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2003 Lyrids
2002 Leonids
Persistent trains
Minor shower search
Ancient meteor imagery
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Front cover photo

This strange and graceful shape is a persistent Leonid train photographed by James Wren on 1998 November 17, 08^h32^m UT through a Canon 200mm f/1.8 lens. This research was part of the ROTSE Collaboration and was supported by it. An analysis of such trains can be found in Peter Jenniskens' paper on page 88; further details of the train shown here can be found in the reference (Zinn et al., 1999) in Jenniskens' paper. Reproduced by kind permission of John Zinn and James Wren of Los Alamos National Laboratory.

Future covers

Have you an interesting or spectacular meteor photograph that you think would look good on the cover of WGN? If so, please offer it to us. For the moment we can only accept machine-readable forms. More or less any image format will do, though ideally not JPEG as the JPEG compression algorithms lose information. A brief description will also be required: this should say what the photograph shows, when and where it was taken, plus (if possible) technical details such as the camera and exposure. We can be contacted at `wgn@imo.net`.

Cover design Rainer Arlt

Editorial — Media or mediocre?

Chris Trayner

Valentin Velkov's letter (below) may arouse heated feelings in others who have experienced media misrepresentation. As often in such situations, understanding both sides can help.

My own experience divides TV crews into two groups: documentary and news. The former often produce good, accurate, informative television (though, sadly, some lack the motivation). But they, like those of us who write scientific papers, have a luxury news reporters often lack: time to get the facts right. This means reading, comparing information sources, checking, re-checking.

In a TV news team, deadlines are tight. It is now mid-day and your news item will be broadcast at 18:00. You cannot spend the afternoon in the Library and then phone someone this evening to ask their opinion. It is actually worse than this: once you have your interview you must edit it for transmission and get it to the studio. This must be in time for the news editor to see if it is satisfactory, well before broadcast.

Meteor showers and comets seem to suffer more than usual here, being unpredictable. I have seen the results often enough, and know the astronomers 'quoted' well enough, to have a strong suspicion of what happens. Knowledgeable astronomers make cautious statements like 'it will possibly be a spectacular shower' or 'it will probably be an impressive comet'. The reporter must edit (e.g.) a fifteen-minute interview down to a two-minute programme slot and cut out all un-necessary words. Working alone in the edit suite, they have only their own judgement, and it is understandable if 'possibly' and 'probably' are edited out. If the event is spectacular, everyone is pleased; but if not, viewers trust the media and blame 'those stupid scientists'.

The public demand instant news; or so the TV channels assure us, though they probably cultivated this demand. The reality is that we need to understand their deadlines and limitations if accurate information is to be broadcast. Interviewers do not try to mis-represent their interviewees, but they are expected to be specialists in everything they report on: aircraft, opera, diving, horse racing, supernovae, farming ... Ideally we would provide all the reporters with a printed handout (a press release) explaining the things they need to know about our speciality. In reality, this may not be possible. Perhaps the best we can do is to ask the reporters if there is anything else they want to ask, and hope that they understood most of it.

You can never get perfection in life, and the Bulgarian event may have done more good and less harm than Valentin fears. One important result was that many people phoned the Observatory. This gave the Observatory some chance to correct misunderstandings and to encourage public interest. It also means that the TV had stimulated public interest in meteors, and that the public are willing to be interested. By being available to the public as an information source, Valentin's observatory made good use of the unexpected publicity. The media are important: they can show astronomy to a wider public. Sometimes we can help them do it well.

Letters

from Valentin Velkov[1]

The following is a short story about the aberrations of the mass media. On 2003 January 28, February 3 and 11, I was able to observe C/2002 V NEAT three times. During my second observation I even managed to photograph it. In the night of February 3/4, after taking pictures of the Comet, I stayed in Avren village to watch meteors. There were no bright meteors and fireballs, the meteors appeared chaotically without any noticeable radiant — neither February Bootids, nor Serpentids. But in the next days we witnessed another kind of curious event — excitement in the mass media generated by a non-existent meteor storm.

The story is as follows: On the morning of February 4, the TV showed an interview with a professional astronomer (our former student in the Varna observatory) who was asked about the interesting astronomical events that were expected in February 2003. Among them he mentioned the Virginid meteor shower and described it as the shower with the longest activity period (February till the end of April). While he was giving these explanations, the journalists (who can not make distinction between meteor shower and meteor storm) were showing directly the motion picture given on the computer screen by the program METSIM designed by Sirko Molau to train observers for watching the Leonid storm. As a result the public was left with the impression that the longest meteor *storm* was expected, lasting from February to April! Similar information appeared even in a newspaper and a web-site. A lot of people phoned to our observatory and asked what a meteor storm was and how they could see it. We were quite puzzled at first and needed three days to find out what had happened and how this rumour was born.

[1] *Astronomical Observatory and Planetarium "N. Copernicus", P.O.Box 120, BG-9000 Varna, Bulgaria*

The 2003 International Meteor Conference in Bollmannsruh, Germany

Jürgen Rendtel

The IMC 2003

The International Meteor Organization (IMO) will hold its next International Meteor Conference (IMC) in Bollmannsruh, Germany, on 18–21 September 2003. The location is about 40 km west of Berlin, or about 20 km northeast of the city of Brandenburg. The IMC 2003 is organized by the German meteor observing society Arbeitskreis Meteore e.V. Part of the program is an excursion to the Berlin Museum of Natural History where Prof. Stöffler will give a lecture about meteorites and their identification and guide participants through the meteorite collection.

Several IMO members and long-term meteor enthusiasts remember that the IMO was founded in 1988 at an IMC in Oldenzaal, the Netherlands. The IMC 2003 marks our 15th anniversary — a good opportunity to look back (with lots of pictures) and to plan for the future. Furthermore, it is the first IMC after the series of spectacular Leonid returns — time for reviews and projects. Please announce your planned contributions as soon as you register. Not only does this make it easier for the organizers, but it may also attract more people who have not yet decided to attend. It could also let participants think about bringing extra (raw, unpublished or preliminary) data and material if a specific topic is announced. (This is always recommended, of course, as discussions may yield new aspects and views on results and data.)

Registration

If you wish to attend the conference, please fill out the registration form on the next page. You can also download it from the IMO website: http://www.imo.net. Send it to: Ina Rendtel, Mehlbeerenweg 5, D-14469 Potsdam, Germany. The registration fee includes lodging, meals and the Proceedings. We offer an early registration fee of 115 EUR if your registration reaches us by 11 July 2003. Participants registrating after that pay a late registration fee of 130 EUR. We are currently checking the possibility of a limited number of reduced registration fees. People interested in such a reduced fee should indicate this on the (pre-)registration. The details will be mentioned on our web page as soon as they are definite. Please note that the IMO also offers travel support (guidelines to be published in the IMO Journal WGN elsewhere).

If there are people interested, we can arrange a program for accompanying persons. Please let us know about people who intend to travel with you but do not wish to attend the IMC. We may organize a program for these guests, who may visit Potsdam with its world-famous castles and parks as well as sights of Berlin. The costs for such a program would depend on the number of participants and on the entrance fees of the places visited.

Administrative

Have a look at the web page of the German Foreign Office:

http://www.auswaertiges-amt.de/www/en/willkommen/einreisebestimmungen/visumangelegenheiten_html

Here you find all information about visa regulations including a visa application form etc. We also provide information on our web site http://aipsoe.aip.de/~rend/2003imc.html which will be updated regularly.

International Meteor Conference

Bollmansruh, Germany, September 18–21, 2003

Registration Form

Each individual participant should fill out a form and return it to *Ina Rendtel, Mehlbeerenweg 5, 14469 Potsdam, Germany*, as soon as possible. Your registration will be guaranteed only after Ina Rendtel has received the minimum pre-payment of 50 EUR. 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: ______________________________ Birth date: __________

Address: ____

____

____

Phone: ____________ Fax: ____________ E-Mail: ____________

- ○ wishes to register for the 2003 *IMC* from September 18 to 21;
- ○ intends to participate, cannot yet register, but wishes to stay on the mailing list.

I intend to travel by ________, together with ______________________

Additional requests:

- ○ I need travel information from ______________ to Bollmannsruh;
- ○ I wish to stay in Germany before or after the *IMC* and require additional information.

For participants wishing to contribute to the program:

Lecture: ____

Duration: ________min. Required equipment: ______________________

Workshop or discussion: ______________________________

Poster presentation: ______________________ Space: ________ m^2

Either the entire fee of 115 EUR or a pre-payment of 50 EUR should be sent to the Treasurer, *Ina Rendtel*. Follow the payment instructions below. Participants making a pre-payment only have to pay the remaining 65 EUR in cash upon arrival in Germany. The registration fee increases to 130 EUR for participants registering after July 11, 2003.

Date and signature: ______________________________

Please send your payment to the Treasurer or one of her assistants as indicated below:

- in Europe: pay in EUR to Ina Rendtel, account number 547234107 at Postbank Berlin, bank code 10010010. No bank checks, please! (Bank checks can only be sent to Robert Lunsford, see below).
- in the UK: proceed as above or pay to Alastair McBeath, 12A Prior's Walk, Morpeth, Northumberland NE61 2RF, England.
- in Japan: pay to Masahiro Koseki, 4-3-5 Annaka, Annaka-shi, 379-01 Gunma-ken, Japan.
- all others pay in USD to Robert Lunsford, 161 Vance Street, Chula Vista, California 91910, USA. In case you pay by bank check, make it payable to Robert Lunsford, *not* the *IMO*!

People wishing to pay in other currencies should contact the appropriate IMO *contact person for exchange rates.*

Financial Support to Participants of the 2003 IMC

communicated by the IMO Council

As last year, the *IMO* makes available funding to support attendance at the *2003 International Meteor Conference* (*IMC*). If you wish to apply for support, proceed as follows:

1. E-mail your application to the *IMO* President, Jürgen Rendtel, at `president@imo.net`. The application must be submitted by an *IMO* member, but may also request support for other meteor workers. The proposal must state that all the candidates are committed to attend the *IMC* (except for unforeseen circumstances) if the requested support is granted in full.

