 17 Berkeley Road, in Bishopston (close to Ashley Down).

The last known image (Figure 3) of Denning is dated April, 1926, and shows a fragile looking man, then well into his late seventies, with his left hand placed upon a large Cary Celestial Globe and his right hand holding a meteor wand used as an aid to fix the position of meteors on the sky. This image of Denning was taken at his 44 Egerton Road, Bishopston address—which he moved to in 1906. A similar facial image, quite possibly taken at the same time as Figure 3, accompanied Denning's obituary by Sir Henry Maddocks in the June 11th, 1931 edition of the *Times of London* newspaper (Figure 4).

Figure 3 is taken from the *In Memoriam* folder presented to the participants at a ceremony unveiling a plaque in honor of Denning at his Egerton Road address on December 18th, 1931 (Figure 5). Many of his close relatives can be identified in Figure 5,

A second formal portrait of Denning (Figure 6), again taken by J. Webb in Bristol, has survived and is dated 1904. The only other known image of Denning was taken in August 1924. This latter picture shows a seated, 76-year old Denning in the backyard at 44 Egerton Road accompanied, once again, by his Cary Celestial Globe (Figure 7).

3 Comet C/1892 F1(Denning) and popular culture

Figure 8 first appeared in *Punch* magazine for April 9th, 1892. The image is entitled *A New Comet*, and accompanies a very short note which reads "Mr. Denning, whose name is well known as a comet-finder, discovered a *small* FAINT *Comet* on Friday, March 18, at Bishopton [sic], Bristol.—Times". The *Punch* text is based upon a short article that appeared in the *Times of London* newspaper for March 22nd. The article reads, "Discovery of a comet. A circular from the Royal Observatory, Edinburgh, says on March 18 at 11.8 pm Mr. W. F. Denning telegraphed from Bristol as follows. 'Discovered small faint comet, ascension 341 deg., declination 59 N., motion rather quick eastwards'." The comet (Comet 1892b) that Denning discovered (Denning, 1892a; Beech, 1998b) on March 18th turned out to be a long-period comet that has subsequently been

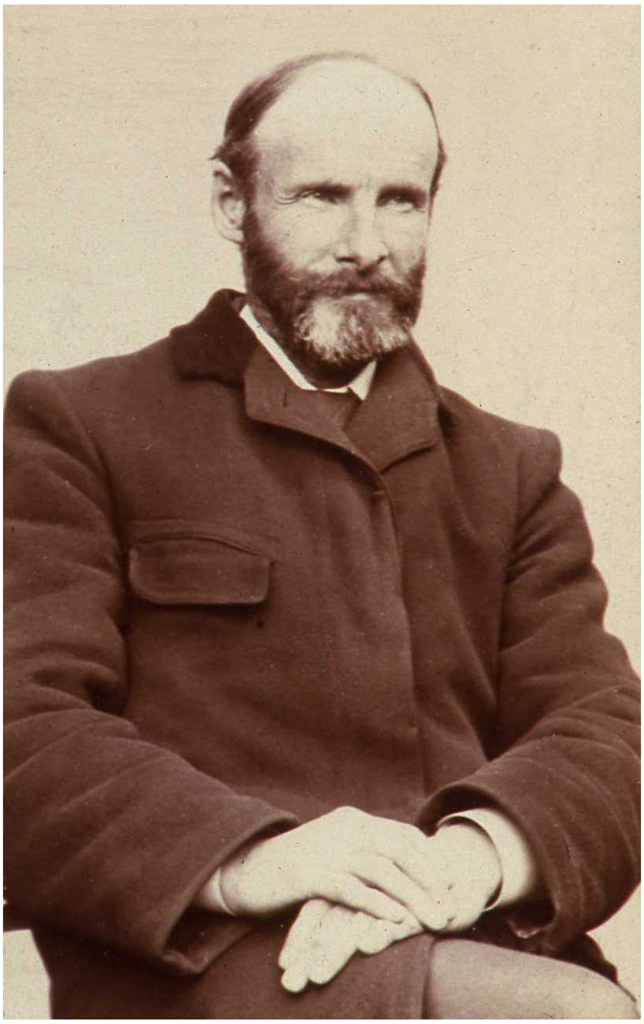

Figure 6 – Formal portrait of Denning, again by J. Webb of Bristol, dating from 1904.

