journal of the international meteor organization

WGN

34:2
april 2006

Leonids
Perseids
Instrumentation
Radio Meteor School
International Meteor Conference

ISSN 1016-3115

WGN Vol. 34, No. 2, April 2006, pp. 33 – 60

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History

Front cover photo

Meteor over the Subaru telescope on Hawaii. Photo: Nik Szymanek.

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

Editorial — Proposed research

Chris Trayner

Research often involves new initiatives, and these can be technical or administrative. Peter Zimnikoval's paper on page 45 is an example of the former, describing an ingenious device to record any polarisation of meteor light.

Meteor research also involves observing campaigns, however, and these need groups of people to be gathered and motivated to perform an organsised observing run. Such administrative initiatives, although less exciting than technical ones, are just as important. They will often be too large for a single group to undertake, and will frequently cross national boundaries.

WGN would seem to be a suitable vehicle for such suggestions. We are therefore adding a new section to the Journal, called Proposed research, to run occasionally. It is intended for people to propose well thought out research campaigns to the readership. Anyone making such a proposal should also be willing and able to administer it themselves — it is not enough to say 'here is an idea, it would be good if someone could run it'.

We start this section on page 40 with a well though out proposal from Josep Trigo Rodriguez and three other well-known researchers, calling for more multi-station work, and with concrete observational objectives.

WGN would be happy to receive other equally well designed proposals.

IMO bibcode WGN-342-editorial NASA-ADS bibcode 2006JIMO...34...33T

Order your copy of the Radio Meteor School 2005 Proceedings now!

The Radio Meteor School organizing committee

Prior to the IMC 2005 in Oostmalle, IMO organized the Second Radio Meteor School. The main goal was to get acquainted with the radio meteor theory developed by professor Oleg Belkovich and his team at the observatory of Kazan University. This theory allows one to determine the shower meteoroid flux density and mass index from properly acquired radio meteor echo counts.

The Proceedings of the Radio Meteor School 2005 will be published shortly. Those interested in getting a copy should contact Jean-Marc Wislez (`jmw@urania.be`). This will allow us to estimate better the number of hard-copies to be printed.

The Proceedings are expected to be published at the end of May, will contain around 120 pages, and will cost €15 including shipping. More details, including the contents, will be published in a future WGN.

IMO bibcode WGN-342-rms2005-procadvert NASA-ADS bibcode 2006JIMO...34...33R

The new Meteor Beliefs Project webpage

Alastair McBeath [1]

As part of the work to revamp the IMO website, a new page is available to publicise further the activities of the Meteor Beliefs Project, for which we have been producing regular articles in WGN in recent years. The page has some general details about the Project, a list of the articles so far, some notes on forthcoming papers for the next few months, and comments on future plans, including the latest development to examine the use of meteors in contemporary song lyrics. We hope that most of those articles already in print can be set online and linked to this page over time. The first of those should be available this way later this year, if all goes to plan.

The page address is `www.imo.net/projects/beliefs`, where it forms part of the new 'Ongoing Projects' segment of the IMO site. Please take a look and let us have your comments (or better still, new ideas for the Project!).

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IMO bibcode WGN-342-mcbeath-mbpweb NASA-ADS bibcode 2006JIMO...34...33M

Conferences

International Meteor Conference 2006
September 14–17, Roden, The Netherlands

The IMC 2006 Organising Committee

25th anniversary

The Meteor Section of the Dutch Association for Meteorology and Astronomy is proud to organize the 25th International Meteor Conference that will take place in The Netherlands. The conference will take place in the village Roden, close to the city Groningen in the north of the Netherlands from September 14-17, 2006.

Hunebeds

The conference will be held at the so-called 'Groepsaccomodatie de Hullen', a youth accommodation in Roden. It's a friendly and cosy accommodation in a green area. The province of Drenthe, in which Roden lies, is famous for its hunebeds, stone tombs in which people who lived here 5400 years ago buried their dead. They consist of stones each weighing more than forty tons.

The weather

The temperature in The Netherlands is typically around 15–20 degrees Celsius (60–70 degrees Fahrenheit) in September.

Currency

The official currency in The Netherlands is the Euro (€). Foreign currency can be exchanged in banks and exchange offices.

The excursion

A traditional part of the IMC program is the excursion. This year we will visit the Low Frequencey Array (Lofar), which will be the largest radio telescope in the world. It is currently under construction; 25 000 antennas are being placed in the northern provinces of the Netherlands and in a part of Germany. Lofar will observe electromagnetic radiation with frequencies ranging from 10 to 250 MHz and is expected to detect signals of the first stars and galaxies after the Big Bang in the early universe.

Participation fee

If you wish to register, please fill out the registration form on the next page or register online at the IMC 2006 website (see below). The participation fee for the IMC 2006 is €120 for people who register before July 1st and €130 for those who register later. This fee includes lodging, meals, excursion and the Proceedings. Either a prepayment of €60 or the total amount should be sent to IMO treasurer Marc Gyssens (details inside back cover and IMC 2006 website).

Visas and invitations

We will gladly send official invitations to people who need these to get a visa, provided that they inform us about this in due time.

Two meteor courses

We proudly present two Meteor Courses this year. The first is the Radio Meteor School 2006, a three-day tutorial (Roden, September 11 to 13) in which several astronomers working in the field of meteor-astronomy from all over the world will give lectures on the physical and mathematical theory of radio meteor observations. This Radio Meteor School is a follow-up from the 2nd Radio Meteor School held in Oostmalle last year. The costs will be announced soon and will be about €120.

IMO bibcode WGN-342-imc2006-advert NASA-ADS bibcode 2006JIMO...34...34I

The second Course is the Meteor Orbit Workshop, held on the same dates (September 11 to 13). So far, the determination of meteor orbits was mainly the domain of a few advanced research groups observing meteors with photographic techniques. Recently, more and more video camera networks appear, e.g. in Germany, the Netherlands, in Spain, Poland, Ireland, and others. These networks start to contribute to regular meteor orbit determinations. Many parallel groups are working on developing the required software for that. The aim of this workshop is to bring together all these groups and share the computational methods for determining meteor orbits. The costs for the workshop will be €120, this includes meals and accommodation. For more information on both courses, please take a look at the IMO 2006 website.

Contact information

For more information, check the IMC 2006 website at `http://www.imo.net/imc2006` or contact the organizers by e-mail at imc2006@imo.net. You can also write to us: IMC 2006 — Joost Hartman, Boschdijkstraat 36, NL-5211VD 's-Hertogenbosch, The Netherlands.

International Meteor Conference
Roden, The Netherlands, 2006 September 14–17
Registration form

Each individual participant should fill out a form and return it to IMC 2006 — Joost Hartman, Boschdijkstraat 36, NL-5211VD 's-Hertogenbosch, The Netherlands, as soon as possible. Your registration will be guaranteed only after Marc Gyssens has received the minimum pre-payment of €60. If you wish to participate, but cannot yet decide, simply return this form with the proper option checked to stay on the mailing list for further circulars.

Name: ______________________ Date of birth (YYYY-MM-DD): __________

Address: ____

____

____

Phone: __________ Fax: __________ E-mail: ______________

- I wish to register for the IMC 2006 from September 14 to 17.
- I intend to participate, cannot yet register, but wish to stay on the mailing list.
- I intend to travel by ______, together with ______________________
- I need travel information from __________ to Roden.
- I wish to stay in The Netherlands before and/or after the IMC and would like additional information.
- Vegetarian.

T-shirt: Size (S-M-L-XL): ________ Gender: ________

For participants wishing to contribute to the program:

Lecture: ______________________________ Duration: ________ minutes

Workshop or discussion: ______________________________

Poster presentation: ______________________ Space: ________ m^2

Required equipment: ______________________________

Comments:

Either the entire fee of €120 or a pre-payment of €60 should be sent to IMO treasurer Marc Gyssens. Follow the payment instructions inside the back cover or on the IMC 2006 website `http://wwww.imo.net/imc2006` . Participants making a pre-payment only have to pay the remaining €60 in cash upon arrival in Oostmalle. The registration fee increases to €130 for participants registering after July 1st.

Report on the Second Radio Meteor School, September 10-14, 2005, Oostmalle, Belgium

Danica Pajović [1]

Received 2006 April 18

The thing about meteors is that when you're even a bit more seriously involved with them, you don't seem to realize that you're suddenly involved with the entire meteor community. There is no such thing as private interest in meteor observations. All different species of meteor observers on this tiny, bluish planet, no matter where they are from or which language they speak, they all have that one thing in common: a supernatural urge to communicate with creatures of their own kind. An International Meteor Conference (IMC) is just one of the legal ways of meeting new people who won't look at you, trembling with horrible fear, while you're so excited talking about the new all-sky camera, sensitive radio receiver or successful laser surgery on your (along with the years of passionate visual observing) wasted eyes.

Some of the people who keep coming to the IMC from its early beginnings have known each other for decades, and this is only because of meteors. Most of them are not into meteor science professionally, but the professional meteor-people, a.k.a. scientists, also have that mysterious, humane urge to share their science-based knowledge with the rest of the flock, getting the empirical, experience-based knowledge of the amateur observers in return. Amateurs are happy with every piece of advice they can get, and professionals/scientists are happy that someone is actually reading and using their papers, and providing data to write new ones. That's the secret bond between amateurs and scientists that, perhaps, only exists in meteor science. And that is why it's always good for the amateur to have a real, live professional scientist around.

Twelve years ago, a couple of guys from Belgium had a dream... They wanted to go to Russia. Their quest was simple and honest, brave and, in their opinion, worth traveling thousands of kilometers (not on foot, of course). They wanted to find Him. The Master. The one man that could teach them what they wanted to know. So, one day, Cis Verbeeck, Jean-Marc Wislez, Tom Roelandts and Werner Depoorter knocked on the door of professor Oleg Belkovich's home in Kazan, Russia, seeking enlightenment on the obscure field of radio meteor astronomy. In the following couple of weeks, right there, in professor Belkovich's living room, at the Engel'hardt Astronomical Observatory, where Oleg was/is working, the First Radio Meteor School took place.

At the 2003 and 2004 IMCs, conversations between Galina Ryabova and Marc Neijts made it clear once again that radio meteor observers face many problems, and Galina noted that Oleg had worked out solutions years ago. When discussing this with the organizers of the IMC 2005 in Belgium, they decided to ask Oleg whether he wanted to hold a new Radio Meteor School (RMS), for a larger and more international audience. Oleg's immediate and enthusiastic yes resulted in the Second Radio Meteor School, which was held in Oostmalle, Belgium, from September 10 to 14, 2005, just before the IMC.

Figure 1 – Oleg Belkovich, with Galina Ryabova (l) and Marc Neijts (r). All photos by the author.

The prime lecturer was — of course — professor Oleg Belkovich. Oleg was the spine and the very heart of the RMS, considering he held most of the lectures, besides the other four lecturers/participants. Oleg's lectures started off with a sketch of the basic parameters relevant in meteor stream modeling: the mass exponent and the meteoroid flux density. After discussing the meteor ablation process and the different ways in which radio waves reflect on ionized meteor trails, we were ready to tackle the processing of radar observations. Oleg told us how to exclude the sporadic background, determine the radar sensitivity, and, after some hard work, how to calculate the meteoroid flux density and the mass index of a meteor stream observed by a radar. Next, Oleg taught us how to generalize all these tricks from radar to forward scatter observations. Finally, he made a comparison of results obtained by different observational methods, including visual observations. We all gained completely new insights by Oleg's lectures.

The RMS had 12 participants (including Oleg). Two attendants of the first RMS were also there: Jean-Marc Wislez, a physicist now working for Space Applications

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IMO bibcode WGN-342-pajovic-rms
NASA-ADS bibcode 2006JIMO...34...37P

Services, and Cis Verbeeck, a mathematician working for Agfa. These guys tracked down and brought professor Belkovich to Belgium and, among others, pioneered the legendary RAMSES project which most of the amateur radio meteor observers still look up to. Jean-Marc presented a lecture on the physics of meteor astronomy with a forward scatter setup, which led to a very animated discussion involving about everyone present.