2. An *IMC* Registration Form for each of the persons for whom support is requested should be returned for the application to be valid, unless such a form has already been sent.

3. The application must also contain a brief curriculum vitae of each of these persons, focusing on aspects relevant to meteor work. Supported participants are expected to present either a talk or a poster at the *IMC* (to be indicated on the Registration Form).

4. The application must explain the motivation for attending the *IMC* and the importance of it to the person or group of persons requesting support.

5. The application must contain a budget for travel costs and registration, and the amount of support requested from the *IMO*. Other sources of external support, or their absence, must be mentioned. Finally, the proposal must also indicate to what extent *IMO* support is essential for being able to attend the *IMC*.

6. The applications should reach the President no later than 2003 July 31. The decision of the *IMO* Council will be made within a week after the this deadline. If the requested support is accorded in full, the registration forms become final. If the requested support is not accorded, or only partially accorded, the candidates should inform the President within three weeks after notification of the *IMO* Council's decision if they want to sustain or withdraw their registration. The accorded support will be paid in cash at the *IMC*. Any unpaid registration fees will be deducted from the amount paid to the candidates.

Should the application be turned down, the standard conference fee (i.e. without the surcharge for late application) will still apply.

We strongly encourage all meteor workers who are motivated to attend the *2003 IMC*, but who are prevented to do so by financial considerations, to make use of this opportunity and to apply for support. Information about this *IMC* can be found on the previous pages.

Leonids

Bulletin 19 of the International Leonid Watch: Population index study of the 2002 Leonid meteors

Rainer Arlt [1]

In this part of a series of global analyses of the Leonid meteor storms, the population index r of the 2002 shower is investigated. Details of the determination of the population index and conversion tables for easy r-estimates and their error margins are given. The study is based on the magnitude distributions with 47 345 Leonids recorded by 195 observers. A dependence of the population index on the radiant elevation is indicated, but no clear trend was found after scrutiny of the problem. A final profile is presented based on magnitude distributions with radiant heights no lower than 55°. A background level of $r = 1.9$ between solar longitudes 236° and 237° is superimposed by two maxima of $r = 2.5 \pm 0.1$ and $r = 3.4 \pm 0.3$ at solar longitudes 236°62–236°65 (November 19, 04:15–05:00 UT) and 236°87 (November 19, 10:12±10 min UT). These peaks are associated with the encounter of the 7-revolution and 4-revolution dust trails, respectively. The r-values convert to mass indices of $s = 1.9 \pm 0.05$ and $s = 2.3 \pm 0.1$, respectively. The paper presents perception characteristics of 90 long-term observers which are specially applicable to data obtained under poor observing conditions.

1 Introduction

Five years of impressive Leonid activity are now behind us, and this is probably one of the last issues of International Leonid Watch Bulletins dealing with storms of Leonids for a large number of years. While the coming years are not likely to provide us with very impressive activity, comparative studies covering the entire epoch of Leonid maxima connected with the return of the parent Comet 55P/Tempel-Tuttle are planned.

Predictions based on the numerical integration of Leonid particles were presented by Lyytinen et al. (2000), McNaught & Asher (2002) and Vaubaillon (2002). These give peak times of November 19, $03^{\rm h}56^{\rm m}$ to $04^{\rm h}04^{\rm m}$ UT ($\lambda_\odot = 236\overset{\circ}{.}606$ to $236\overset{\circ}{.}612$; eq. J2000.0) for the 7-revolution-old dust trail, and times between $10^{\rm h}34^{\rm m}$ and $10^{\rm h}47^{\rm m}$ UT on the same day ($\lambda_\odot = 236\overset{\circ}{.}885$ to $236\overset{\circ}{.}894$) for the 4-revolution-old dust trail. McNaught & Asher mention that a lower population index for the 7-revolution trail than for the 4-revolution trail is likely, because the particles coming close to Earth have smaller semi-major-axis deviations from the Comet and may thus be larger in general.

The observers faced strong lunar interference during the peak night of 2002 November 18/19. The Moon set just before dawn, and there was a short period when the limiting magnitudes at most locations improved by a few tenths of a magnitude before the Sun's depression became too small.

A large number of observers were alert mostly located in Europe and North America for the two expected storms. Although the first peak was well observed also from northern Africa and in its rise also from the Near East, we will term this storm 'European' for simplicity (from the 7-revolution dust trail); the second peak will be termed 'American' (from the 4-revolution dust trail).

The following list gives the names of those meteor observers who were successful in recording magnitude distributions for the 47 345 Leonids used in this analysis, but fails to acknowledge the efforts of all those who were clouded out and could not afford to travel long distances to clear patches on Earth. By March 2003, the 195 contributors of the total of 3107 magnitude distributions of the 2002 Leonids are

Sana'a Abdo (ABDSA, 243), Ioan Adam (ADAIO, 23), Ardalan Alizadeh (ALIAR, 61), Milica Andjelić (ANDML, 350), Rainer Arlt (ARLRA, 660), Jure Atanackov (ATAJU, 1651), Aleksandar Atevik (ATEAL, 70), Lars Bakmann (BAKLA, 334), Igor Balyuk (BALIG, 2), Ana Banković (BANAN, 489), Aleksander Baransky (BARAL, 499), Zohreh Barzegar (BARZO, 26), Luc Bastiaens (BASLU, 867), Jaydeep Belapure (BELJA, 63), Abdellaif Bendahhou (BENAE, 143), Orlando Benítez Sanchez (BENOR, 222), Lance Benner (BENLA, 418), Bojan Besednik (BESBO, 256), Sushrut Bhanushali (BHASU, 6), Daniel Bil (BILDA, 159), Nicolas Biver (BIVNI, 99), Lukas Bolz (BOLLU, 530), András Borsos (BORAF, 12), Adriyan Bozinovski (BOZAD, 66), Emil Brezina (BREEM, 56), Ivan Bryukhanov (BRYIV, 1), Andreas Buchmann (BUCAN, 696), Vasko Cacanoski (CACVA, 119), Lucia Cachovanová (CACLU, 28), Igor Chalenko (CHAIG, 407), Neophite Chanev (CHANE, 70), Gábor Csomós (CSOGA, 17), Tibor Csörgei (CSOTI, 29), Haakon Dahle (DAHHA, 912), Zolfaqar Daneshi (DANZO, 58), Mark Davis (DAVMA, 185), Parag B. Deotare (DEOPA, 4), Maribel Díaz Martin (DIAMA, 103), Aleksandra Dimitrievska (DIMAL, 172), Sergey Dubrowsky (DUBSE, 2), Tomas Dvořak (DVOTO, 496), Shlomi Eini (EINSH, 249), Dunja Fabjan (FABDU, 924), Ján Fabricius (FABJA, 290), Farzad Falahati (FALFA, 36), Boglárka Farkas (FARBO, 573), David Fernández Barba (FERDB, 589), Mark Fox (FOXMA, 1), Xing Gao (GAOXI, 64), Petros Georgopoulos (GEOPE, 399),