assigned a slightly hyperbolic orbit. Remarkably, Denning's comet discovery was the second to be made on that night. Indeed, Rudolf Spitaler at Vienna Observatory picked up Comet 1892c at almost the very instant that Denning sent his telegram to Edinburgh—this latter detection was in fact the recovery of what is now known as periodic comet 7P/Pons-Winnecke (the parent to the June Boötid meteor shower—an association, in fact, that was first suggested by Denning). There was some initial confusion about these two comets promulgated by the Editor of *Nature* magazine (Denning, 1892b) who added a comment to Denning's discovery letter to the journal that "this is stated to be Winnecke's comet". Denning correctly pointed out in the next issue of the journal (Denning, 1892c) that two entirely different comets had, in fact, been observed. Denning was awarded the 9th Donohoe Medal of the Astronomical Society of the Pacific for his discovery.

The cartoon that accompanies the *Punch* article (Figure 8) concerning the new discovery is signed in the lower left-hand corner with a stylized "ETR", and it is accordingly attributed to Edward Tennyson Reed (1860–1933). Born in Greenwich, Edward T. Reed was son to Sir Edward James Reed, Chief Naval Architect and onetime Member of Parliament for Cardiff. Reed apparently took up drawing in 1883 after spending several years accompanying his father on tours of Egypt, China, and Japan. Encouraged by the Pre-Raphaelite artist Edward Burne-Jones, Edward Reed showed distinct promise as a caricaturist, and, in 1890, was appointed to the staff of *Punch*. Starting in 1893, Reed produced a highly popular series of humorous cartoons under the title of *Pre-historic Peeps*, in which, for the first time ever, dinosaurs were widely featured. Also in 1893, Reed took over the post of parliamentary caricaturist at *Punch*—a cherished post that he held until 1912. Reed is often described as introducing a hint of the grotesque to *Punch*, and was widely accredited with having a skilled hand at capturing facial attributes.

The key to unraveling Reed's cartoon, I believe, is in the wording that accompanies it, namely "*small* FAINT *Comet*". Indeed, the image shows the caricature of a contented observer (Denning), the happy discoverer basking in the Comet's stylized glow, and a humanized-cometary coma containing a face that is beset with a faint, even deathly expression. The humor is not exactly side-splitting. The caricature of Denning is not an obvious one given the facial features that can be discerned in his surviving photographs—the closest picture in time to Reed's rendition being that of 1896 (Figure 1). The observer's coat in Reed's cartoon, however, is distinctive and certainly similar to that worn by Denning in, e.g., Figures 3 and 7. Indeed, Denning often referred to his British Army Great Coat as an invaluable aid against the cold of a winter's night (Denning, 1891).

Edward Reed's cartoon and the mention of Denning's cometary discovery are not obvious copy for the *Punch* magazine. Indeed, *Punch* was a satirical magazine mostly concerned with the baffling intrigues of British politics. Certainly, there is no mention within the magazine of Denning's other cometary discoveries of 1881 and 1890, nor is there any mention of his co-discovery (with Edward Barnard in the United States) of Comet C/1891 F1. *Punch* magazine was not, in general, concerned with scientific matters or new discoveries, and it seems clear that the Denning piece was intended purely as humorous filler. Interestingly, the text that accompanies the cartoon comments that Denning is "well known as a comet-finder", suggesting that it was taken for granted that the general reader should have been aware of this, indicating (or at least suggesting) that Denning had a recognized name within popular British culture. This being said, it is unlikely that Denning was a recognized figure at that time—hence the less than convincing rendition of Denning's features by Reed, who was otherwise renowned for his accurate and convincing caricatures of political figures. Reed's acuity is illustrated in an earlier cartoon, also published in *Punch* magazine, and entitled *A Scientific Centenary* (Figure 9). This cartoon shows a very clear likeness of Michael Faraday addressing the muse of science. The caption to the image reads, "Faraday (returned). 'Well, Miss Science, I heartily congratulate you; you have made marvelous progress since my time'." While Faraday's features would probably have been familiar to many *Punch* readers, Denning's would most likely not have been.