From distant Argentina (or shall we say Antarctica?), came Juan Martín Semegone, a witty engineer who spent a lot of time on a mission on Antarctica studying the ionosphere and local phenomena. Currently, he works as engineer in the Instituto Argentino de Radioastronomía in Buenos Aires. He brought us his impressive Standard Meteor Receiver, the result of almost ten years of devoted designing, testing and study, and which is meant to be easily and cheaply copied for use by other observers.

From the equally exotic Venezuela, we welcomed Antonio Martínez Picar, an engineer working for a satellite TV company, passionately interested and involved in radio and visual meteor observations.

Another engineer, from the Netherlands, Frans Lowiessen-Balu, brought us, besides his enormous experience and good humor, a complete radio setup for radio meteor observing, including a several meters high dipole antenna, which he installed in the backyard of the Center, just in front of our classroom. One evening, he showed us the magic of the EZNEC antenna software.

Pavel Zigo is also an engineer, working at the Modra Observatory in Slovakia. He showed us some great meteor photographs, and described the Bologna-Modra forward scatter set-up he has been using for several years.

Among all those engineers, there were actually some astronomers/astrophysicists too. There was Michiel Brentjens, (also from the Netherlands), closely involved in the gigantic LOFAR project, who was expecting twins at the time we bothered him with our questions on antennas and interferometry. (Well, his wife was expecting, but he was also very excited about that — as we've heard recently, the babies are gorgeous.) He held two interesting lectures on interferometry.

Another astrophysicist-lecturer was Saša Nedeljković, a Serb now living in Canada, whose Ph.D. thesis is about meteor forward scattering at multiple frequencies, and who presented us a thought-provoking lecture on that subject. For the record, Saša got married only a couple of months later.

Galina Ryabova (from Russia, but hundreds of kilometers away from her old friend Oleg) is a data-hungry, cheerful astronomer who showed us some very good and picturesque meteor stream models in two lectures about the general principles of mathematical modeling and its application to the Geminid and Perseid meteor streams.

We also had professional help from a real social adviser; Marc Neijts from the Netherlands combines this job with being an experienced visual meteor observer, radio amateur and father of two interested in radio meteor observations.

And me? Being only a first year student of Electronic Engineering in Belgrade, Serbia and Montenegro, and being the youngest (only by age, not necessarily by spirit), I had the rare and special opportunity to meet all these great people, learn from them, and make friends with them. My goal was to find out more on meteor physics and meteor streams — I wanted to understand what am I actually listening to with the radio set-up, because I want to help founding the department for radio meteor astronomy back home in the Petnica Meteor Group that I recently became a member of.

The RMS lectures consisted of some pretty complicated mathematics, but a basic knowledge of calculus is really sufficient for understanding it, so I had no problems with that. The real, solid proof of how serious, good and practically useful the lectures were for me and everybody else, is the fact that I managed to spend only 18 Euros and 20 cents during the five day course I attended. So, for me, this was definitely not a shopping visit to Belgium — there was simply not enough time or energy for that. What's more important is that after every lecture, we had time to discuss it, comprehend it completely and start writing a report; in that way, we laid the basis for the Radio Meteor School Proceedings. These will be published shortly by IMO, and will contain the reader's digests of all the interesting lectures we had. Though these Proceedings are about radio meteor physics (leaving the practical hardware issues to be resolved), they will be of great help to people who want to obtain the meteoroid flux density and mass index of a meteor stream from radio observations.

During the evenings, most participants spontaneously continued to discuss, write, think and calculate until the early hours. Such was the enthusiasm shared by all of us. Moreover, we had some useful and creative discussions on several topics, which led to some innovative ideas. One spontaneous discussion focused on the way in which radio meteor data could be shared and archived for future use. We concluded that the most valuable way in which to archive observational data, is to store unprocessed raw measurements and context in-

formation. As FITS (`http://fits.gsfc.nasa.gov/`) is a widely used and flexible format for which many software tools already exist, we got the idea to define a standard format for keeping and storing radio meteor data, using the FITS format. After many discussions, we believe this METFITS (METeor FITS) data format has evolved into a useful standard. The METFITS specification will be published in the RMS Proceedings, and can also be downloaded at `http://www.astro.rug.nl/~brentjen/metfits.html`. We encourage all radio meteor observers to use METFITS as the standard format for keeping and storing radio meteor data, as well as to provide possible suggestions for further improvement of this format.

What was also unique for the RMS is the atmosphere. People of different ages, nationalities, academic backgrounds etc. all united in the quest for the Answers. Strangely enough, we found out that we all have more common interests and habits than just meteors. So there was a lot of laughter, late night work, lots of caffeine and even some C_2H_5-OH (mostly in some fine and famous Belgian beers...).

Frequent visits of Rainer Arlt (who was attending another conference in Belgium just before the IMC), Jan Verbert, Luc Bastiaens and the rest of the Belgian organizational squad, destroyed any chance of our course getting monotonous. The moment I think we'll always remember as a funny one, was when Saša and Frans, two rather tall and big fellows, shared one extra portion of the salmon we had for lunch (yes, the food and the accommodation in the Center were really great and comfortable), assuming that Rainer would be too late for dinner anyway. Eventually, poor Rainer showed up just before closing time and only got a vegetarian plate, and we were laughing at Saša and Frans for the rest of the week, hiding our own plates in front of their hungry paws.

Besides all that fun, our great hosts, Cis and Jean-Marc, along with the best both amateur and professional tourist guide ever, Marc Gyssens, took us on a little excursion to the wonderful utopian-like observatory near Antwerp, called Urania (where Marc is the beloved boss), and few days later, we went on an extensive walk-tour through the wonderful, colorful and picturesque city of Antwerp, filled with fairy-tale stories about almost every building, cathedral, fountain or monument where Marc led us to. The river Schelde that flows to the North Sea is really impressive, but not more than that wonderful city which lies on its banks.

After the last lecture of the Radio Meteor School, we had some time to contemplate about the wonderful things we've heard, seen and done, waiting anxiously for the upcoming International Meteor Conference, which started the next day and which most of us also participated in. But that's another story... After everything was over and everyone was back home, we decided to turn the IMO radio questions address `radio@imo.net` into a mailing list, enlisting the RMS participants, and open to all radio observers interested. This way, the combined knowledge of many radio observers can be used when someone has a question about radio meteor observing, and of course, this mailing list is also used as a forum to discuss all kinds of radio meteor topics. Everyone seriously interested in radio meteor observing is welcome to join this mailing list. If you're interested, send a mail to `webmaster@imo.net`. In fact, several observers from around the globe have already joined this mailing list and from time to time, interesting discussions take place there.

Though many questions on radio observations have been answered, it still is a very complicated hobby or obsession, and that means there are plenty of questions left. That's why IMO organizes a Third Radio Meteor School from September 11 till 13, 2006 in Roden, Holland, just before the IMC. We strongly advise the seriously interested radio meteor observer to grab that occasion with both hands. For more information, please refer to `http://www.imo.net/imc2006/radio.php`.

For information on the Proceedings, see page 33. –Ed.

Proposed research

Multiple station meteor observations: an international program for studying minor showers exploring IMO potentiality

Josep M. Trigo-Rodríguez, [1] *Jérémie Vaubaillon,* [2] *Esko Lyytinen* [3] *and Markku Nissinen* [4]

The International Meteor Organization (IMO) should promote between its members and collaborators the development of multi-instrument campaigns in order to study minor meteor showers. It is well known that amateurs can contribute to professional research by participating in the atmospheric monitoring of the night sky for meteor and fireball recordings. The determination of atmospheric trajectories and heliocentric orbits of meteoroids is a valuable contribution to different research fields such as: orbital dynamics, non-gravitational effects, interplanetary processes (collisions, fragmentation, etc...), meteoroids' physical properties and atmospheric interaction. At the same time, these studies can be complemented with meteor spectroscopy that can provide valuable information on the meteoroid (and parent body) chemical composition and the effects of space weathering.

Received 2006 March 29

1 Minor showers: a challenge for professional and amateur astronomers

The study of minor meteor showers is really a challenge from all points of view.

In the last decade the priority of IMO for promoting the interest of meteor studies and for making recognized the effort of hundreds of amateurs has been remarkable. However, future studies for the unequivocal identification and analysis of minor streams should be seriously considered now that IMO is enjoying a phase of growing international cooperation. At this point, many members are providing valuable information on the Zenithal Hourly Rates (ZHRs) and spatial fluxes of large and moderate meteor showers with typical ZHR > 50. In any case, during the year many minor showers (with $3 <$ ZHR < 50) can be interesting targets for our teams, but usually the low activity of these streams makes it difficult to get conclusive studies. In fact, the study of minor streams will require full collaboration between the members and the different countries represented in IMO. Since its creation IMO has been a reference for collaboration between amateur and professional astronomers, and also a nice example of international cooperation. We would like here to send a call for a new step, a new spirit for collaboration in minor showers research that would be perfectly programmed from WGN. This journal informs us periodically of current activities and activities of IMO members. However, we have realized that although the IMO Meteor Shower Calendar is an excellent initiative for promoting the observation of major streams, it should be complemented with the publication in WGN of particular campaigns to study (or, in some cases, to confirm) the activity of minor meteor showers. The main reason to propose this is because we should obtain the maximum possible information on meteor showers that produce low levels of meteor activity in order to progress in our knowledge in some areas of meteor science: dust trail evolution, orbital diffusion, etc. Nice examples of meteor campaigns promoted from WGN were the different Aquarid or Leonid Projects (e.g. Koschack and Rendtel, 1991; Brown, 1991). The current status and quality level of meteor studies performed by IMO teams suggest that we can start to promote image recording to increase in our knowledge on minor meteoroid streams.

2 Exploring IMO potentiality for minor shower studies

The excellent spatial coverage around the globe of IMO members can help us to confirm or discard the presence of meteors associated with minor showers. To observe minor showers can be very time consuming, and not everybody can regularly spend a whole night recording the meteors. That is why the development of automatic devices is encouraged. The already existing software such as *MetRec* is of considerable value, and it is clear that electronic cameras are the best way to conduct automatic surveys. We are trying to be practical here, but perhaps the best way is to take profit of the existing amateur groups in order to promote multiple-station observations from IMO. This is an important step because single-station meteor observations in this particular case should be complemented with other optical techniques like photography, video or/and CCD imaging (Figure 1 and back cover). Then, in the campaigns we should include as many observers and techniques as possible. Novel observers can initially feel that the fact to incorporate cameras to their observations is increasing the degree of difficulty, but the methodology is quite simple (see e.g. Rendtel, 1993). However, some basic details are given in sections 2.1 and 2.2. In any case, it is clear that experienced amateur groups should lead the

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IMO bibcode WGN-342-trigorodriguez-multistn
NASA-ADS bibcode 2006JIMO...34...40T

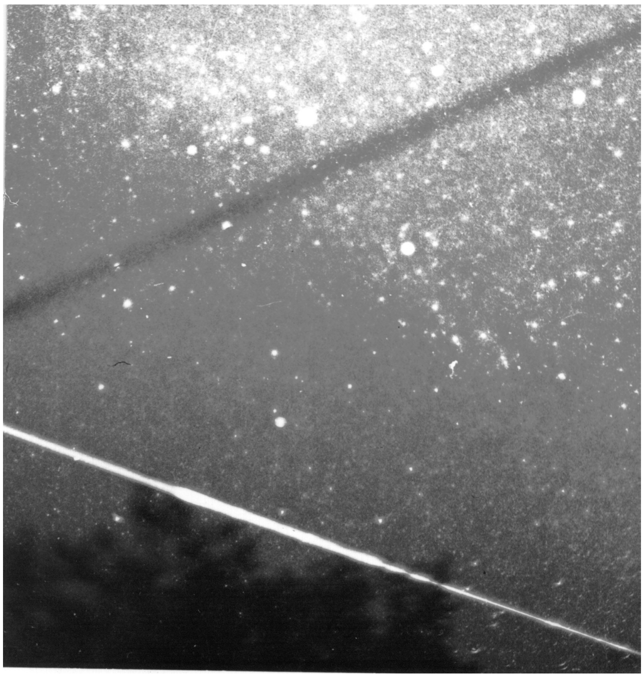

Figure 1 – The study of the activity of rare meteor showers is feasible with the help of amateurs. This $m_V = -6$ fireball photographed on 1981 November 2 by José Berenguer from Valencia (Spain) was probably associated to the Bielids, a highly perturbed stream that nowadays presents a few members crossing the orbit of the Earth. The photograph was exposed for two minutes using a lens of $f = 50$ mm at $f/1.4$. A cable was also photographed crossing the field. The fireball flight is from left to right, crossing Cygnus. Deneb is at top center. Image from the SPMN archive.

initiatives for minor meteor research, promoting these studies 'around' their countries at the same time that they are contributing to IMO.