[1] *Friedenstr. 5, D-14109 Berlin, Germany. E-mail:* rarlt@aip.de

Christoph Gerber (GERCH, 1), Jaroslav Gerboš (GERJA, 310), George W. Gliba (GLIGE, 420), William Godley (GODWI, 45), Shelagh Godwin (GODSH, 63), Darja Golikowa (GOLDA, 296), Nelida González (GONNE, 30), Michał Goraus (GORMI, 5), Sylvie Gorkova (GORSY, 374), Bjorn H. Granslo (GRABJ, 587), Vered Greenberg (GREVE, 223), Valentin Grigore (GRIVA, 19), Eva Grillova (GRIEV, 239), Pavol Habuda (HABPA, 98), Mahmood Hajzaman (HAJMH, 51), Christian Bernt Håkonsen (HAKCH, 143), Joost Hartman (HARJS, 525), Takema Hashimoto (HASTA, 120), Amir Hassanzadeh (HASAM, 70), Dorottya Hatvani (HATDF, 134), Roberto Haver (HAVRO, 26), Robert Hays (HAYRO, 41), Lars Trygve Heen (HEELA, 809), Iva Hlavackova (HLAIV, 24), Ken Hodonsky (HODKE, 399), Nathalie Hontelé (HONNA, 409), Martin Hörenz (HORMJ, 119), Kamil Hornoch (HORKM, 895), Hao Jia (HAOJI, 4), Paul Jones (JONPU, 478), Bhargav Joshi (JOSBH, 88), Javor Kac (KACJA, 1040), Jan Karabas (KARJA, 28), Manos Kardasis (KARMN, 204), Roy Keeris (KEERO, 670), Lance Kelly (KELLA, 2), Ákos Kereszturi (KERAK, 173), Timo Kinnunen (KINTI, 40), Maksim Kititsa (KITMA, 117), André Knöfel (KNOAN, 48), Ralf Koschack (KOSRA, 265), Detlef Koschny (KOSDE, 343), Jakub Koukal (KOUJA, 630), Tomasz Kowalski (KOWTF, 104), Zoltan Kuli (KULZF, 178), Maciej Kwinta (KWIMA, 459), Nina Lampič (LAMNI, 663), Semion Levin (LEVSE, 242), Anna S. Levina (LEVAN, 266), Michael Linnolt (LINMI, 46), Hai Lu (LU HA, 50), Hartwig Lüthen (LUTHA, 206), Jose Luis Maestre García (MAEJO, 45), Juan Jesús Maestre García (MAEJU, 8), Prajakta Mahajan (MAHPR, 20), Veikko Mäkelä (MAKVE, 202), Grigoris Maravelias (MARGE, 285), Fernando G. Marin (MARIN, 28), Vladimir Marjanović (MARVL, 171), Christophe Marlot (MARCH, 425), Adam Marsh (MARAD, 1), Pierre Martin (MARPI, 654), Marc Mathay (MATMR, 595), Bert Matous (MATBE, 561), Alastair McBeath (MCBAL, 18), Zuzana Medvedová (MEDZU, 41), Koen Miskotte (MISKO, 9), Leonid Molchanov (MOLLE, 2), Thom Morgan (MORTH, 264), Sándor Nagy (NAGSA, 14), Kiyohide Nakamura (NAKKI, 11), Sven Näther (NATSV, 199), Aleksandr Naumov (NAUAL, 315), Sergey Nazarov (NAZSE, 3), Martin Nedved (NEDMA, 7), Marc Neijts (NEIMA, 495), Tooru Nishino (NSNTO, 2), Francisco Ocaña Gonzalez (OCAFR, 81), Arkadiusz Olech (OLEAR, 262), Erika Ollé (OLLER, 29), Kazuhiro Osada (OSAKA, 265), Daniel Paletti (PALDA, 320), Irena Pickova (PICIR, 341), Maesumeh Poorali (POOMA, 48), Mayuresh G. Prabhune (PRAMY, 69), Sreejit Purushothaman (PURSR, 41), Pavol Rapavy (RAPPA, 355), Valerij Rashkov (RASVA, 59), Petra Rendtel (BALPE, 182), Jürgen Rendtel (RENJU, 276), Ian Rigney (RIGIA, 82), Jelyl Rufat (RUFJE, 286), Márton Rózsahegyi (ROZMF, 160), Łukasz Sanocki (SANLU, 476), Krisztián Sárneczky (SARKR, 199), Mikiya Sato (SATMK, 9), Tomoko Sato (SATTM, 5), Bruno Sciolla (SCIBR, 362), Mazyar Seyyednezhad (SEYMA, 78), Jonathan Shanklin (SHAJO, 473), Brian Shulist (SHUBR, 38), Vladimir Slusarenko (SLUVL, 327), Krzysztof Socha (SOCKR, 50), Jiři Srba (SRBJI, 158), Mark Stafford (STAMA, 134), Sergey Staryi (STASE, 155), Tomas Stec (STETO, 441), Svetozár Štefeček (STESV, 276), Chris Stephan (STECR, 350), Enrico Stomeo (STOEN, 103), Pavel Svozil (SVOPA, 54), David Swann (SWADA, 77), Konrad Szaruga (SZAKO, 72), Richard Taibi (TAIRI, 79), Kazumi Terakubo (TERKA, 5), Cristina Tinta (TINCR, 137), Rafaél R. Torregrosa Soler (TORRQ, 14), Josep M. Trigo Rodríguez (TRIJO, 76), Marian Trlica (TRLMA, 54), Shigeo Uchiyama (UCHSH, 37), Lubos Ulicny (ULILU, 13), Kirill Ushakov (USHKI, 1), Koen van Gorp (VANKE, 1069), Steven Van Impe (VANST, 649), Daniel van Os (OSVDA, 19), Michel Vandeputte (VANMC, 987), Vishnu Vardhan (VARVI, 71), Kristina Veljković (VELKR, 417), Cis Verbeeck (VERCI, 520), Jan Verbert (VERJN, 1293), Tamás Veress (VERTA, 15), Marcel Vonk (VONMA, 552), Yevgenij Yu. Vovk (VOVYE, 76), Thomas Weiland (WEITH, 111), Vaya Willemen (WILVA, 808), Jean-Marc Wislez (WISJE, 459), Jan Woloszcuk (WOLJA, 563), Oliver Wusk (WUSOL, 55), Quanzhi Ye (YE QU, 6), Kim S. Youmans (YOUKI, 189), Jure Zakrajšek (ZAKJU, 1045), Joseph Zammit (ZAMJO, 956), Shibo Zhang (ZHASH, 112), Kamil Złoczewski (ZLOKA, 192) and Przemysław Żołądek (ZOLPR, 67),

who are from the following countries:

Algeria, Australia, Austria, Belarus, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Iran, Israel, Italy, Japan, Jordan, Luxembourg, Macedonia, Malta, Morocco, Netherlands, Norway, Poland, Romania, Russia, Slovakia, Slovenia, Spain, Switzerland, Turkey, UK, Ukraine, USA and Yugoslavia.

2 Compensation for the lunar conditions

The analysis of the 2002 Leonid storms suffers from the bad lunar conditions under which the observers were logging their data for most of the recording time. Moonset coincided with the first tinge of dawn at most locations. While a correction for the limiting magnitude is standard in the computation of population index and activity measures (ZHR and particle flux), additional effects may influence the meteor reports because the observers were logging the data under unusual conditions. We will try to assess the individual perception correction for a number of observers, with special attention to conditions with low limiting magnitudes.

Similarly to the perception determination in Arlt & Buchmann (2002), the sporadic hourly rates are used for the calibration of observers' perceptions. A large set of all observations from 1995–2002 was compiled from the Visual Meteor Database (VMDB; Arlt, 1999). For a suitable picture of sporadic activity, it would be necessary that these observations contain a sufficiently consistent measure of sporadic meteor rates. The VMDB files contain a column in which the observing style is coded. For our purposes, observations are of particular interest in which the IMO shower list was applied in full. The list is not meant as a full listing of existing meteor showers, something which is a sheer impossibility, but rather comprises the most relevant radiants for visual observing purposes. Given this list, a fairly consistent measure of sporadic activity can be derived from the numbers of observed sporadics. Since 1995, this list has not been changed (Arlt, 1995), and we thus selected the period 1995–2002 for the sporadic-rate calibration.

The average sporadic meteor rate from 36 370 observing periods of this type is 10.86 per hour. We have to note that observations of all seasons and all times of the night contribute. Any attempt to use a fixed sporadic rate for calibration should be made with large numbers of observations anyway in order to average out the seasonal and diurnal variations. A set of 90 observers out of the full list of 351 observers who provided any Leonid data (no magnitude distributions from some of them) delivered data of the mentioned categories (consistent measure of numbers of sporadics) in the last years.

Details are listed in Table 1. The first sporadic rate given there for each observer, $\mathrm{HR_{low}}$, is the rate derived from observations with $\mathrm{LM} \leq \overline{\mathrm{LM}} - 0.1$, i.e. from observing periods with limiting magnitudes lower than a tenth less than the average limiting magnitude $\overline{\mathrm{LM}}$ based on all observing periods available from that particular observer. The difference to 'ordinary observations' might have been chosen to be larger than 0.1 magnitudes, but the number of intervals would quickly diminish and make our estimates of required corrections highly uncertain.

If we relate this $\mathrm{HR_{low}}$ to the average sporadic rate of 10.86 for 'shower-list' observations, we obtain the perception factor c_P. This will on its own depend on the population index. Therefore, a perception correction in terms of a limiting-magnitude shift is given, $\Delta\mathrm{LM}$. This is the quantity which is applied in correcting data for future purposes. The sign of D indicates whether the sporadic rate for low limiting magnitudes, $\mathrm{HR_{low}}$, has decreased ($-$) or increased ($+$) compared with the total average of sporadic rates recorded by the observer as 'shower-list' observations. Unchanged rates are denoted by 0. The obvious majority of observers tends to give reports resulting in overestimated sporadic rates when the Moon is up.

A last quantity gives the sporadic rate of the days August 11–13 inclusive, when the observer faced high Perseid numbers. Again, only 'shower-list' observations are used. An observing report giving Perseids, κ-Cygnids, and a class for all Aquarids and Capricornids is also a valid data point in this respect, because the sporadic rate is fairly 'clean' although the Aquarid information is useless. If no such observations were available, a hyphen indicates this. Note, however, that the actual number of observing periods behind these PER-maximum sporadic rates may be small.

3 Population index profile

3.1 Applicability of r

All available magnitude distributions for the 2002 Leonids were selected from the VMDB. For the observers listed in Table 1, their $\Delta\mathrm{LM}$ was applied to the magnitude file. We first test the data on the applicability of the concept of a population index, namely the exponential dependence of the true meteor number on the meteor magnitude. The true number of meteors is calculated from the observed number of meteors in a given magnitude class, corrected with the average detection probabilities derived by Koschack & Rendtel (1990; Table 15 therein) for a field of view of 105° diameter. To be sure that classes up to +4 are well in the observable range, magnitude distributions with limiting magnitudes $\mathrm{LM} \geq +5.25$ were selected. The true meteor numbers can be added for several observations and over a relatively small period.

Three periods were chosen which — as we will see later — exhibit different population indices: $\lambda_\odot = 236\overset{\circ}{.}5$ to $236\overset{\circ}{.}6$, $\lambda_\odot = 236\overset{\circ}{.}6$ to $236\overset{\circ}{.}7$ and $\lambda_\odot = 236\overset{\circ}{.}84$ to $236\overset{\circ}{.}90$. The distributions are shown in Figure 1. In this logarithmic plot, exponential functions are straight lines. The distributions are indeed close to exponential in the magnitude range from -1 to $+4$. Numbers for classes brighter than this are still affected by fluctuations due to the small numbers of meteors. The dotted line, for example shows a 'peak' for class -2, which is based on 10 meteors (the detection probability is near 100% for such bright meteors, so the true number is equal to the observed meteor number). A suitable error bar for the natural fluctuations would be ± 3 and makes the variations in this part of the curve insignificant.

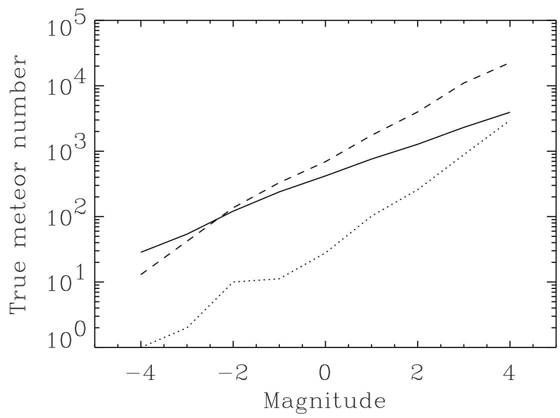

Figure 1 – Distribution of true meteor numbers versus visual magnitude from observations with $\mathrm{LM} \geq +5.25$. The solid line refers to the pre-peak period $236\overset{\circ}{.}5$–$236\overset{\circ}{.}6$, the dashed line is from $236\overset{\circ}{.}6$–$236\overset{\circ}{.}7$ and the dotted line is from $236\overset{\circ}{.}84$–$236\overset{\circ}{.}90$.