Figure 7 – Denning at his Egerton Road home in August of 1924. The setting for this photograph is the same as that used in Figure 3. By this stage of his life, Denning had become a distinct recluse and was rarely seen outside of the confines of his garden (Beech, 1990).

Figure 8 – *A New Comet* by Edward Tennyson Reed. Published in the April 9th, 1892 edition of *Punch* magazine.

Figure 9 – *A Scientific Centenary* by Edward Tennyson Reed. Published in the June 27th, 1891 edition of *Punch* magazine. The rendition of Michael Faraday (1781–1867) is very convincing, and the image sets out to illustrate the many advances in communications technology that had appeared in the later half of the 19th century.

Denning's fame was certainly in its ascendency during the 1890s; in the final decade of the 19th century he would discover several new comets, and his many meteor and planetary observing reports were commonly found within the well-known journals and newspapers of the day. In addition, Denning published in 1891 the well-received (Anonymous, 1891) introductory astronomy text *Telescopic Work for Starlight Evenings*, and became the first Director of the Cometary Section of the newly formed British Astronomical Association—a post he held until 1893. Later on, towards the end of the decade and the beginning of the new century, Denning was so well known that H. G. Wells could refer to him directly (Beech, 1990), adding a nice touch of realism in Chapter 2 of his *The War of the Worlds*, published in 1898. Denning also published a brief biographical account in the large-circulation and widely-read magazine *Tit-Bits* for August 31st, 1895. This magazine specialized in human-interest stories, and it also contained short stories by leading authors of the day—H. G. Wells amongst them. Not only was Denning becoming a well-known cultural figure towards the end of the 19th century, he was also gaining increased recognition from professional organizations. He was awarded the Valz Prize of the French Academy of Science in 1895, and the Gold Medal of the Royal Astronomical Society in 1898 (Beech, 2007).

4 Concluding remarks

Few scientists every achieve both public and professional acclaim within their lifetime. While it has long been clear that Denning was a recognized and influential figure in the world of professional and amateur astronomy (Beech, 1998a; Chapman, 1999; Beech, 1990), it now begins to appear that he was also something of a recognized public persona—albeit a rather reclusive one (Beech, 1990). His name, if not likeness, was not only known to the leading astronomers from around the world, it was also known to the newspaper and general magazine reading public.

While only six photographs, and one cartoon, of Denning have been described in this article, it is my guess that many more images of Denning do exist and await (re)discovery. The most likely source for these "new" images will be the common newspapers and the general science/mechanics magazines published in the two decades surrounding the turn of the 20th century.

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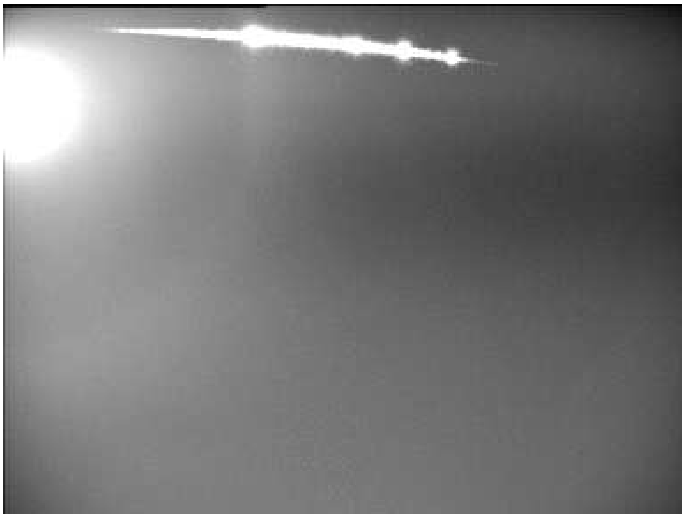
Handling Editor: Marc Gyssens