2.1 Multiple-station camera observations

Multi-station observations are of considerable value since they provide information on the orbit of a meteoroid, which is the best way to link it with a shower. Any dynamical study is based on such association, and new parent bodies are expected to be discovered using this method. To program multiple-instrument recording of meteors from different stations is not an important deal today. Several software applications are currently available, developed by IMO and the Dutch Meteor Society (DMS). We would like only to remark that the Spanish Meteor Network is using the *Photographic centers for multiple station meteor observations* (Trigo-Rodríguez, 2002). This software is currently available for groups of other countries on request. Basically, by defining the different network stations the software derives the common atmospheric center for each station depending on the geometry of meteor apparitions and the geographical coordinates of each station. The program provides the equatorial coordinates of the projected vector in the celestial sphere, and a plot of these centers in celestial gnomonic charts. The centers and charts can be printed out nicely.

The basic procedure is simple. From each station several photographic cameras, or CCD detectors equipped with rotating shutters should be installed (Trigo-Rodríguez et al., 2004, 2005). Camera operators should record exposure times and time of meteor appearance with an accuracy of one second. Later on, common meteors should be astrometrically reduced by using standard methods (Steyaert, 1990; Trigo-Rodríguez et al., 2003). Visual observations are perfectly compatible and recommended during multi-instrument recording. For example, one member of the team could be in charge of the camera exposures, while the rest monitor meteor activity using standard IMO procedures. Meteor plotting is also recommended when the activity level allows it.

In recent years video systems have increased their capabilities, and automatic analysis software has been developed. This is important because the amount of generated video data every night can be huge and it is very time consuming to analyze manually. Recent software that has been used in the *Ursa Astronomical Association Meteor Section* has been SkyPatrol and UFOCapture. UFOCapture especially has proved itself to be a good analyzing software package and it has already helped with the discovery of October Camelopardalids (Jenniskens et al., 2005). By developing a video network, a few operative stations can provide significant amount of information about meteor activity in almost real time.

Another important topic that would be included at the same time is the record of additional information on large fireballs. We will not go over this topic here, but it is evident that increasing the number of multiple-station recording hours worldwide we will get valuable information on fireball events. Collaboration between professionals and amateurs in the last decade has been very important, with nice examples to remark (Spurný et al., 2004; Trigo-Rodríguez et al., 2004, 2005b)

2.2 Meteor spectroscopy

At the same time that multiple-station meteor recordings are performed, diffraction gratings can be easily installed on the front of the camera lenses in order to get the spectral lines associated with the different chemical elements ablated along the meteor trail. We are not including here more details on the procedure because general overviews are available in Millman (1954), Rendtel (1993), and Majden (1998a). However, photographic spectra are limited to bright meteors (or fireballs) while the new video and CCD camera systems are allowing the recording of spectra from faint meteors. Meteor spectra are being considered as a valuable technique that can provide complementary information to high-cost missions to comets. In fact, detailed analyses of meteor spectra provide direct information on the meteoroid chemistry (Borovička, 1993; Borovička et al., 2005; Trigo-Rodríguez et al., 2004, 2005). In the last decade, the amateur contribution to meteor spectroscopy has been remarkable (Majden, 1998b; Weber, 2005) and should encourage other people to develop spectroscopic campaigns in the near future. Although

Table 1 – Minor meteor showers in good lunar conditions to be studied during 2006. The Program column recommends coverage: 'Fol' from general following (intensive effort from all IMO members), 'Ver' from verification of the existence of the shower. References: [1] (Arlt & Vaubaillon, 2006); [2] (Lyytinen & Jenniskens, 2003); [3] (Jenniskens et al., 2005).

Stream Name (Ref)	Program	Activity Period	Maximum	V_g (km/s)	ZHR_{max}	Ref	Moon conditions
Lyrids (LYR)	Fol	Apr 16–Apr 25	Apr 22	49	< 20	IMO	Last quarter
π Puppids (PPU)	Ver	Apr 15–Apr 28	Apr 23	18	Variable	IMO	Last quarter
η Aquarids (ETA)	Fol	Apr 19–May 28	May 6	66	60	IMO	First quarter
τ Herculids	Ver	May 28–Jun 6	June 1–2	16	Variable	[1]	First quarter
τ Cetids (CET)	Ver	Jun 18–Jul 4	Jun 27	66	< 5	IMO/AMS	New moon
June Bootids (JBO)	Fol/Ver	Jun 26–Jul 2	Jun 27	18	Variable	IMO	New moon
κ Pavonids	Ver	Jul 16	23^h23^m UT	?	Dust trail	[2]	Full moon
Piscis Austrinids (PAU)	Fol	Jul 15–Aug 10	Jul 28	35	< 10	IMO	New moon
South δ Aquarids (SDA)	Fol	Jul 12–Aug 19	Jul 28	41	20	IMO	New moon
α Capricornids (CAP)	Fol	Jul 3–Aug 15	Jul 30	23	5	IMO	First quarter
β Perseids	Ver	Aug 8	02^h50^m UT	?	Dust trail	[2]	Full moon
Kappa Cygnids (KCG)	Ver	Aug 3–Aug 25	Aug 18	25	< 10	IMO	Last quarter
π Eridanids (ERI)	Ver	Aug 20–Sep 5	Aug 27	59	5	IMO	New moon
δ Aurigids (DAU)	Ver	Sep 16–Oct 10	Sep 23	64	< 5	IMO/AMS	New moon
October Camelopardalids	Ver	Oct 1–Oct 10	Oct 5	47.3 ± 0.5	20 (in 2005)	[3]	Full moon
α Monocerotids (AMO)	Ver/Fol	Nov 15–Nov 25	Nov 21	65	Variable	IMO	New moon
Coma Berenicids (COM)	Fol	Dec 12–Jan 23	Dec 20	65	< 10	IMO	New moon
Ursids (URS)	Fol	Dec 17–Dec 26	Dec 22	33	Variable	IMO	New moon

the chance of capturing a fireball associated with a minor shower is very low, there is an intrinsic interest in recording as many spectra as possible, even if they are produced by sporadic fireballs. Although the information provided by meteor spectra is very important, the truth is that spectroscopic observations are still a marginal occupation of amateur meteor observers. One of the reasons is that only a few people do have the courage to take the time to analyze and understand a meteor spectrum. Then, we encourage the creation of a basic tool (software) able to perform a first and simple analysis. A database of spectra can also be created, like the one recording every fireball. This would enable a quick comparison between different showers.

2.3 Identifying some first targets: working list of 2006 minor streams

In order to promote minor meteor stream monitoring by IMO members we are here proposing a first working list for the rest of 2006 (Table 1). Of course, not all minor streams are included, and some that can be considered major streams are also included (like e.g. Lyrids or η Aquarids). We should consider Table 1 as only a small selection to be used for the different groups for planning common research. Please note that in the column 'program' we emphasize the type of coverage that should be made: 'Fol' from general following (intensive effort from all IMO members), and 'Ver' from verification of the existence (or e.g. its *presence* in some particular return in case of dust trails). We remark this because the verification campaigns should include mainly optical recording (video, photography, CCD, etc...) while those of general following would be also based in visual observations.

The *Ursa Astronomical Association's Meteor Section* also suggests observing the December Draconids first noticed by the experienced Leo Rajala. The activity of this likely minor shower needs confirmation; it starts in the last week of November and ends in the first week of December. The apparent radiant is located at $\alpha = 135°$ and $\delta = +65°$.

Probably we are missing some important targets here. However, the important thing is that we will be able to identify common targets to be studied in common, and we start a new epoch of close collaboration among our groups. We offer our help in the organization of some specific campaigns by joining efforts with other groups worldwide. Other particular stream research proposals should be send to the next issues of WGN. Please feel free to contact us for additional ideas.

3 Conclusion

International cooperation between amateur and professional astronomers can be very useful in order to obtain orbital and spectroscopic information on minor stream meteoroids. IMO has developed the necessary infrastructure to promote this kind of programs, and WGN should be an excellent place to announce international campaigns that allow us learning more on these fascinating meteor sources.

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Ongoing meteor work

Polarization of light emitted by meteors

Peter Zimnikoval [1]

A special rotating shutter designed to measure the polarization of light coming from meteors was constructed. After many years of occasional observations, three meteors were recorded. None of the three events were bright enough for precise evaluation. Despite this, there are some indications that the light of two recorded meteors was polarized. The technical instrument used, method of processing and first results are described. The results are discussed.

Received 2006 January 26

1 Introduction

The first idea arose some twenty years ago when the determination of colour indices of meteors was needed. I suggested using a rotating shutter to obtain more information about the light emitted by a meteor. The disc of the shutter should consist of different colour filters. A cheap but not very precise way to realise that idea was to use acrylic glass to construct it. These materials are optically good and their non-ideal spectral properties are possible to calibrate. A disc was therefore constructed containing seven segments — transparent (all visible), yellow, blue, grey (as neutral), black and two more from polarizing sheets. The polarizers were set so that the plane of polarization of one was perpendicular to the other. Meteor photography through this rotating disc started in 1995. The equipment was used occasionally, mostly during the activity maximum of main showers. There was no observation during the Perseids because we observed them in the mountains without the source of electricity needed for the shutter. That fact, and the relatively short effective time of use of the equipment, meant that no meteor was recorded. Moreover, the problem of the colour index of meteors became less interesting because of adequate data obtained by spectrography. The observing program was not effective and was terminated. After later discussion with people who know well the problems of meteor light emission (Rajchl, *pers com*), I was recommended to continue with this kind of observation. Consequently, I designed and constructed a new rotating disc, this one dedicated to polarization measurements only.

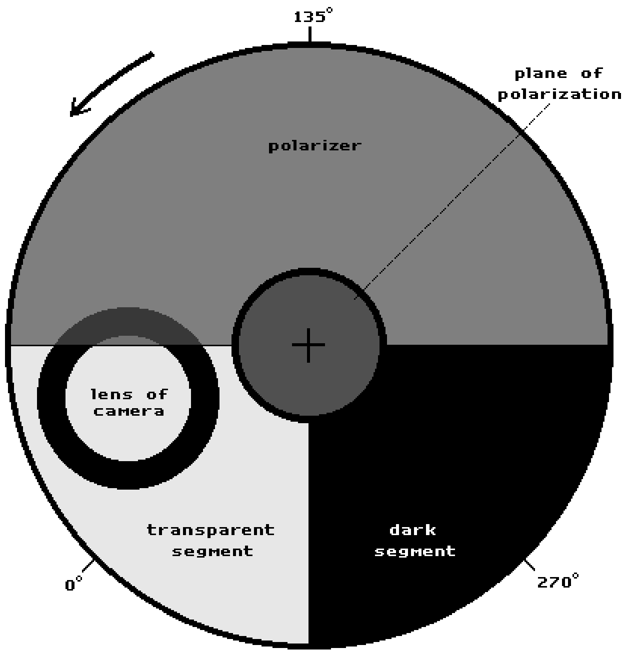

Figure 1 – Geometry of the rotating disc.