3.2 Tentative profile

The data were now averaged with an adaptive-bin size algorithm which tries to maintain a user-defined optimum meteor number per bin. This meteor number was set to 300. For the case that not enough meteors are available (before and after the peaks), a maximum bin size of 1° was given. The minimum bin size was set to $0\overset{\circ}{.}01$ which is a bit less than 15 minutes. No correction for the topocentric encounter with the Leonid meteoroid stream is applied. The population index profile is too coarse to be affected by encounter time differences for different locations (typically ±5 min).

The average distance from the limiting magnitude, $\overline{\Delta m}$ is used to determine the population index. Since

Table 1 – Perception factors and limiting-magnitude corrections for a number of long-term observers. The values of $\mathrm{HR_{low}}$ are the average sporadic meteor rates for observations with low limiting magnitudes $\mathrm{LM} \leq \overline{\mathrm{LM}} - 0.1$ where $\overline{\mathrm{LM}}$ is the average limiting magnitude of *all* observing periods of this observer. Sporadics are taken as those not on the IMO Shower list. The value of c_P is the factor derived from $\mathrm{HR_{low}}/10.86$; the value of $\Delta\mathrm{LM}$ is the limiting-magnitude shift according to $r = 3.0$; D indicates whether the observer has lower ($-$) or higher ($+$) sporadic rates under poor conditions compared with his personal average of all observations (sporadic again defined by the IMO List). $\mathrm{HR_{per}}$ denotes the average sporadic rate for the observations on August 11–13 as an indication of whether the observer tends to misclassify a lot of meteors during major-shower maxima.

Observer	$\mathrm{HR_{low}}$	c_P	$\Delta\mathrm{LM}$	D	$\mathrm{HR_{per}}$	Observer	$\mathrm{HR_{low}}$	c_P	$\Delta\mathrm{LM}$	D	$\mathrm{HR_{per}}$
HORKM	5.36	0.49	−0.65	−	6.03	KOSDE	15.23	1.40	+0.31	+	10.79
TAIRI	5.51	0.51	−0.61	−	–	HONNA	15.33	1.41	+0.31	+	20.34
GODSH	6.45	0.59	−0.48	+	–	PICIR	15.28	1.40	+0.31	+	20.01
LEMAN	6.45	0.59	−0.48	+	5.68	ATAJU	15.43	1.42	+0.32	+	15.04
LEMMA	6.65	0.61	−0.45	+	–	GORMI	15.61	1.43	+0.33	+	–
TRIJO	7.18	0.66	−0.38	+	3.39	KWIMA	15.52	1.43	+0.33	+	8.92
KARKR	7.83	0.72	−0.30	+	–	VANJR	15.78	1.45	+0.34	+	–
DORDA	7.92	0.73	−0.29	+	4.85	DIAMA	15.89	1.46	+0.34	0	–
ZLOKA	8.75	0.80	−0.20	+	–	SERIV	16.25	1.49	+0.36	+	15.11
RENJU	9.08	0.83	−0.17	−	10.32	BASLU	16.07	1.48	+0.36	−	18.26
SANLU	9.08	0.83	−0.17	+	6.16	ZAKJU	16.08	1.48	+0.36	+	15.56
ARLRA	9.06	0.83	−0.17	−	7.90	RAPPA	16.82	1.54	+0.39	+	–
KOSRA	9.19	0.84	−0.16	+	8.00	KACJA	17.37	1.60	+0.43	+	12.94
SVOPA	9.23	0.85	−0.15	0	–	SOCKR	17.68	1.62	+0.44	+	–
WINRO	9.38	0.86	−0.14	0	–	KOUJA	18.09	1.66	+0.46	+	14.23
GRIVA	9.65	0.89	−0.11	+	6.62	DVOTO	18.05	1.66	+0.46	+	10.17
LUTHA	9.66	0.89	−0.11	+	10.48	FAJTO	18.04	1.66	+0.46	+	9.89
BALPE	9.72	0.89	−0.11	−	15.93	NEDMA	18.17	1.67	+0.47	+	10.36
RODFR	9.79	0.90	−0.10	+	7.74	MCETO	18.50	1.70	+0.48	+	–
BIVNI	9.90	0.91	−0.09	−	–	VANKE	19.21	1.76	+0.51	−	22.29
GRIEV	9.93	0.91	−0.09	+	10.88	ABDSA	19.95	1.83	+0.55	+	–
VERCI	10.28	0.94	−0.06	−	14.23	KNOAN	20.10	1.85	+0.56	+	7.37
HASAM	10.58	0.97	−0.03	−	–	GLIGE	20.11	1.85	+0.56	+	–
MARPI	10.80	0.99	−0.01	+	9.60	LINMI	20.21	1.86	+0.56	+	16.40
WUSOL	10.93	1.01	+0.01	+	9.67	SEYMA	20.40	1.87	+0.57	+	–
GORSY	11.09	1.02	+0.02	+	7.94	BHASU	20.97	1.93	+0.60	0	–
BARAL	11.17	1.03	+0.03	+	–	OFEER	21.22	1.95	+0.61	+	–
SHUBR	11.40	1.05	+0.04	+	8.23	MARGE	21.46	1.97	+0.62	+	12.09
VANMC	11.51	1.06	+0.05	−	14.18	DAVMA	22.16	2.03	+0.64	+	21.06
WOLJA	11.67	1.07	+0.06	+	7.07	BABJL	22.38	2.06	+0.66	+	–
ROJYU	11.68	1.07	+0.06	0	20.64	VENRO	22.57	2.07	+0.66	+	–
MOLLE	12.08	1.11	+0.09	+	–	MCBAL	23.11	2.12	+0.68	+	20.75
GERJA	12.17	1.12	+0.10	−	–	DUBSE	23.77	2.18	+0.71	+	–
WEITH	12.34	1.13	+0.11	−	9.60	HABPA	23.84	2.19	+0.71	+	15.35
NATSV	12.28	1.13	+0.11	+	13.40	GEOPE	23.84	2.19	+0.71	+	11.10
YOUKI	12.52	1.15	+0.13	+	–	WISJE	25.03	2.30	+0.76	+	21.41
MISKO	12.92	1.19	+0.16	−	15.49	RUZAN	25.09	2.30	+0.76	−	–
BUCAN	13.06	1.20	+0.17	+	17.99	ZAMJO	26.67	2.45	+0.82	+	–
OLEAR	13.96	1.28	+0.22	+	11.26	BALIG	26.96	2.48	+0.83	+	23.84
MARAD	14.05	1.29	+0.23	+	–	VERJN	29.78	2.73	+0.91	+	31.28
BENOR	14.70	1.35	+0.27	+	15.05	BRYIV	32.58	2.99	+1.00	+	–
SZAKO	14.79	1.36	+0.28	+	9.80	OCAFR	34.75	3.19	+1.06	+	–
GERCH	14.93	1.37	+0.29	+	–	MATBE	37.55	3.45	+1.13	+	–
STOEN	15.00	1.38	+0.29	+	6.77	HASTA	55.10	5.06	+1.48	+	28.29
HAVRO	15.11	1.39	+0.30	+	9.10	OSAKA	65.87	6.05	+1.64	+	70.61

the limiting magnitude of each individual magnitude distribution is involved in this average, we can sum up data of various observers who have observed under various conditions. The conversion from $\overline{\Delta m}$ to r is given in Table 2. Simulations of large numbers of artificial magnitude distributions yielded the corresponding error margins of 65% confidence level depending on r and the total number of meteors n in the average $\overline{\Delta m}$. These errors are listed in Table 3.

Table 2 – Conversion table for the population index r and the average distance from the limiting magnitude, $\overline{\Delta m}$, from magnitude distributions. As a simple example imagine a magnitude distribution with a +1, a +3 and a +4 meteor seen at LM = +5.9. Then $\overline{\Delta m} = 3.23$ whence $r = 2.55$. A total of three meteors is, of course, insufficient.

r	$\overline{\Delta m}$	r	$\overline{\Delta m}$	r	$\overline{\Delta m}$
1.5	5.830	2.6	3.180	3.7	2.400
1.6	5.301	2.7	3.079	3.8	2.353
1.7	4.894	2.8	2.987	3.9	2.308
1.8	4.568	2.9	2.902	4.0	2.266
1.9	4.298	3.0	2.823	4.1	2.226
2.0	4.069	3.1	2.750	4.2	2.187
2.1	3.872	3.2	2.682	4.3	2.151
2.2	3.700	3.3	2.618	4.4	2.116
2.3	3.549	3.4	2.559	4.5	2.082
2.4	3.413	3.5	2.503		
2.5	3.291	3.6	2.450		

The resulting profile of the population index is shown in Figure 2. All of the values shown comprise at a minimum of 300 meteors. The values of the period $236.^{\circ}6$–$236.^{\circ}7$ are actually based on many more meteors whence the tiny error bars.