The International Meteor Organization

web site `http://www.imo.net`

Sporadic fireball



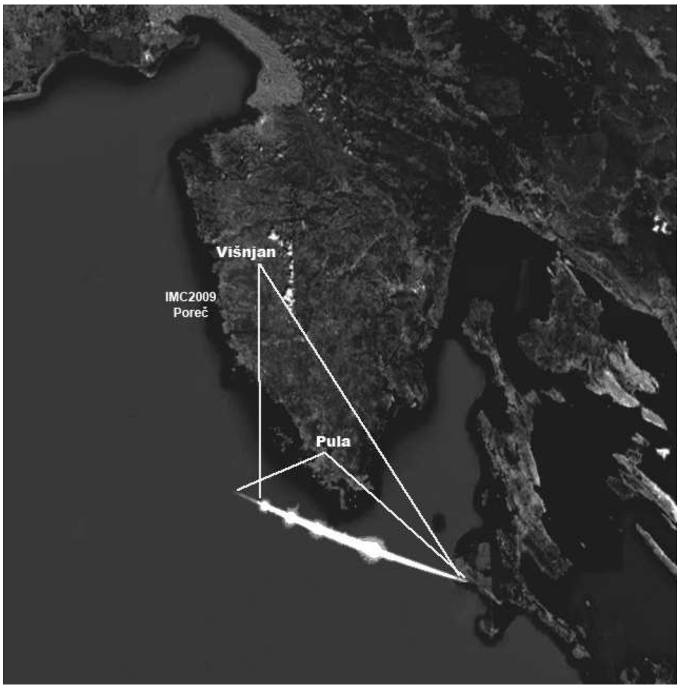
CMN_Pula_A, Damir Šegon

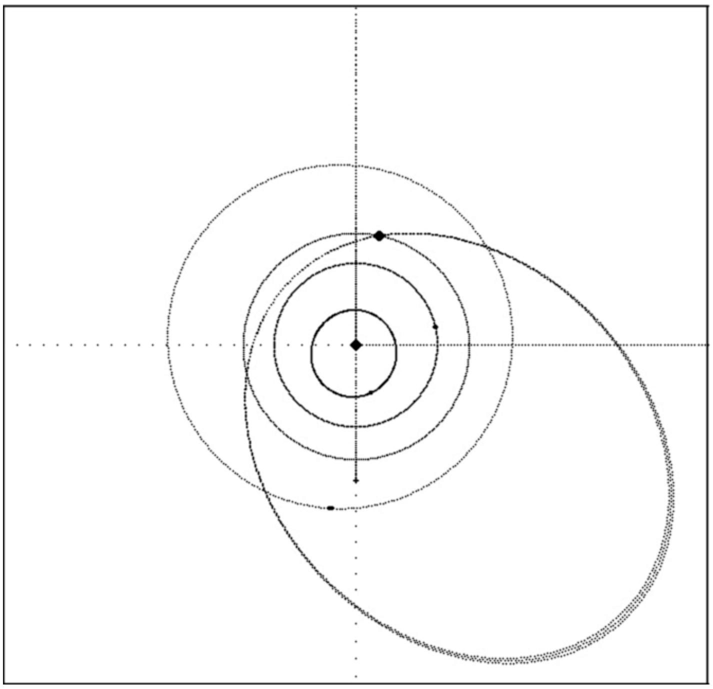
CMN_Visnjan, Maja Crnić

CMN_Merenje, Željko Andreić

CMN_Sibenik_B, Berislav Bračun

This sporadic fireball with multiple bursts was recorded by four video meteor cameras of the Croatian Meteor Network (CMN) on 2008 December 9 at $18^h21^m26^s$ UT. The fireball started 96.2 km and terminated 57.1 km above ground and lasted 3.5 s.





Ground projection of the fireball's trajectory just south of the Istria peninsula (left) and its orbit (right).