2 The equipment

The new rotating shutter is constructed as a two segment wheel made from acrylic sheet (Figure 1). One half of the disc is transparent. Half of this part is painted black. The second part is made from acrylic sheet with a Polaroid designed for photographic reproduction purposes. The disc is rotated by a small direct-current electric motor giving around 15 revolutions per second. Due to the rotation of the disc, the plane of polarization rotates as seen by the light source. The angle of the Polaroid segment is 180°. Therefore, if the light is polarized each revolution must contain both the maximum and the minimum of the polarizer's trans-

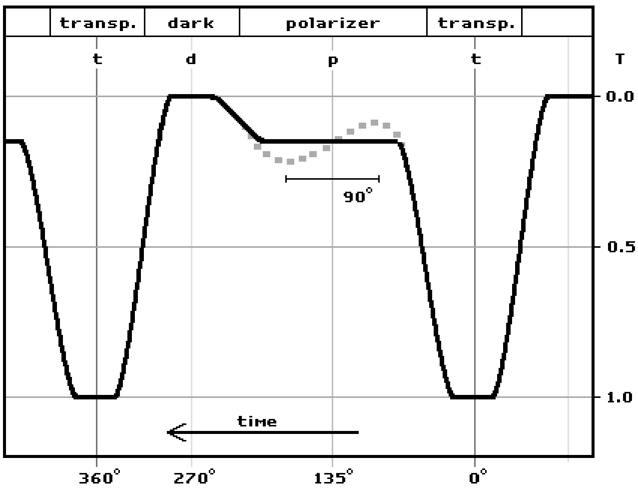

Figure 2 – Theoretical transmittance profile of the disc.

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IMO bibcode WGN-342-zimnikoval-pol
NASA-ADS bibcode 2006JIMO...34...45Z

mittance. A conventional camera with a $f = 50$ mm, $f/2$ lens is used to photograph observations through the disc. Images of stars through the polarizer are shifted from the images obtained through the transparent segment due to the non-ideal planarity of both segments and the not quite identical refractions of the materials used. This fact does not seem to be problematic for obtaining good polarization measurement results.

The theoretical profile of the transmittance T of the disc is shown in Figure 2. Let the rotation angle be 0° when the position of the disc is such that the lens lies behind the centre of the transparent segment. Then the centre of the polarizing filter will be at 135° and centre of the dark segment at 270°. These three basic positions of the shutter are marked as **t** (transparent), **p** (polarizing) and **d** (dark) in the following text. The transmittance of the polarizer for unpolarized light is around 0.15, which is equivalent to a decrease of approximately 2 magnitudes. The black curve of the profile characterises transmittance for an unpolarized moving light source (meteor) according to the rotation angle of the disc. In the case of polarized light the profile around line **p** will not be linear but will have a maximum below and minimum above the line. The grey dotted curve in Figure 2 presents one possible form of the transmittance changes. The angular distance between maximum and minimum points must be 90°. The relative position of those points and line p gives the angle between the polarizer's and the observed light's planes of polarization.

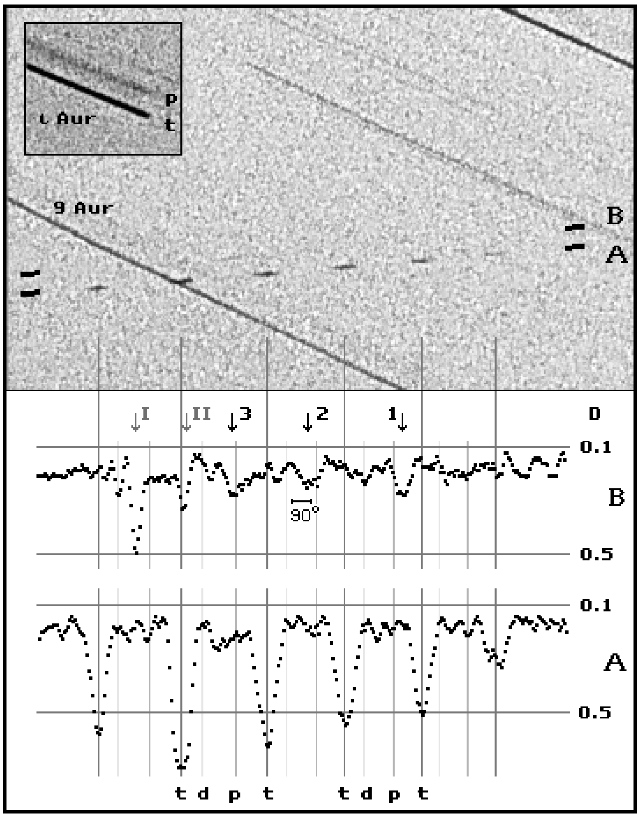

Figure 3 – Meteor PM 2 and density profiles along cuts A and B.

3 Observations

Photographic observation through the new rotating disc was realised during Perseid activity mainly starting in 2002, but weather conditions in summer were very bad in recent years. A unique opportunity, the 2002 Leonids, was missed due to a trivial technical problem. Incorrect transport of the film in the camera caused all 10 exposures to be on one black frame. The first successful observation was made during the Perseid maximum in the region of Valachovo, Slovakia on 2004 Aug 11/12. Three meteor images were recorded through the rotating disc. The first meteor (here marked PM 1) was in the interval from $21^{h}35^{m}$ to $22^{h}19^{m}$ UT. The second two meteors (PM 2 and PM 3) were exposed on the frame from $01^{h}40^{m}$ to $02^{h}05^{m}$ UT. A 400 ASA Ilford film was used. All three events were relatively faint and at first sight show only the path of the meteor through the transparent segment of the disc. Later the weak track of meteor PM 2 exposed through the polarizer was found after further analysis. First evaluations indicated that the polarizing path is too weak and that, consequently, it would not be possible to identify the pertinent effect of polarization from this image. Observations with the polarizing disc were stopped. But a lot of effort spent on the project caused the processing to start anew in January 2006.

4 Evaluation

A new attempt at evaluation was made for meteor PM 2 (Figure 3). The meteor was a Perseid and appeared near star 9 Aur ($m_{\rm V} = +5.0$). Its estimated magnitude was about −1. The original photographic film was scanned to digital form as an image with a resolution of 9.72 mega pixels per frame and with a depth of 24 bits per pixel. A photometric cut was made along the meteor path (A). The width of the cut was 3 pixels in a direction perpendicular to the movement of the meteor. This value was found to be optimal. The total density of the meteor path was taken to be the mean value of these three pixels. The density of a single pixel is here given as the mean value of the components in the RGB system. Therefore density 0 corresponds to $r = 0$, $g = 0$ and $b = 0$ and density 1 is $r = 255$, $g = 255$ and $b = 255$. Due to the relatively high level of noise (granularity of the photographic film) the values along the cut were smoothed using a moving average of 5 points of the cut. Thus each point of the luminosity curve represents the mean value of densities of the actual point of the cut, two points laying to the left and two points to the right in the cut. This smoothing was necessary due to the big dispersion of densities caused by the film grain. The same process was applied for the path through the polarizing segment (B), too. The relative position of the path through the polarizer is taken from the paths of stars. This shift is equal on all frames of the film. On the fragment inserted in Figure 3 is the path of the star ι Aur ($m_{\rm V} = +2.7$) and it shows the shift between the direct image and the image through the polarizer. The fragment is from the same frame and was rectangularly shifted to that position.

Profile peaks of the cut along the path through the transparent segment give good information about the

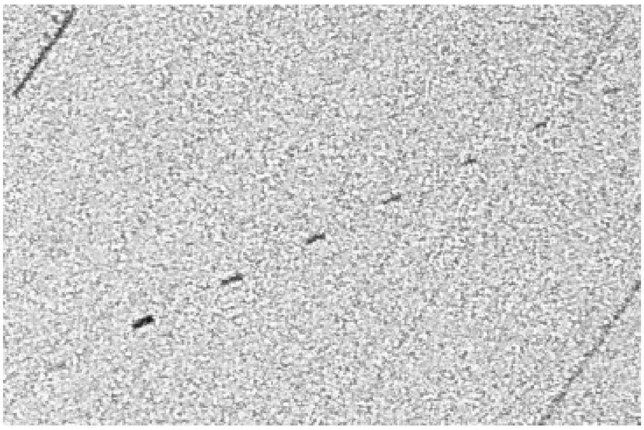

Figure 4 – Meteor PM1.

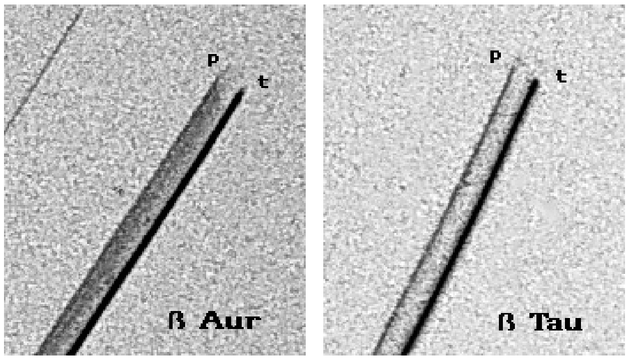

Figure 5 – Images of stars β Aur and β Tau.

luminous distribution along the trail of the meteor. These peaks define well the position of the disc on the time axis. Maximal densities correspond to positions **t** of the rotating disc and therefore this allows one to determine other two — the **p** and **d** positions of the disc. On the cut B, peaks marked I and II dominate. Peak I is caused by the star 9 Aur and peak II is probably any small defect or piece of dirt on the film. The part between peaks I an II belongs to the path of the star 9 Aur through the polarizer. Peaks 1, 2 and 3 are easily visible, too. These three peaks are created by light from the meteor coming through the polarizer. The peaks and troughs should theoretically be the same width, but the peaks were measured as narrower than the troughs. Moreover, to the left of each peak is the minimum of the density. Those minima of density are displaced from the maxima by a distance corresponding to an angle 90° of the disc. The minima are in zones where light has had to come through the polarizer. According to these facts, the light of the meteor was polarized. It was probably linear polarization. The degree of polarization was not evaluated. The maxima of peaks are not quite at the same distances from the lines p. This may be explained by the plane of polarization changing along the meteor trail.

At first sight, the evaluation of meteor PM 1 (Figure 4) seemed to be impossible. The image of meteor PM 1 is the brightest of all the recorded meteors but the path through the polarizer is not visible. Later the instrumental error which caused this was found. The polarizing path of the stars in all eight frames exposed during the night shows that images of stars through the polarizer are systematically extended from the right edge of the image to the left. Figure 5 illustrates the problem. The image of the star β Aur is from the left and star β Tau from the right of the same frame. These two stars have almost equal brightnesses and spectral types. The extension has one possible answer: the axis was not perpendicular to the plane of the rotating disc. Therefore the zones of the frame where the lens of the camera is nearest the disc are not equally sharp. The meteor PM 1 was located almost in the left of the frame and therefore its poor polarized path is too diffuse to be visible. Meteor PM 3 is near left edge, too. Meteor PM 2 was not ideal from this point of view, lying to left of the centre, but not as much as the other.

The estimated magnitude of meteor PM 1 is about -1, too. Its bigger density on the film relative to meteor PM 2 is caused by a rather lower angular velocity. This was not a Perseid. The direction of it corresponds very well with SDA or NIA, but the computed velocity gives a value around 25 km s^{-1} which does not correspond with geocentric velocities of these showers. The α Capricornids have similar velocities, but the meteor direction passes too far from the radiant. Therefore the meteor PM 1 was probably a sporadic. The direction of the meteor's movement on the frame is almost the same as the direction of its shifted image through the polarizer.

The process of evaluation was similar to the processing of meteor PM 2. The luminous curves obtained are shown in Figure 6. On the curve above, two peaks are easily visible. The peaks marked I are caused by diffusion of the direct image of the meteor in the photographic emulsion because the path through the polarizer lies too near to the direct path of the meteor. Peak II is probably caused by some small impurity on the frame. Minima 1, 2 and 3 are interesting. All these minima lie in places where light was coming though the polarizer. Maxima before and after each minimum are at distances corresponding to 180° on the disc. This is probably caused by the fact that the plane of polarization of the meteor's light was perpendicular to the plane of rotation of the polarizer when the disc was in position **p**. The planes of polarization of meteor and disc were almost the same when the light comes through the edges of the disc. Peak 4 lies around the line **p**. Here is the maximum with minima before as well as after it. The distance between minima is 180°, too. If this is really caused by polarizations of the meteor's light then the plane of polarization was suddenly changed by approximate an angle of 90°. Between zones 3 and 4 was the maximum of the meteor's luminosity, where a change in some physical condition could have affected the light emission.