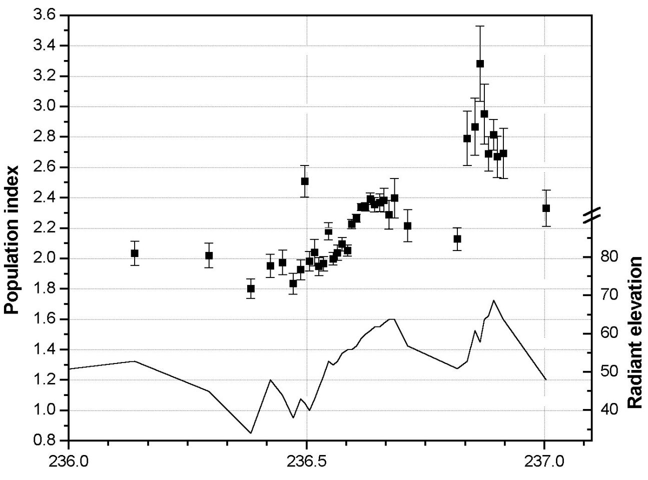

Figure 2 – Combination of the graphs of the average population index and the average radiant elevation (solid line with vertical axis on the right hand side) for the 2002 Leonid meteor storms. Unfortunately the plotting software refused to place ticks at the correct spacing on the $\lambda_\odot$ axis.

The high population index near the predicted time of the American Leonid peak is evident. The highest value occurred near $\lambda_\odot = 236.^{\circ}865$ (November 19, $10^{\rm h}05^{\rm m}$ UT). Population indices larger than 3 are very atypical for major meteor showers. The association of this high r with the fact that material is ejected very recently from the comet is quite appealing. Also the increase of the population index towards the predicted time of the first Leonid peak is very striking. There is actually also a maximum in r, but we have to consider the evidence of a decline after $\lambda_\odot = 236.^{\circ}65$ is not highly convincing. If we consider the maximum with the small error bars the most significant, it occurred at $\lambda_\odot = 236.^{\circ}634$ or November 19, $04^{\rm h}36^{\rm m}$ UT, reaching $r = 2.39$. A third interesting fact is the high population index just before $236.^{\circ}5$ with $r = 2.5$, not coinciding with any predicted feature. In a graph with finer resolution, this maximum is confirmed by a number of high averages.

3.3 Radiant height dependence

The significance of the variations in the population index needs to be scrutinized. Along with the r-values, the average radiant elevation in each bin is plotted in Figure 2. We should note that many of the averages are composed of large numbers of periods; between $\lambda_\odot = 236.^{\circ}58$ and $\lambda_\odot = 236.^{\circ}66$, the averages are made up of more than 100–400 individual magnitude distributions. The value at $\lambda_\odot = 236.^{\circ}615$ ($04^{\rm h}08^{\rm m}$ UT) comprises 406 distributions with 9016 Leonids! The entire profile has only a few exceptions where the number of magnitude distributions is less than 20. Nevertheless, clear trends in the average radiant elevation are visible. Since observers are located in 'clumps' in Asia, Europe, and America, the average radiant elevation is not independent of time as it should be for a uniform distribution of observers.

The correlation of r with the average radiant elevation is alarming. At first glance, nearly every feature in the population index profile appears to be accompanied by a synchronous variation in the radiant height. We should be most concerned with the fact that the two r-peaks near the predicted maxima of the shower coincide with maximum average radiant elevations.

However, it is not too unlikely that the correlation is spurious. Let us assume that the population index is independent of the local radiant elevation. The stream structure could imply higher population indices for the two peaks. Since the observers naturally tend to be located at the few favorite locations found in mid-November, they will synchronously see the radiant rising as well as the population index going up, although the two quantities are not linked physically.

The question of how strongly the population index may be influenced by the radiant height was approached by selecting three periods from the magnitude distributions. The periods are short and may represent periods of constant r. We will discuss whether this is a suitable assumption in a minute. In each of these three periods, average r-values were derived for certain bins of radiant elevations $h_{\rm R}$. Figures 3, 4 and 5 show the results for the periods $\lambda_\odot = 235.^{\circ}80$ to $236.^{\circ}45$, for $\lambda_\odot = 236.^{\circ}50$ to $\lambda_\odot = 236.^{\circ}60$ and for $\lambda_\odot = 236.^{\circ}60$ to $236.^{\circ}70$, respectively. The periods explicitly exclude the high r just before $236.^{\circ}50$.

Table 3 – Tabulated error margins for r with a given number of meteors n. The meteor numbers grow exponentially; it is therefore wise to interpolate between the logarithms of the meteor numbers to obtain good $\Delta r(r, n)$.

r	n	Δr	r	n	Δr	r	n	Δr	r	n	Δr
1.5	10	0.379752	2.0	73	0.179494	2.5	549	0.101775	3.0	4164	0.053896
1.5	15	0.219151	2.0	109	0.143732	2.5	823	0.081740	3.0	6246	0.044512
1.5	22	0.165281	2.0	163	0.114343	2.5	1234	0.068843	3.0	9369	0.036256
1.5	33	0.131182	2.0	244	0.091651	2.5	1851	0.055295	3.1	10	2.440642
1.5	49	0.102965	2.0	366	0.074552	2.5	2776	0.046040	3.1	15	1.699362
1.5	73	0.080319	2.0	549	0.060542	2.5	4164	0.037057	3.1	22	1.277410
1.5	109	0.064846	2.0	823	0.050896	2.5	6246	0.030630	3.1	33	0.840605
1.5	163	0.053270	2.0	1234	0.041503	2.5	9369	0.024652	3.1	49	0.660876
1.5	244	0.041216	2.0	1851	0.034326	2.6	10	1.886711	3.1	73	0.499063
1.5	366	0.034888	2.0	2776	0.026454	2.6	15	1.284824	3.1	109	0.385151
1.5	549	0.028634	2.0	4164	0.022019	2.6	22	0.849563	3.1	163	0.306956
1.5	823	0.023285	2.0	6246	0.018188	2.6	33	0.580280	3.1	244	0.252339
1.5	1234	0.019041	2.0	9369	0.015188	2.6	49	0.425682	3.1	366	0.202753
1.5	1851	0.015555	2.1	10	0.057628	2.6	73	0.330708	3.1	549	0.159620
1.5	2776	0.012889	2.1	15	0.685918	2.6	109	0.265326	3.1	823	0.133152
1.5	4164	0.010515	2.1	22	0.484146	2.6	163	0.215390	3.1	1234	0.108004
1.5	6246	0.008768	2.1	33	0.339138	2.6	244	0.169364	3.1	1851	0.086421
1.5	9369	0.007442	2.1	49	0.249572	2.6	366	0.139457	3.1	2776	0.070335
1.6	10	0.415861	2.1	73	0.199467	2.6	549	0.111722	3.1	4164	0.058019
1.6	15	0.279552	2.1	109	0.162360	2.6	823	0.090894	3.1	6246	0.047207
1.6	22	0.198924	2.1	163	0.130052	2.6	1234	0.073860	3.1	9369	0.038961
1.6	33	0.151938	2.1	244	0.105684	2.6	1851	0.060459	3.2	10	2.448796
1.6	49	0.123133	2.1	366	0.085554	2.6	2776	0.050376	3.2	15	1.830660
1.6	73	0.098398	2.1	549	0.070256	2.6	4164	0.038988	3.2	22	1.378509
1.6	109	0.076588	2.1	823	0.057548	2.6	6246	0.032885	3.2	33	0.940650
1.6	163	0.063498	2.1	1234	0.046212	2.6	9369	0.026547	3.2	49	0.668478
1.6	244	0.051711	2.1	1851	0.036743	2.7	10	1.954565	3.2	73	0.512562
1.6	366	0.042288	2.1	2776	0.030770	2.7	15	1.261201	3.2	109	0.417727
1.6	549	0.034389	2.1	4164	0.025043	2.7	22	0.933237	3.2	163	0.325357
1.6	823	0.027788	2.1	6246	0.020547	2.7	33	0.649252	3.2	244	0.266452
1.6	1234	0.022091	2.1	9369	0.017256	2.7	49	0.450696	3.2	366	0.212681
1.6	1851	0.018556	2.2	10	0.305126	2.7	73	0.370813	3.2	549	0.172356
1.6	2776	0.015489	2.2	15	0.804922	2.7	109	0.292480	3.2	823	0.139413
1.6	4164	0.012853	2.2	22	0.547546	2.7	163	0.232533	3.2	1234	0.115507
1.6	6246	0.010519	2.2	33	0.376048	2.7	244	0.181588	3.2	1851	0.092331
1.6	9369	0.008760	2.2	49	0.288119	2.7	366	0.152115	3.2	2776	0.075704
1.7	10	0.474862	2.2	73	0.221617	2.7	549	0.121051	3.2	4164	0.062575
1.7	15	0.335184	2.2	109	0.180786	2.7	823	0.099535	3.2	6246	0.050508
1.7	22	0.251577	2.2	163	0.141767	2.7	1234	0.079382	3.2	9369	0.041619
1.7	33	0.180021	2.2	244	0.116620	2.7	1851	0.065285	3.3	10	2.640826
1.7	49	0.145088	2.2	366	0.096016	2.7	2776	0.053564	3.3	15	1.914526
1.7	73	0.115178	2.2	549	0.077317	2.7	4164	0.043161	3.3	22	1.487040
1.7	109	0.092257	2.2	823	0.061371	2.7	6246	0.034534	3.3	33	0.975261
1.7	163	0.075846	2.2	1234	0.051882	2.7	9369	0.029408	3.3	49	0.745342
1.7	244	0.061049	2.2	1851	0.041710	2.8	10	2.076587	3.3	73	0.541467
1.7	366	0.048790	2.2	2776	0.033617	2.8	15	1.419875	3.3	109	0.441275
1.7	549	0.040399	2.2	4164	0.027708	2.8	22	1.004098	3.3	163	0.361195
1.7	823	0.032452	2.2	6246	0.023315	2.8	33	0.691073	3.3	244	0.283405
1.7	1234	0.027392	2.2	9369	0.018439	2.8	49	0.517773	3.3	366	0.226937
1.7	1851	0.021750	2.3	10	1.406381	2.8	73	0.376886	3.3	549	0.178080
1.7	2776	0.017970	2.3	15	0.869193	2.8	109	0.318611	3.3	823	0.151141
1.7	4164	0.014622	2.3	22	0.567262	2.8	163	0.248719	3.3	1234	0.120867
1.7	6246	0.012219	2.3	33	0.440556	2.8	244	0.196878	3.3	1851	0.100166
1.7	9369	0.010162	2.3	49	0.319485	2.8	366	0.163748	3.3	2776	0.081132
1.8	10	0.757086	2.3	73	0.256217	2.8	549	0.131172	3.3	4164	0.065658
1.8	15	0.410681	2.3	109	0.191788	2.8	823	0.107513	3.3	6246	0.054303
1.8	22	0.293342	2.3	163	0.156197	2.8	1234	0.086208	3.3	9369	0.043927
1.8	33	0.215377	2.3	244	0.131547	2.8	1851	0.072489	3.4	10	2.729479
1.8	49	0.172113	2.3	366	0.103035	2.8	2776	0.056960	3.4	15	1.902180
1.8	73	0.137292	2.3	549	0.083944	2.8	4164	0.047446	3.4	22	1.495403
1.8	109	0.111343	2.3	823	0.069126	2.8	6246	0.038079	3.4	33	0.069958
1.8	163	0.087962	2.3	1234	0.056965	2.8	9369	0.031483	3.4	49	0.841170
1.8	244	0.070995	2.3	1851	0.046057	2.9	10	2.168441	3.4	73	0.587803
1.8	366	0.058166	2.3	2776	0.038103	2.9	15	1.519604	3.4	109	0.456060
1.8	549	0.046214	2.3	4164	0.031025	2.9	22	1.131316	3.4	163	0.370941
1.8	823	0.037344	2.3	6246	0.025342	2.9	33	0.746994	3.4	244	0.301193
1.8	1234	0.031156	2.3	9369	0.020421	2.9	49	0.553942	3.4	366	0.243164
1.8	1851	0.025243	2.4	10	1.605871	2.9	73	0.411507	3.4	549	0.192315
1.8	2776	0.021226	2.4	15	0.945157	2.9	109	0.330427	3.4	823	0.155870
1.8	4164	0.016916	2.4	22	0.720291	2.9	163	0.276425	3.4	1234	0.130058
1.8	6246	0.014392	2.4	33	0.459445	2.9	244	0.217965	3.4	1851	0.106966
1.8	9369	0.011780	2.4	49	0.357805	2.9	366	0.174839	3.4	2776	0.085449
1.9	10	0.785954	2.4	73	0.278879	2.9	549	0.138785	3.4	4164	0.071025
1.9	15	0.478983	2.4	109	0.220859	2.9	823	0.114302	3.4	6246	0.057453
1.9	22	0.340590	2.4	163	0.180413	2.9	1234	0.094685	3.4	9369	0.046734
1.9	33	0.250788	2.4	244	0.141902	2.9	1851	0.073555	3.5	10	2.723614
1.9	49	0.196233	2.4	366	0.116752	2.9	2776	0.061944	3.5	15	2.006364
1.9	73	0.154341	2.4	549	0.093598	2.9	4164	0.050260	3.5	22	1.580289
1.9	109	0.126555	2.4	823	0.077368	2.9	6246	0.041590	3.5	33	1.184411
1.9	163	0.102668	2.4	1234	0.062232	2.9	9369	0.033896	3.5	49 .	853488
1.9	244	0.083123	2.4	1851	0.051040	3.0	10	2.352136	3.5	73	0.634819
1.9	366	0.067794	2.4	2776	0.042117	3.0	15	1.655180	3.5	109	0.501864
1.9	549	0.052514	2.4	4164	0.033139	3.0	22	1.184792	3.5	163	0.395756
1.9	823	0.044626	2.4	6246	0.027915	3.0	33	0.847752	3.5	244	0.318778
1.9	1234	0.036349	2.4	9369	0.022796	3.0	49	0.604588	3.5	366	0.252984
1.9	1851	0.029122	2.5	10	1.751145	3.0	73	0.458395	3.5	549	0.207443
1.9	2776	0.024066	2.5	15	1.103714	3.0	109	0.365559	3.5	823	0.165135
1.9	4164	0.019621	2.5	22	0.768255	3.0	163	0.285552	3.5	1234	0.137467
1.9	6246	0.015933	2.5	33	0.503229	3.0	244	0.222993	3.5	1851	0.110002
1.9	9369	0.013149	2.5	49	0.416405	3.0	366	0.181364	3.5	2776	0.092971
2.0	10	0.942661	2.5	73	0.311718	3.0	549	0.154622	3.5	4164	0.075185
2.0	15	0.539446	2.5	109	0.239784	3.0	823	0.119369	3.5	6246	0.060694
2.0	22	0.392566	2.5	163	0.194010	3.0	1234	0.101554	3.5	9369	0.050000
2.0	33	0.295380	2.5	244	0.158123	3.0	1851	0.079308			
2.0	49	0.226038	2.5	366	0.126820	3.0	2776	0.067412			