The meteor PM 3 is too faint for evaluation. It was a Perseid with estimated brightness about $m_{\rm V} = 0$. Only three interruptions of it are recorded on the frame.

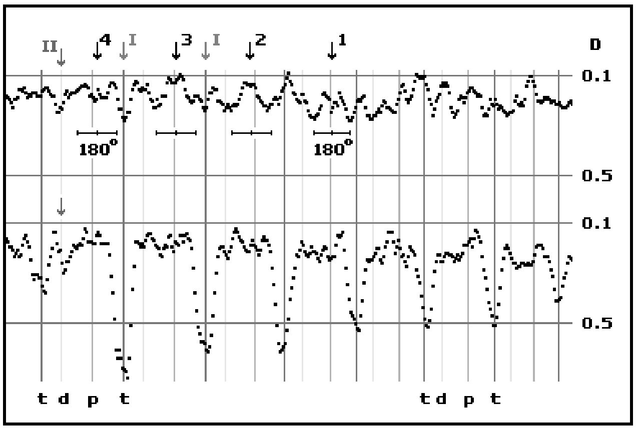

Figure 6 – Density profiles of meteor PM 1.

5 Conclusion

All results are based on two recorded meteors, moreover with a signal level only slightly over the noise. The correspondence between the rotation period of the disc and the positions of simple peaks does not seem to be coincidence. Therefore the polarization of light of meteors PM 1 and PM 2 is probably real. Smoothing of the photometric profiles was necessary due to a high variability of pixel densities caused by the granularity of the photographic film. An average density of 5 pixels along cuts was shown to be optimal to obtain the best results. This average brings an uncertainty of around 18° in the positions of the profile peaks relative to the position of the rotating disc. Due to low brightness of both meteors, more precise analysis is not possible. To obtain better results, much more observations are needed after elimination of technical failures.

Perseids

Temporal evolution of a Perseid fireball spectrum

Jiří Borovička [1], *Miloš Weber* [2] *and Jaroslav Boček* [3]

We present spectra of a −8 magnitude Perseid fireball obtained by three techniques: a photographic grating spectrograph, a photographic prism spectrograph and a television grating spectrograph. The prism spectrum was used to study the temporal evolution of three representative emissions: the Mg I lines coming from the main spectral component, the Ca II lines coming from the high temperature component, and the N_2 bands of atmospheric origin. The high temperature component developed around the height of 95 km, which is consistent with the beginning of the formation of meteor shock wave.

Received 2006 February 28

1 Introduction

Meteor spectroscopy is a tool for studying details of meteoroid ablation and interaction with the atmosphere as well as the composition of meteoroids. Meteor spectra can be obtained by putting a dispersion element (prism or grating) in front of a wide field camera. Since the meteor position on the sky is unpredictable, a wide field is advisable. A wide field can be achieved by using a lens with a short focal length but this also reduces spectral resolution. Another option is to use a large detector. Large format photographic cameras are still the best solution for a large field of view, large spectral resolution and good spectral coverage. However, the sensitivity of photographic cameras is low and their use is restricted to the spectroscopy of very bright meteors — fireballs. A successful capture of a fireball spectrum requires hundreds of hours of exposure time (Weber, 2005), in particular outside the activity of major meteor showers. Television cameras are much more sensitive but provide much lower spectral resolution because of limited number of pixels per image. Astronomical CCD cameras can provide a kind of compromise solution. Resolution comparable to photographic cameras can be achieved while the sensitivity of CCD is much higher (e.g. Jenniskens & Mandell, 2004). The cost is a limited field of view and a limited spectral coverage (in that only a part of the spectrum lies in the field of view).

Figure 1 – A part of the photograph from the guided all-sky camera showing the EN 090897 fireball in the summer sky. The field of view is approximately 50 degrees. The short trail in eastern Cygnus is a satellite track. The photo was taken with a Zeiss Distagon $f = 30$ mm, $f/3.5$ fish-eye lens using a 9 cm ×12 cm sheet film. The film was exposed from $20^{h}23^{m}35^{s}$ to $23^{h}46^{m}10^{s}$ UT. Photo Aleš Kolář.

Perseid spectra are among the most frequently observed meteor spectra (e.g. Russel, 1960; Halliday, 1961; Millman & Halliday, 1961; Cook et al., 1971; Millman et al., 1971; Evans & Ridley, 1993; Borovička & Betlem, 1997; Borovička & Majden, 1998; Airey, 1999; Trigo-Rodríguez et al., 2003; Borovička, 2005). Bright Perseids — like other high velocity fireballs — contain two components of meteoric vapors, the main component (≈ 5 000 K) and the high temperature component (≈ 10 000 K). The origin of the high temperature component discovered more than ten years ago (Borovička, 1994) is still not quite clear but is likely connected with the meteor shock wave. In addition to the meteoric lines, Perseid spectra also contain emissions from the heated atmosphere.

In this paper we present an example of a Perseid fireball spectrum captured by three different cameras: a photographic grating camera providing high resolution, a photographic prism camera providing lower resolution but higher sensitivity, and a television (TV) camera. The TV spectrum extended the spectral coverage to the near infrared but a large part of it was saturated. We mainly concentrate on the prism spectrum which covers the whole meteor. Temporal evolution of the representative emissions is studied.

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IMO bibcode WGN-342-borovicka-perseid
NASA-ADS bibcode 2006JIMO...34...49B

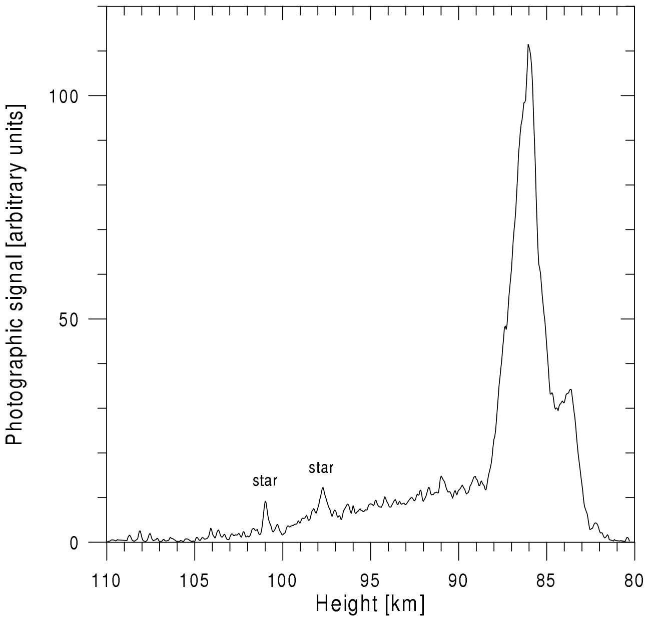

Figure 2 – Photometric scan of the fireball image in Figure 1. The directly measured photographic signal as a function of fireball height is given. Some of the peaks on the curve have been caused by overlapping star images.

Figure 3 – The prism spectrum of the EN 090897 fireball. The wavelengths increase from the bottom upwards. The fireball image has been interrupted by a rotating shutter with the frequency of 10 Hz. The photo was taken with a Xenar 3.5/150 mm camera and a 30° objective prism using a 9 cm ×12 cm sheet film. The film was exposed from $21^{\mathrm{h}}40^{\mathrm{m}}10^{\mathrm{s}}$ to $00^{\mathrm{h}}50^{\mathrm{m}}40^{\mathrm{s}}$ UT. Photo Miloš Weber.

2 The meteor

The fireball studied here, EN 090897, appeared on 1997 August 9, $22^{\mathrm{h}}57^{\mathrm{m}}58^{\mathrm{s}}$ UT. It was captured at three stations of the European Fireball Network. The photo from the guided camera in Ondřejov is given in Figure 1. The trajectory and orbit were published by Spurný et al. (2005). The fireball was an early Perseid with initial velocity of 60.0 km/s and trajectory slope (angle to the horizontal) of 42°.5. The photographic beginning height was 104.3 km and the fireball terminated at the height of 81.5 km. Figure 2 shows the fireball light curve extracted from the guided camera image. The increase of the fireball brightness was gradual and linear down to the height of 88 km, where a sudden onset of a flare begun, culminating by the peak at 86 km. The maximum photographic brightness was measured to be $M_{\mathrm{ph}} = -7.4$ (Spurný et al., 2005) but in reality the brightness was somewhat higher because the maximum point was hidden by the rotating shutter on the non-guided camera.

3 The prism spectrum

The prism spectrum was taken at the Chouzavá observing site as part of the program of M. Weber (Weber, 2005) and is reproduced in Figure 3. The whole meteor was covered, except for breaks caused by the rotating shutter. The shutter is used in meteor spectroscopy for distinguishing the radiation of the meteor head from the wake. Nevertheless, no wake emissions are seen in the shutter breaks in this case.

The negative was scanned with the Microtek ArtixScan 2500F flatbed scanner in the 2500 dpi resolution and measured on computer. The spectrum of the star α Andromedae, located next to the meteor spectrum, was used to derive the spectral response of the camera/film combination. The response shows a relatively deep minimum near 500 nm (Figure 4). The photometric scan of the spectrum at the brightest point — corrected for the spectral response — is given in Figure 5. Prisms produce spectra with non-linear dispersion. Spectral resolution is much better in the blue part than in the red part of the spectrum. In total, 14 main features can be seen in the spectrum. The two brightest lines, numbered 5 and 6, belong to the ionized calcium Ca II. All other features are in fact blends of many spectral lines. We could use our experience and the grating spectrum, which has much higher resolution, to identify the main contributors. The identifications are discussed in Section 6.

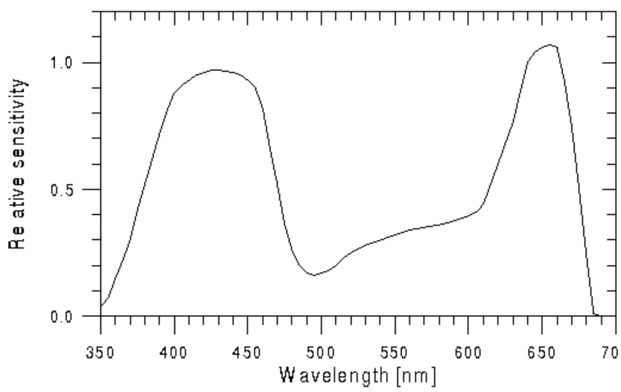

Figure 4 – Spectral response of the camera and film combination used to capture the prism spectrum.

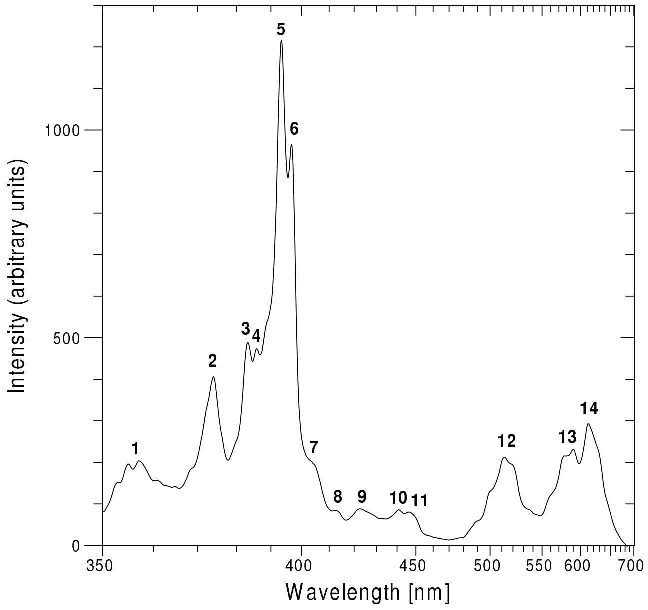

Figure 5 – The prism spectrum of the EN 090897 fireball at its maximum. The spectrum was corrected for the spectral response of the camera. The main emission features are numbered.