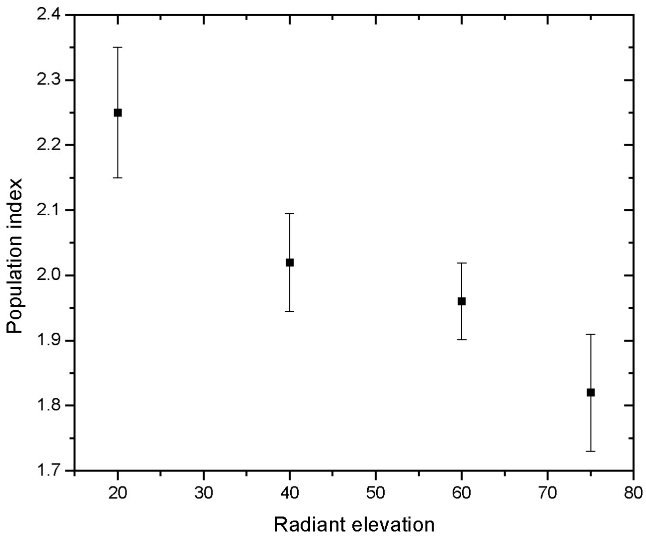

Figure 3 – Radiant height dependence of the population index for the period $\lambda_\odot = 235.^\circ 80$ to $\lambda_\odot = 236.^\circ 45$ (November 18, 08:40–November 19, 00:10 UT). Bins are 20° wide except 70°–80°.

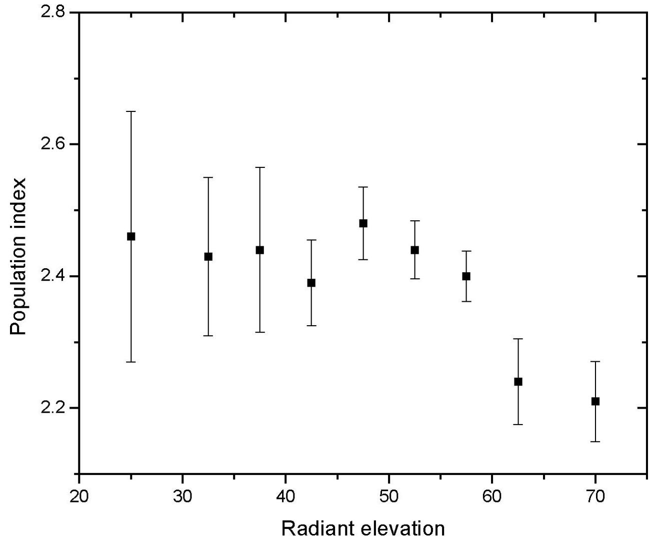

Figure 4 – Radiant height dependence of the population index for the period $\lambda_\odot = 236.^\circ 50$ to $\lambda_\odot = 236.^\circ 60$ (November 19, 01:24–03:47 UT). Bins are 5° wide except for 25° and 70°.

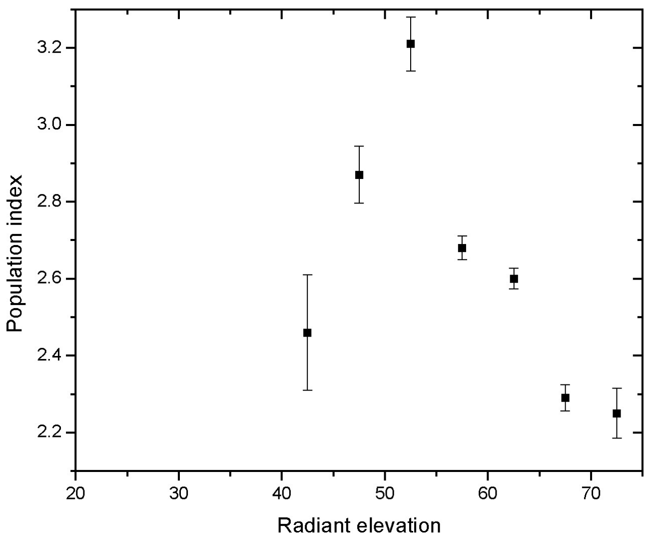

Figure 5 – Radiant height dependence of the population index for the period $\lambda_\odot = 236.^\circ 60$ to $\lambda_\odot = 236.^\circ 70$ (November 19, 03:47–06:10 UT). Bins are 5° wide.

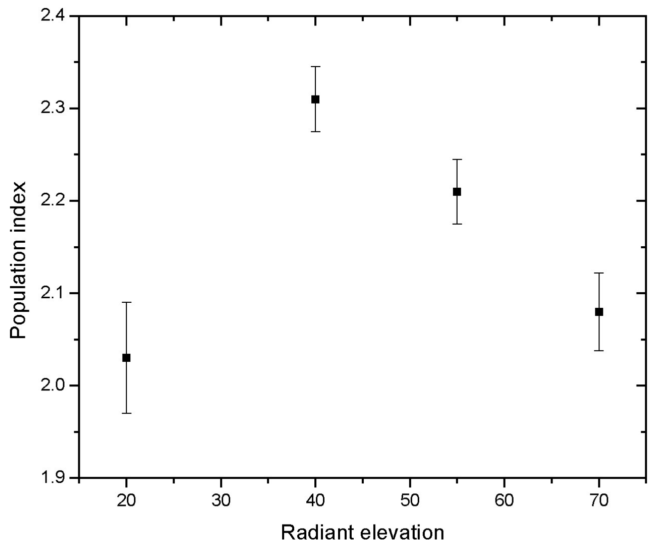

Figure 6 – Radiant height dependence of the population index of the 2000 Leonids for the period $\lambda_\odot = 236.^\circ 08$ to $\lambda_\odot = 236.^\circ 26$. The non-storm year 2000 provided this period with almost constant population index for comparison.