Figure 6 – The blue part of the photographic grating spectrum of the EN 090897 fireball in its brightest part. The wavelengths increase from the left to the right and cover nearly the region 350–460 nm. The fireball flew from the top to the bottom. The rotating shutter frequency was 15 Hz. The photo was taken with the Tessar $f = 360$ mm, $f/4.5$ lens and 600 grooves per mm objective grating using 18 cm ×24 cm sheet film. The film was exposed from $20^h31^m00^s$ to $02^h38^m50^s$ UT. Photo Aleš Kolář.

4 The photographic grating spectrum

The photographic grating spectrum S 25196 was taken at the Ondřejov Observatory and its part is reproduced in Figure 6. Due to lower sensitivity of the camera, only the bright part of the meteor, between the heights of 92 and 83 km, was captured. Moreover, at the peak brightness, the meteor was hidden by the rotating shutter. The best spectrum was therefore obtained at the height of 87 km. The spectrum contains almost 40 spectral lines, most of them lie in the blue part below 450 nm. The spectral scan is presented in Figure 8. The majority of the lines are quite faint. The groups of lines forming the features seen in the prism spectrum are marked. Features 1 and 12 were not detected in the grating spectrum because of lower sensitivity.

The grating spectrum was analyzed at the height of 87 km by Borovička (2005). The temperature of the main component and of the high temperature component were found to be 5 000 K and 10 500 K, respectively. The chemical composition was similar to other Perseid and Leonid meteors. In comparison with CI chondrites, an enhancement of Na, Si, and possibly Ca, and depletion of Fe, Mn, and Cr was detected.

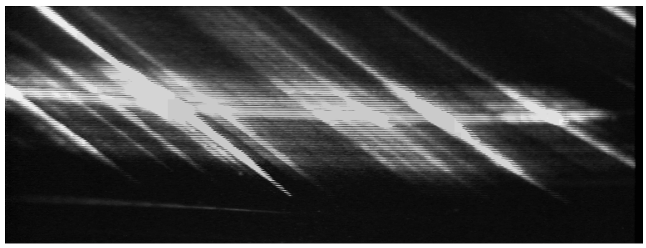

Figure 7 – The television grating spectrum of the EN 090897 fireball. Seven video frames have been co-added. The wavelengths increase from the right to the left. Most lines belong to the high spectral orders (second to fourth). The fireball flew from the top to the bottom. The spectrum was taken with the SIT-vidicon camera using a Stigmar $f = 50$ mm, $f/0.75$ lens and 300 grooves per mm objective grating. Author Jaroslav Boček.

5 The television spectrum

The television grating spectrum TVS 192 was taken at the Ondřejov Observatory and is reproduced in Figure 7. Only the terminal part of the fireball below the height of 92 km was in the field of view. The spectrum was captured in high spectral orders on the non-blazed side of the grating. Despite this, the signal in spectral lines was strongly saturated during the fireball flare because of the high sensitivity of the TV camera. The TV camera is sensitive up to ~ 850 nm. Well known lines of oxygen and nitrogen (Millman & Halliday, 1961; Spurný et al., 2005) were detected in the infrared part not accessible for the photographic observations. In general, however, it was very difficult to extract quantitative information from the TV spectrum because of signal saturation and overlap of lines from different spectral orders. The TV camera would be much more useful if the beginning of the fireball were captured.

6 Temporal evolution of the main emissions

In the following we will concentrate on the temporal evolution of the main emissions using the prism spec-

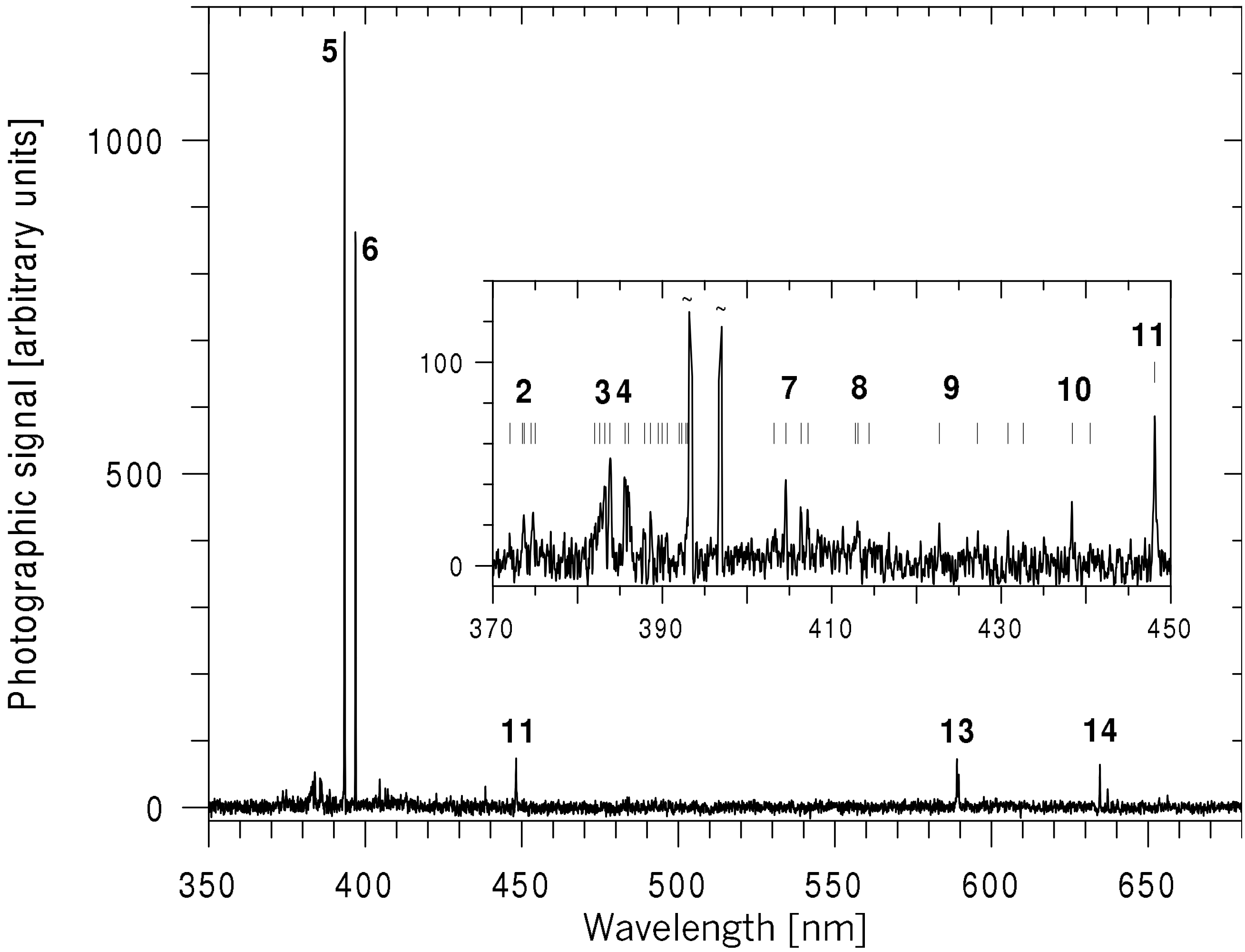

Figure 8 – Photometric scan of the photographic grating spectrum of the EN 090897 fireball at the height of 87 km. The spectrum was *not* corrected for the spectral response of the camera. The blue part of the spectrum is shown in more detail in the inset. Positively identified lines are marked by vertical dashes. The numbers correspond to the numbers of features seen in the prism spectrum (Figure 5).

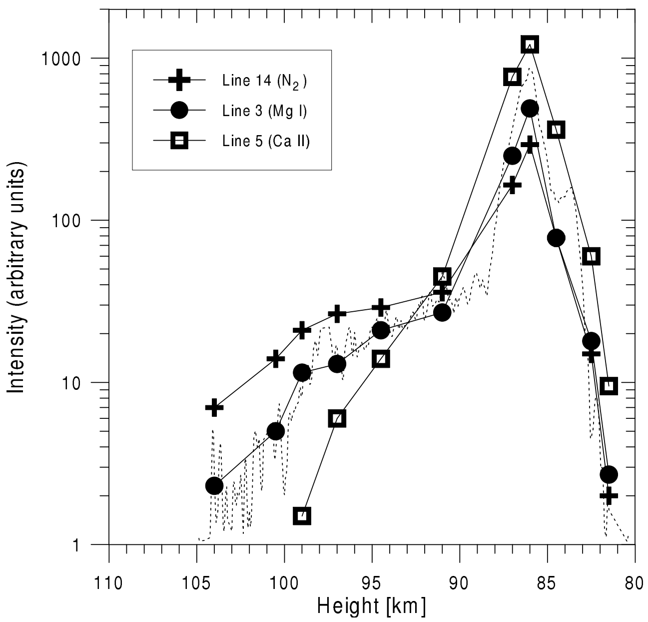

Figure 9 – Three monochromatic light curves of the EN 090897 fireball. Intensities of three emissions are given as a function of fireball height. The dashed line is fireball light curve in white light (in different scale) adapted from Figure 2.

trum. More specifically, line intensities as a function of fireball height will be studied. The spectral features seen in the prism spectrum (Figure 5) are identified in Table 1. The lines of neutral atoms belong to the main spectral component while the lines of ionized atoms belong to the high temperature component. In addition, the bands of the nitrogen molecule contribute significantly to the red part of the spectrum. The ionized nitrogen molecule, recently identified in a Leonid spectrum by Abe et al. (2005), may contribute in the ultraviolet part. The nitrogen molecule came from the atmosphere while the metals were ablated from the meteoroid.

Most of the spectral features were detected only during the bright phase of the fireball. Nevertheless, three representative emissions could be studied over a significant part of the fireball trajectory. These are feature 3 belonging to the main spectral component and due mainly to Mg I, feature 5 belonging to the high temperature component and due to Ca II, and feature 14 due to the atmospheric N_2. The temporal evolution of these emissions is shown in Figure 9.

The most interesting result is that the Ca II lines which are by far the brightest lines in the fireball flare were not seen from the beginning. They started to be visible at the height of 99 km. They brightened rapidly and became the brightest lines in the spectrum at the height of 91 km, i.e. already before the onset of the flare. Their dominance even increased in the flare and at lower heights. On the other hand, the atmospheric N_2 was the dominant emission at the fireball beginning but became less important at latter phases. In the flare, the meteoric emissions of both components increased more than N_2 and also — as TV spectrum shows — more than atomic N and O. This can be naturally explained by the fact that the flare was caused by violent evaporation of meteoric material after meteoroid fragmentation.

The latter onset of the Ca II lines and other high temperature lines was noted earlier by Borovička & Majden (1998). The height scale was, however, unknown. If the high temperature component is connected with the shock wave, it must develop at the time when the so-called continuous flow regime forms around the meteoroid. This occurs when the molecular mean free path in the plasma around the meteoroid becomes smaller than the meteoroid size. The size of the meteoroid was a few centimeters in this case. According to the computations of Popova (2005), the transition to the continuous flow may have occurred at the heights of 90–95 km. This indeed nearly corresponds to the increase of the Ca II lines.

7 Conclusions

We have presented three spectra of a bright Perseid obtained with three different techniques. In this paper we concentrated on the analysis of the photographic prism spectrum. The spectral resolution was relatively low and most of the observed spectral features are in fact blends of many lines. On the other hand, the sensitivity was good and bright emissions could be observed along the whole trajectory. We have studied the temporal evolution of three emissions of different origin. The high temperature meteoric component was absent at the fireball beginning and developed around the height of 95 km. This development likely corresponds to the beginning of the formation of the meteor shock wave when the hydrodynamic flow around the meteoroid was transiting into the continuous flow regime. On the other hand, the atmospheric nitrogen emissions were dominant at the fireball beginning. Though atmospheric emissions were present until the end of the trajectory, they became relatively less important in latter phases when meteoroid evaporation increased. The main meteoric component showed intermediate behavior between the high temperature and atmospheric components.

Acknowledgements

This work was supported by grant no. 205/05/0543 from GAČR.

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Table 1 – Identification of spectral features seen in the prism spectrum

Feature no.	Wavelength [nm]	Main contributors*	Additional contributors*
1	357	Fe I (23, 24)	Cr I (4), N_2^+
2	374	Fe I (5, 21)	Ca II (3)
3	383	Mg I (3)	Fe I (4, 20, 45)
4	386	Fe I (4)	Si II (1)
5	393	Ca II (1)	
6	397	Ca II (1)	
7	404	Fe I (43)	Mn I (2)
8	413	Fe I (43), Si II (3)	
9	423	Ca I (2)	Fe I (42), Cr I (1)
10	441	Fe I (41)	Fe I (2)
11	447	Mg II (4)	Fe I (2)
12	515	Mg I (2)	Fe I (1), Fe II (42)
13	585	Na I (1)	N_2
14	(630)	N_2	Si II (2)

* Multiplet numbers according to Moore (1945) are given in the parentheses.

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Leonids

Sudden Ending Leonids: the inverse problem

Martin Beech [1] *and Pavel Koten* [2]

A special case ablation model is developed for those Leonid meteors whose light curves show a linear rise to maximum brightness but no decreasing brightness branch thereafter. It is shown that the meteoroid mass loss rate must increase exponentially to explain such light curves, and it is suggested that this is indicative of an ablation mode in which the meteoroid crumbles and fragments into smaller and smaller components as it descends through the Earth's upper atmosphere.

Received 2006 January 18

1 Introduction

During the past several years numerous research groups have recorded many thousands of Leonid meteor light curves. As a consequence of this, it is now clear that there is no such thing as a unique Leonid meteor light curve and indeed, the observations show that early, late and symmetrically peaked profiles are all possible (Murray *et al.*, 2002; Koten *et al.*, 2004a). In addition, a number of surprising light curve morphologies have also been recorded, including 'fuzzy' meteors that produced emission over an extended area at extreme atmospheric heights (LeBlanc *et al.,* 2000; Spurny *et al.,* 2000), double-humped light curves (Murray *et al.,* 1998; Rietmeijer, 2002)). Further, at the Meteoroids 2004 conference held at the University of Western Ontario, Canada, Koten *et al.*, (2004b) reported on the observation of sudden ending Leonid (here after SEL) light curves. These Leonids showed a near linear rise to a maximum brightness and displayed no (or virtually no) decreasing brightness branch after maximum (Figure 1).

One of the key reasons for recording meteor light curves is to learn something about meteoroid structure and the possible modes of meteoroid ablation. The aim in principle is to solve the inverse problem, going from the observed brightness variation to the meteoroid mass loss rate, to some inference about the underlying structure of the meteoroid. The dustball model (Hawkes and Jones, 1975), composed of a range of fundamental grain sizes, has been invoked to describe the observed variation in Leonid meteor light curve morphology (Beech and Murray, 2003), but the model makes no claim to providing a unique solution. Campbell-Brown and Koschny (2004), for example, can also explain the range of Leonid light curve morphologies via a fragmentation model and by evoking mass loss via a combination of sublimation and vaporization.

In this article we wish to explore the inverse problem as it applies to the SEL meteors. Indeed, the light curves exhibited by these meteors are such that the mass loss rate can be written down explicitly.

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IMO bibcode WGN-342-beech-leonids
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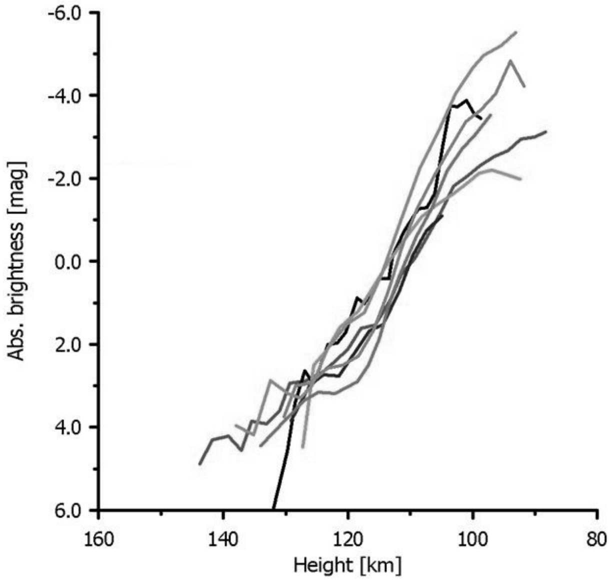

Figure 1 – Sudden ending Leonid meteors. These seven SEL meteors were observed from Arizona during the 2001 Leonid outburst. Over 600 double station meteors in total were recorded during the display.

2 Light variations

The variation in the brightness of a meteor with time, its light curve, is described by the change in the instantaneous kinetic energy of the material ablated from the surface of a meteoroid as it descends through the atmosphere. If I is the intensity of radiation emitted into a solid angle of 4π steradians, then

$$I = \tau \left(-\frac{\mathrm{d}m}{\mathrm{d}t} \right) V^2 \qquad (1)$$

where V is the meteoroid velocity (assumed constant), $\mathrm{d}m/\mathrm{d}t$ the instantaneous mass loss rate; and τ, the luminosity coefficient, represents the portion of the kinetic energy of ablated material converted into electromagnetic radiation per unit time. The equation for the meteor's brightness M in stellar magnitudes is then,

$$M = -2.5 \log_{10} I + \text{constant} \qquad (2)$$

where the constant in equation (2) is related to the measured energy flux of a zero-magnitude star. Photographic and image intensified video observations of meteors are generally reduced to provide the time variation of the magnitude $M(t)$.

At first glance it might seem that the reconstruction of the ablation history of a meteoroid (the inverse problem) from its observed light curve should be a straightforward process. This, however, is not generally the case. This statement having been made immediately requires the qualifier that it is the exact mode of the ablation that can not be determined in general. Certainly the total mass loss rate at any point in the meteoroid's trajectory can be determined from the observations, but this does not constrain the process by which the mass was actually lost from the meteoroid. Indeed, Bronshten (1981) lists six different modes of possible meteoroid ablation. These are, mechanical breaking between fracture boundaries; crumbling of friable material into grains; husking; the spraying of molten droplets; pulverization and powdering. To these one can also add sublimation of volatile elements and sputtering. In general, therefore, the meteoroid mass loss rate can be written in the form:

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \dot{m}_{\text{fragmentation}} + \dot{m}_{\text{fusion}} + \dot{m}_{\text{sublimation}} + \dot{m}_{\text{sputtering}} + \ldots \quad (3)$$

The complicating point, of course, is that the various modes of ablation will operate at different times (or heights) during a meteoroid's decent through the atmosphere. In general, therefore, a unique inverse solution identifying the behavior of all possible ablation modes is not currently possible.

3 Sudden Ending Leonids (SEL)

The SEL light curves are particularly interesting for at least two reasons. Firstly they show no, or virtually no descending branch after reaching maximum brightness, and second, the variation in brightness is approximately linear with time, t, such that $M(t) = -\psi t + k$, where ψ is the slope and k is a constant.

Under the constant velocity approximation, which applies to a good order of accuracy in the case of Leonid meteoroids, the classical ablation mass loss rate varies as $(\mathrm{d}m/\mathrm{d}t) \sim m^{2/3}\rho(h)$, where $\rho(h)$ is the atmospheric density at height $h(t)$. In this manner, $\mathrm{d}m/\mathrm{d}t$ is small to begin with, because $\rho(h)$ is small in the upper atmosphere, reaches some maximum value and then decreases again as the mass approaches zero, due to rapid ablation, at lower atmospheric heights. In this respect the magnitude variation (determined via equations 1 and 2) will simply follow that of the $\mathrm{d}m/\mathrm{d}t$ term — that is show a classical light curve, which gently rises to a maximum brightness and thereafter falls rapidly in brightness. As shown by Beech and Hargrove (2005a; 2005b), such a classical light curve must always result for a monolithic meteoroid ablating at constant velocity in an isothermal atmosphere. For SEL light curves, however, the linearity of the rising branch (and there being no descending branch) places tight constraints on the total mass loss rate as a function of time (or atmospheric height).

4 The SEL inverse problem

In general the mass loss rate due to ablation can be a constant, an increasing or a decreasing function of time. To produce a linear variation in the brightness of a meteor, however, the mass loss rate must be constant or increase/decrease continuously with time. In this latter sense the three options for the time variation of the meteoroid mass $m(t)$ are:

$$m(t) = \begin{cases} m_0[\alpha - \exp(\beta t)]/(\alpha - 1) & (4a) \\ m_0 - \beta t & (4b) \\ m_0 \exp(-\beta t) & (4c) \end{cases}$$

where t is the time, $\alpha > 1$ is a constant, m_0 is the initial meteoroid mass, and where β relates to the gradient of the resultant linear light curve. Differentiating equations 4(a, b and c) with respect to time, and inserting the resultant expressions in equations into (1) and (2) will yield linear magnitude versus time light curves.

A constant velocity meteoroid varying in mass according to either equation (4a) or (4c) will produce a linear light curve of slope $\phi = 2.5\beta/\ln(10)$; the only distinction being that in the first case the meteor increases in brightness and in the second it decreases in brightness. Hence the (4a) mass variation is the interesting case. Equation (4b) will produce a flat, linear light curve. The duration (T) of meteors with mass variations given by equations (4a) and (4b) will be $\ln(\alpha)/\beta$, and m_0/β respectively. If m_{E} is the mass at which ablation ceases, then the duration of the meteor produced by a mass variation in the form of equation (4c) is $T = -\ln(m_{\mathrm{E}}/m_0)/\beta$. The relationship between the various forms of the mass loss variation and the resultant light curves is shown schematically in Figure 2.

Equation (4a) provides the correct form for the mass loss rate in the case of the observed SEL meteors. Hence the total ablation rate for these meteors increase exponentially with time, such that

$$\mathrm{d}m/\mathrm{d}t = -[m_0\beta/(\alpha - 1)]exp(\beta t), \quad \alpha > 1 \quad (5)$$

The variation ΔM between the brightness at first detection (i.e., at $t = 0$) and maximum (at $t = T$) is given by the expression:

$$\Delta M = 2.5\beta T/\ln(10) \quad (6)$$

where $T = \ln(\alpha)/\beta$ is the duration of the meteor. The constants α and β can be derived from the observed light curves (figure 1). We find that the average gradient of all the light curves is $< \Delta M/\Delta h > \ = 0.22 \pm 0.04$ mag/km, which if we assume a velocity of 70 km/s translates to a value of $\beta \approx 14$ mag./sec. From the relationship $T = \ln(\alpha)/\beta$ we find a range of α-values bounded by $10^2 < \alpha < 10^4$.

5 Discussion

By the appropriate choice of constant terms, mass loss equation (5) can be transformed into the 'standard' ablation mass loss equation (see e.g., Bronshten, 1991, p.

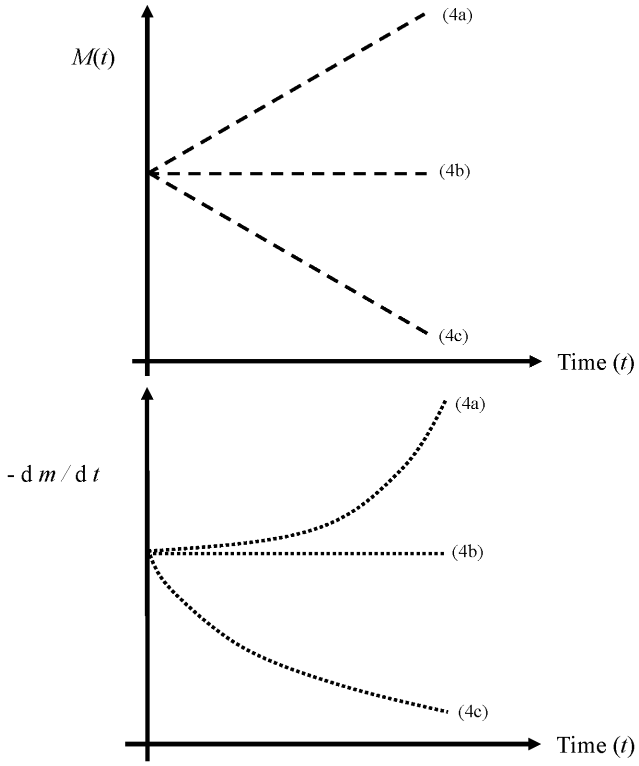

Figure 2 – Schematic variation of meteor brightness and the ablation mass loss rate. The lines are labeled according to equation (4).