We learn two things from these graphs. Firstly, the picture is all but consistent with a clear trend in r as a function of h_R. Secondly, the population index shows no obvious indication of an increase with h_R in any of the Figures 3–5 as was originally suggested by Figure 2. The assumption of a constant r over 2.4 hours is most critical in the third of these periods (Figure 5), since the peak predictions were roughly in the solar-longitude range of $236.^\circ 61$–$236.^\circ 62$. The function $r(h_\mathrm{R})$ could actually be a function of *time*, $r(t)$, if the observers were very closely located.

In order to get an independent idea of the radiant height dependence of the population index, we look back to the 2000 Leonids when no strong meteor storm was observed. If there is a physical effect causing r to be a function of radiant elevation, it is unlikely to be specific to 2002, but it is not impossible that it is specific to the Leonid meteor shower because of its high entry velocity in the Earth's atmosphere. So we select a Leonid shower for comparison, but choose another year with a different r-profile. The population index profile of 2000 exhibited a fairly constant plateau between $\lambda_\odot = 236.^\circ 08$ and $236.^\circ 26$ (Arlt & Gyssens, 2000). We did the same computation of the population indices in bins of radiant height that we did for Figures 3–5. The result is shown in Figure 6. The tendency in r is weak; if there is any it is negative, again contrasting with the trend suggested by Figure 2, that a higher radiant comes along with a higher population index. The 2000 dependence could be compared — if at all — with Figure 4.

Summarizing the results of Figures 3–6, we find that there is an unambiguous downward trend of r for radiant elevations higher than 50°. Three of the four graphs

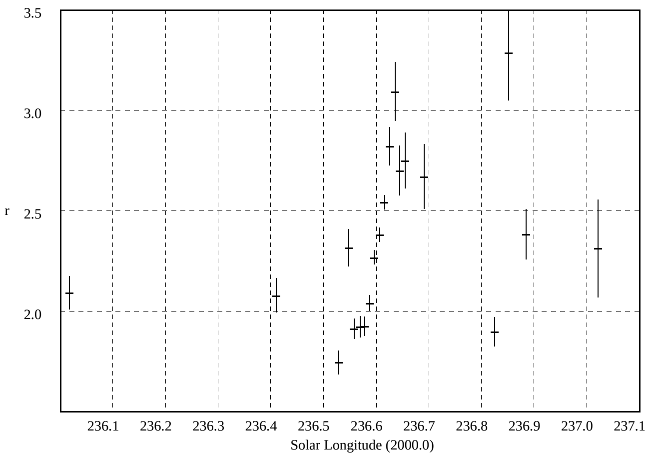

Figure 7 – Population index profile of the 2002 Leonids using only observing periods where the average radiant elevation is 50°–60°.

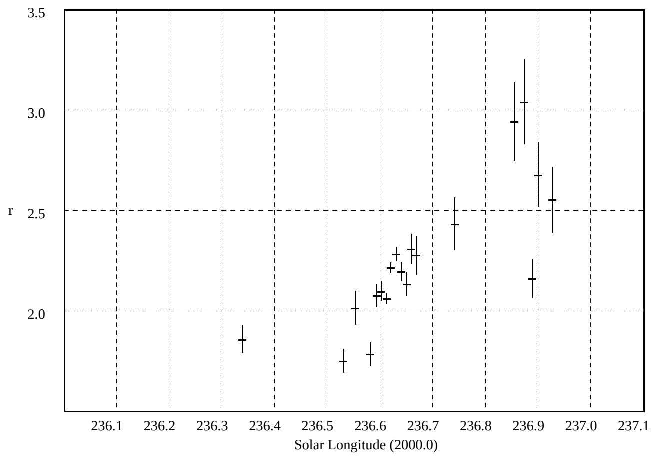

Figure 8 – Population index profile of the 2002 Leonids using only observing periods where the average radiant elevation is 60°–70°.

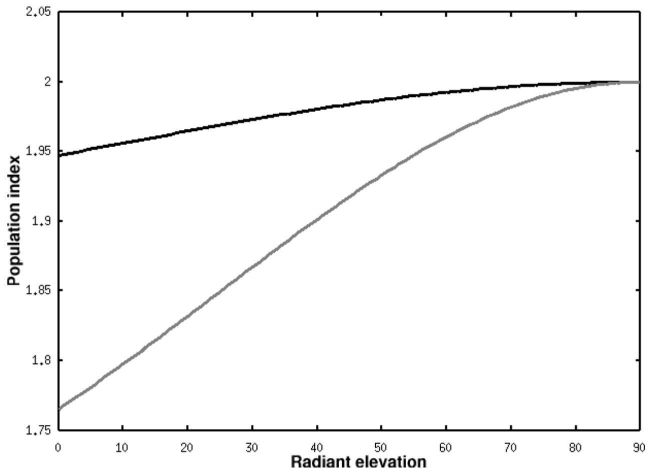

Figure 9 – Dependence of the population index r on the radiant elevation according to observational material (black) and single-body integration (gray), after Bellot Rubio (1995). A zenith-r of 2 was assumed.

(including the one from 2000) show a maximum in r for radiant elevations between 40° and 50°.

Another way to shed light on the population index problem is the construction of r-profiles from a small range of radiant elevations only. Most magnitude distributions were provided with radiant heights between 50° and 60° (1265 records) and between 60° and 70° (1208 records). Two profiles were constructed using these fairly small windows of radiant heights. The window may effectively be slightly larger because $h_{\rm R}$ is given for the middle of the period for which a magnitude distribution is given, and at the beginning/end of the period the radiant height might lie outside our selection window. But the effect is negligible during the maxima of the Leonids, when magnitude distributions cover only short periods — in most cases 15 minutes or less.

The results of these two r-profiles are shown in Figures 7 and 8. The averaging procedure applied an optimum meteor number of 300, a minimum step width of $0.^\circ1$ and a maximum step of 1°. First, it is satisfying to note that the number of magnitude distributions are still providing significant results after such strong restrictions in $h_{\rm R}$.

The first of these two graphs shows a steep increase in r between solar longitudes $236.^\circ55$ and $236.^\circ63$. Let us note again that the predicted times of maximum *activity* fall near $236.^\circ61$. The r-maximum of $r = 3.09 \pm 0.15$ at $\lambda_\odot = 236.^\circ636$ ($04^{\rm h}38^{\rm m}$ UT) seems significant. This means that the largest fraction of faint meteors in the Leonid stream was encountered after the activity maximum. A high value for the average r is also available for the American peak with $r = 3.3 \pm 0.3$, but far fewer magnitude distributions are available there. Both r-peaks are extraordinarily high compared with most other visual meteor showers.

The second graph — comprising observations at higher radiant elevations — shows a less striking feature for the European peak. It does show a local maximum though, with $r = 2.28 \pm 0.04$ at $\lambda_\odot = 236.^\circ631$ ($04^{\rm h}31^{\rm m}$ UT) based on 3000 meteors (the two values before are based on even more meteors). However, because of the three following averages starting after $236.^\circ65$, the maximum mentioned is not evident and rather looks like a gradual increase of r towards the American peak with $r = 3.0 \pm 0.2$. As a side note, we can already clearly state that the population index maximum for the 7-revolution dust trail occurred after the activity peak found by Arlt et al. (2002).

Summarizing the above considerations, we find that an increase of the population index with radiant elevation is not confirmed. A closer look at Figure 2 reveals that the maxima in $h_{\rm R}$ actually occur *after* the r maxima. This is almost obvious for the American peak, and is also noticeable for the European peak if the additional high r at $\lambda_\odot = 236.^\circ72$ ($06^{\rm h}38^{\rm m}$ UT) is given less weight because of the relatively large error bar. An analysis of observational material by Bellot Rubio (1995) lead to a weak dependence of r on the radiant height with r actually increasing towards higher elevations. His modeling of a single-body flight in the atmosphere lead to a stronger dependence but in the same direction, hence in contrast with the findings here for $h_{\rm R} > 50°$. Figure 9 shows the results of Bellot Rubio graphically.

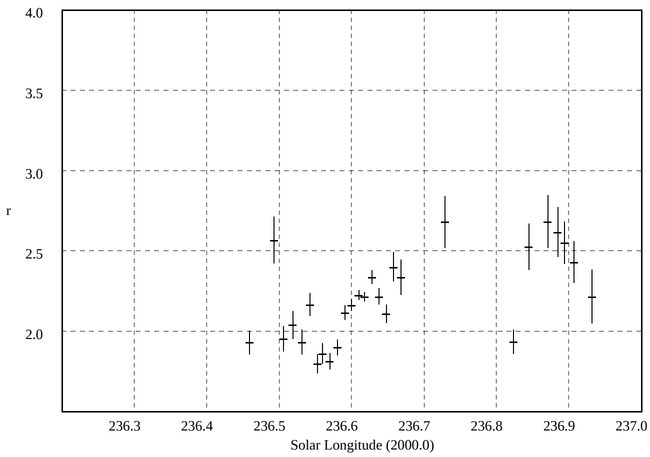

Figure 10 – Population index profile of the 2002 Leonids including only observations which lasted longer than 3.2 hours in total.