12 – equation 3.2). The interesting point, however, is that the transform only holds true provided the cross-section area of the meteoroid (S) is a constant independent of the meteoroid mass. This corresponds to the $\mu = 0$ light curve model presented by Levin (1963) — see his figure 1. Under 'classical' ablation conditions the meteoroid is assumed to be self-similar (i.e., a sphere) at all times and correspondingly $S \sim m^{\mu}$ with $\mu = 2/3$. The $\mu = 0$ condition would be satisfied for a cylinder-like meteoroid with ablation taking place from just one end face. The ablation condition would require the unreasonable constraint of constant end-on orientation as the meteoroid descended through the atmosphere. This scenario, therefore, does not seem reasonable for an explanation of the SEL phenomenon.

The SEL meteors observed by Koten *et al.,* (2004b) begin at atmospheric heights between 145 and 130-km altitude. This beginning height suggests that the meteoroid material must be very friable. Campbell-Brown and Koschny (2004) suggest that it is the sublimation of volatile elements that is responsible for the high beginning heights observed for Leonid meteors. This may well be true, but the sublimation mass loss mechanism alone won't account for the observed behavior of the SEL meteors. This is because the sublimation varies as the exposed surface area (which in turn varies as the mass to the 2/3 power), and this becomes smaller with time and increasing penetration into the Earth's atmosphere. The mass loss rate for SEL meteors, in contrast, and as indicated in equation (5), requires an exponential increase in the $\mathrm{d}m/\mathrm{d}t$ term with time. This mass loss growth rate suggests some form of crumbling or continuous fission-like fragmentation to a very fine 'powder'. The descending branch is 'avoided' in this situation, we suggest, because of the continuous breakup of the material into smaller and smaller fragments.

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History

Meteor Beliefs Project: Meteoric imagery in SF, Part III - A Third Anniversary entertainment

Alastair McBeath[1] *and Andrei Dorian Gheorghe*[2]

Notes based on four movies featuring meteoric appearances with especially silly to ridiculous aspects are presented, by way of celebrating the Meteor Beliefs Project's third anniversary.

1 Introduction

In the first of our SF articles within the Meteor Beliefs Project (McBeath & Gheorghe, 2005), we noted that we had identified some films for the Project's anniversary article. These are items which either push the bounds of what suspension of disbelief can realistically contain, especially for a scientifically-minded audience, or which have some other entertaining qualities not intended by their originators. As usual, if you have come across any similar things with meteoric content, we would welcome learning of them. We present notes on four films here, in date order, though our information has been extracted from written synopses, as neither of us have seen any of these films. Overall, we are not sorry this is so...

2 'Cat-Women of the Moon' (1953)

Most of the following details came from the excellent (Warren, 1982, pp. 104–109 & 412). This was one of a number of films made in the 1950s and 60s with mildly salacious titles, and featuring scantily — or only partly — clothed, attractive young women, films intended to appeal chiefly to a young adult male audience. Made by Z-M Productions in black-and-white, it has been shown sometimes under the title 'Rocket to the Moon', and incredibly was remade as 'Missile to the Moon' in 1958. Incredibly, because, '*Cat-Women of the Moon* is one of the most alarmingly awful films in the history of movies' (*op. cit.*, p. 105), and 'The special effects aren't' (*op. cit.*, p. 108).

Astoundingly, there were two meteoric events of note in it. In the first, while a rocketship was *en route* to the Moon, there was a collision with a 'meteor', in which some acid in the rocket's lowest compartment (Warren actually called it 'the basement', which gives a clue as to how poor the sets were) caught fire. Please do not ask us for an explanation; there is none... The problem was solved by spinning the ship end over end (largely using the very cheap effect of rotating the camera), to make the 'meteor' fall off — which it did (*op. cit.*, pp. 104–105).

When the rocket eventually reached the Moon, as the explorers moved out across the surface, 'A meteor, blazing and dropping sparks, swoops down at them, but they duck and it heads back into space. As it leaves, it sucks up the sparks it was dropping' (*op. cit.*, p.107). Any comment we might make to this would be superfluous.

3 'Riders to the Stars' (1954)

An A-Men Production colour film, directed by Richard Carlson, and made in the USA, this is a curiosity, mostly for the reactions of the critics to it. In its day, it was generally well-received, but presumably by those for whom 'science' was merely a word, rather than an approach to try to understand the universe. Although more modernly considered a poor film, this is supposedly because it too-worthily presents itself as science-fact than fiction. For instance, Fane-Saunders (2001, p. 276) described it as a text-book account of how genuine problems encountered during space-travel might be overcome, and criticized the dry analysis in the script which stopped the action from being workable. From the meteor science angle, this entirely misses the real problems.

Moving on to a more useful source, Warren (1982, pp. 182–185 & 431) noted that despite the title, the film's rockets never got beyond the Earth's ionosphere, and that although there was too much scientific explanation, the science was patently ludicrous. The special effects were very poor too, it seems, including the dubious pleasures of rockets running on wires, which did nothing to help. The central theme of the plot was meteors, as Bill Warren (*op. cit.*, p. 182) explained:

'According to *Riders to the Stars*, cosmic rays crystallize and destroy metals and minerals outside the Earth's atmosphere. One character even points out that these cosmic rays are "turning the Moon into a ball of dust." ' ... 'But meteors travel through space unharmed, burning up only when they enter Earth's atmosphere. Therefore, reasons Dr. Donald Stanton (Herbert Marshall), they must be protected in some way.'

Consequently, manned rockets were planned to be sent above the atmosphere to catch a 'meteor' and return it intact. Having discovered the nature of the coating protecting said meteor(oid), the plan would continue to replicate this to protect future spacecraft from destruction by cosmic rays. As Warren stated, even in 1953 all this was nonsense. To be fair, we might wish

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IMO bibcode WGN-342-mcbeath-mbp19
NASA-ADS bibcode 2006JIMO...34...58M

to capture some pre-atmospheric meteoroids still today, and return them intact to the surface for examination, though the technology to do so would need to be rather more sophisticated than that in this movie.

Much of the film was devoted to the tediously thorough, slow, selection process, whereby three astronauts were chosen to fly the 'meteor-catching' rockets: Stanton (played by William Lundigan), Lockwood (actor-director Richard Carlson) and Gordan (Robert Karnes). They were then duly sent off on their missions, using scoops to catch the 'meteors' in. The 'meteors' were intended to be large enough to be seen easily, but since Warren did not mention any such details in the film, we too shall pass quietly over the whole question of velocity-mass and deceleration in this respect.

Gordan tried to catch an object too big for his scoop, and his craft exploded. Lockwood saw Gordan's body floating in space, went mad, and shot his rocket off into the depths of space. Thus Stanton was left alone to secure a 'flying rock', as Warren put it, and return it to Earth. 'There it is discovered that the meteor is covered with crystallized carbon: diamond. No one seems to wonder at just how all these meteors became covered with diamond, and the potential expense of making diamond-encrusted rockets croggles the mind' (*op. cit.*, p. 183).

Quite how a diamond-coated meteoroid would be protected from highly energetic cosmic rays, capable of passing through the Earth and its atmosphere virtually unhindered, yet still ablate by the less energetic process of frictional heating in the upper atmosphere was not explored by the film either, let alone explained. Warren pointed this out too.

4 'The Astounding She-Monster' (1958)

A Hollywood International black-and-white film, made in the USA. Released in Britain as 'The Mysterious Invader', although the American title is probably a better warning. Bill Warren's comment (Warren, 1986, p. 5): 'it's one of the worst science fiction films ever made.' Warren (*op. cit*, pp. 2–5 & 731) provided most of the following details, including that the film was shot in just four days. This tight schedule will become important, as we shall discover, though the meteoric event is really just a convenient excuse to use this film here.

A meteor-like spacecraft was sent on a mission to Earth from a planet around Antares (α Scorpii, for those who might care about such things). When it arrived one night, a lone geologist in a forest near Los Angeles, California, USA, saw a singularly unconvincing meteor ('a fuzzy ball of light' (*op. cit*, p. 2)) fly over the close-by trees and crash into the forest a little way off. After this, the craft's occupant, an alien, though still distinctively human, woman was seen 'frightening' various stock-footage shots of startled animals, and casting aside an obviously rubber snake. She wore a tight-fitting, sparkling, spandex jumpsuit and shiny shoes, apparently meant to show that she was glowing with radiation.

The essential concept here is the 'tight-fitting jumpsuit'. Most unfortunately, although less so from our perspective, the actress wearing it bent over to 'kill' another character on the first day of filming, and ripped the back of the suit. As there was no time to repair it, she entered and exited all her subsequent scenes facing the camera, commonly walking backwards to do so - 'but aliens are weird', as Warren (*op. cit*, p. 3) helpfully noted.

5 'First Spaceship On Venus' (1960)

An East German-Polish colour film by the Defa/Iluzjon film-unit, Polski-Centrala Productions. Released in East Germany as 'Der Schweigende Stern' ('The Silent Star'), in Poland as 'Milczaca Gwiazda' ('Planet of the Dead'), in 1960, running to either 130 or 109 minutes. A cut-down, poorly-dubbed, version, lasting just 78 minutes, was released in the West in 1962 as 'First Spaceship On Venus'. The movie was based on Stanislaw Lem's novel 'Astronauci' ('The Astronauts'), although Lem was said to have disliked the film adaptation. Our notes here derive primarily from (Warren, 1986, pp. 627–631 & 741), who described it as being largely an anti-nuclear war story masquerading as a space-exploration one.

The film was set in the then future of 1985, during the irrigation of the Gobi Desert. A mysterious rock was discovered there, containing a spool of tape, somehow identified as of extraterrestrial origin. Again by unexplained means, it was deduced that this rock was a fragment of the Tunguska event of 1908 June 30, and it transpired that the Tunguska event was really an exploding spacecraft, while the tape spool was ejected just before the craft blew up (how fortunate...). While initially indecipherable, somehow its origin on Venus was made known, and so an international space mission was launched to Venus - together with the tape spool, so the crew could decipher it along the way.

During the flight, there was the obligatory near-disaster from a 'meteor shower'. Though Warren commented that this danger was overcome rather more realistically than in American films, the 'realism' once again ignored minor problems, such as the relative velocities involved. While most of the 'meteor fragments' were dodged, one still managed to strike the ship, in a non-critical area, naturally, making the ship lurch, and throwing the crew into an untidy heap. There followed the equally obligatory space-walk to repair the external damage.

In spite of such distractions, the crew still found time to decipher the tape. From this, they discovered the original craft was to invade Earth, and conquer it using bursts of intense radiation. After landing on Venus, they found much of that planet had been devastated by a nuclear disaster, just as the attack on Earth was about to get underway, and which, by some unexplained mechanism, also caused the spacecraft at Earth to explode.

Ludicrous though it may be, we wondered if Lem received any royalties for the repeated use of his idea that the Tunguska event was due to an alien spacecraft, as this remains a popular 'explanation' in some quarters. It was revived yet again in 2004 August (see the Cambridge Conference Network e-notices between the CCNet Extra of 2004 August 10 and CCNet 109/2004 for August 31, for the initial press notice and subsequent comments), when one of us — AM — felt compelled to add a brief note to the CCNet discussion regarding this matter of potential royalties.

6 Conclusion

We hope the above provided a little amusement. Although we have included the better examples found so far, it does not exhaust the stock of poor-quality meteoric appearances in films.

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A θ Ophiuchid in Sagittarius

Photograph by Pedro Arranz Garcia at Lillo, Toledo (Spain)
on 1991 June 9/10 at $23^h40^m00^s$–$23^h43^m00^s$ UT.
Camera: Ricoh. Lens: $f = 28$ mm, $f/2.8$. Film: Ektar 100 ISO. Photographic field: Sagittarius.
Apparent reported meteor magnitude: $-2/-3$. Photo from SPMN archive.
For more details, see the paper on page 40.