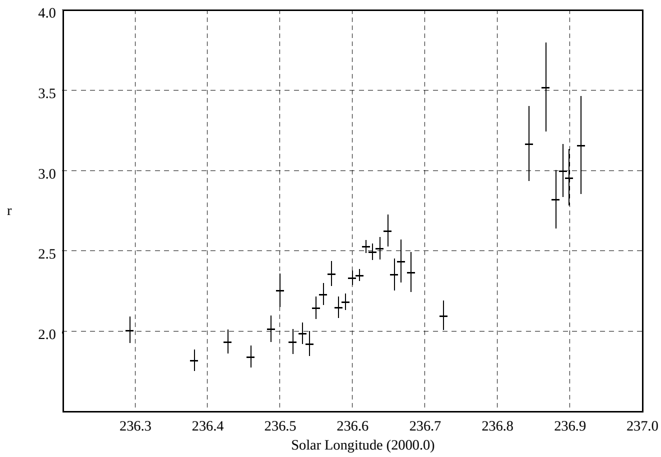

Figure 11 – Population index profile of the 2002 Leonids using only observations which lasted less than 3.2 hours in total.

3.4 Observers' fatigue

The analysis of the 2000 Leonids showed that fatigue effects play a role, affecting the population index and thus the ZHR. Faint meteors are more easily missed after 1–2 hours of observation. An attempt to check for such an effect in the 2002 data is shown in Figures 10 and 11. When dividing the data set into observations with a total effective time of more than 3.2 hours and those with less, the set is split into halves. It was not checked whether the long-term observers actually took longer breaks, too — the crude attempt in the Figures already shows a significant difference. Long-term observers report lower population indices (smaller fraction of faint meteors) than short-term observers.

In the period up to $\lambda_\odot = 236\overset{\circ}{.}7$ containing the European Leonid storm, the difference between the two groups is about $\Delta r = 0.2$. This is compatible with the differences found in Arlt & Gyssens (2000). The population index of the American peak is changed drastically by roughly $\Delta r = 0.5$. The number of magnitude distributions is smaller though than for the European peak, and it is entirely possible that the difference is exaggerated by an accidentally unfavorable selection of data.

Figure 12 shows the distribution of true meteor numbers as in Figure 1, but now separating the two cases of observers with effective observing times less than $3\overset{h}{.}2$ (solid line) and those reporting more than $3\overset{h}{.}2$ (dashed line). The period $236\overset{\circ}{.}6$ to $236\overset{\circ}{.}7$ was chosen, because the differences in r are — according to Figures 10 and 11 — largest then. The minimum limiting magnitude is now set to +5.5 in order to have a chance of a reasonable look at +5 meteors too.

We can see that the possibly fatigued observers miss a lot of +5 meteors. If we scale their +4 meteors with the 'fresh' observers, the fatigued group should have come up with a true number of roughly 60 000 meteors of magnitude +5, but they actually reached only 56% of them. While the solid line for the 'fresh' observers is nicely exponential, the dashed line shows a lack of very bright meteors, too. A sort of laziness in estimating the more complicated negative magnitudes has perhaps moved many bright meteors into the −1 or 0 class.

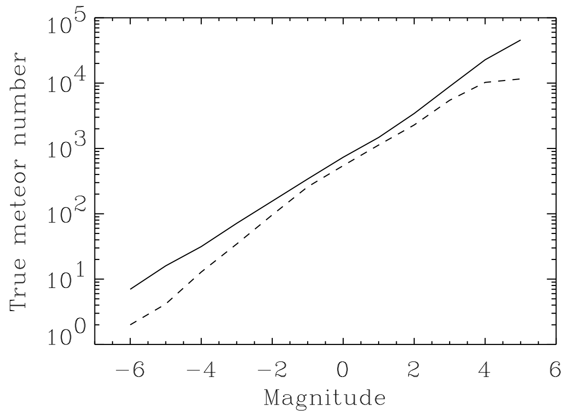

Figure 12 – Magnitude distributions of the period $\lambda_\odot = 236\overset{\circ}{.}6$–$236\overset{\circ}{.}7$ for two groups of observers: with observations lasting less than $3\overset{h}{.}2$ (solid line) and with observations lasting longer than that (dashed line). The data for the second group was divided by 3 for better visibility; the actual numbers are very similar. Fatigue is expressed in the second group by a lack of magnitude +5 meteors. The minimum LM for this graph was +5.5.

The bad thing with fatigue is that it leads to a reduced population index which is then used to correct hourly rates for the limiting magnitude. The reduced r will produce underestimated Zenithal Hourly Rates (ZHR); but not only this! Since the number of meteors seen is reduced by fatigue, an underestimated meteor number is even under-corrected by a low r. The problem thus enters the ZHR computation twice, and we must not use magnitude distributions which appear to be affected by fatigue.

4 Final profile and conclusion

In a last attempt to construct the population index profile of the 2002 Leonids, a hybrid graph is compiled as the most reasonable solution. Because of the apparent problems with fatigue during the European (7-revolution trail) peak, we use only the observers who have observed for less that $3\overset{h}{.}2$ effective time. This concerns the solar-longitude range $\lambda_\odot > 236\overset{\circ}{.}5$ and $\lambda_\odot < 236\overset{\circ}{.}7$. The American (4-revolution trail) peak has too few magnitude distributions to make a more restrictive selection. Figure 13 proves that r for the American peak is close to the peak of $T_{\text{eff}} < 3^{\text{h}}.2$-observers anyway. For the rest of the time, we thus plot the averaged values from magnitude distributions with radiant elevation higher than 55° at the middle of the individual period from which the distribution is derived. This selection reflects the fact that, even in the case of possible radiant height effects, the standard measure of the population index should ideally refer to a radiant at the zenith. The minimum averaging bin was set to $0^\circ.01$, the minimum meteor number was set to 200. A total of 1577 magnitude distributions was available for this combined profile. See Figure 13 for the final graph and Table 4 for the numerical values.

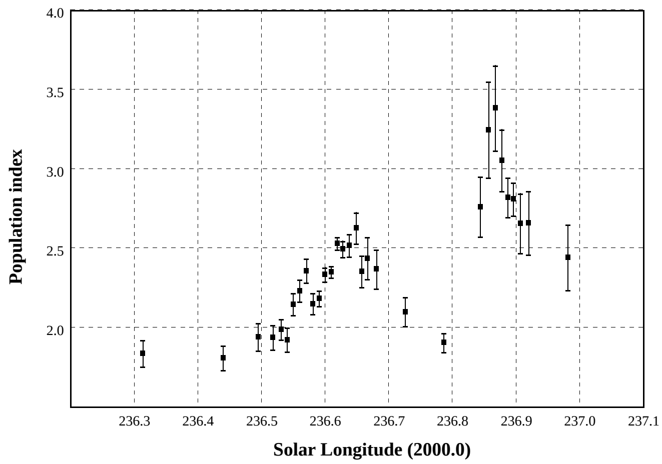

Figure 13 – Final population index profile of the 2002 Leonids as derived from magnitude distributions for which $h_{\text{R}} \geq 55°$ at the middle of the individual period covered, and observations lasting shorter than $3^{\text{h}}.2$ for the period $236^\circ.5$ to $236^\circ.7$.

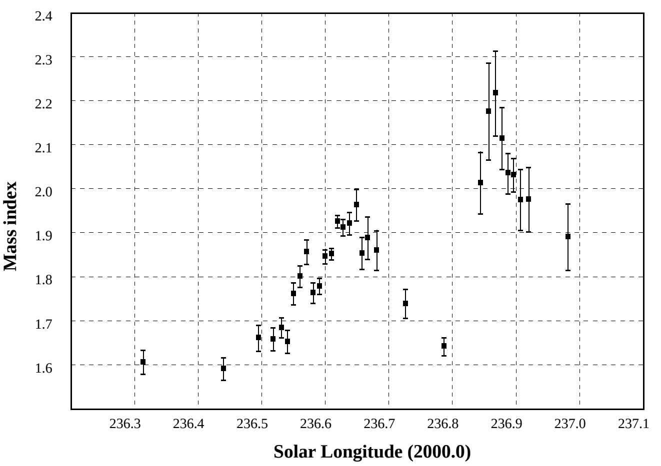

Figure 14 – Mass index profile as derived from the population index profile in Figure 13. Error bars are also adapted from that Figure.

A common feature of most of the population index profiles shown is the background r of about 2.0. We conclude that there are two superimposed maxima of r with $r = 2.5 \pm 0.1$ and $r = 3.4 \pm 0.3$ at solar longitudes $236^\circ.62$–$236^\circ.65$ (November 19, $04^{\text{h}}15^{\text{m}}$–$05^{\text{h}}00^{\text{m}}$ UT) and $236^\circ.87$ (November 19, $10^{\text{h}}12^{\text{m}} \pm 10$ min UT), respectively. The population index maximum of the 7-revolution dust trail is actually a plateau lasting until 45 minutes *after the activity maximum* reported by Arlt et al. (2002). The beginning coincides well with the observed activity peak at $04^{\text{h}}10^{\text{m}}$ UT taken from that paper. The r-maximum of the 4-revolution trail occurred 0.5 hours *before the activity maximum* found by Arlt et al. ($10^{\text{h}}47^{\text{m}}$ UT). These will be an interesting facts to be scrutinized by numerical modeling of the Leonid meteoroid stream. The fact that the population index during the 7-revolution trail peak is lower than during the 4-revolution trail peak was already predicted by McNaught & Asher (2002). The low 'base-r' of roughly 2 is not in the scope of their model, since it is certainly due to material ejected many revolutions ago.

Table 4 – Numerical data of the entire population index profile of the 2002 Leonid meteor shower. Solar longitudes refer to eq. J2000, times are in UT, D is the number of magnitude distributions, N is the number of Leonids, $\overline{\text{LM}}$ is the average limiting magnitude of these D distributions, and r is the population index.

$\lambda_\odot$	Time	D	N	$\overline{\text{LM}}$	r
234.000	Nov	4	21	5.72	1.974 ± 0.396
234.652	18/19	5	45	5.92	2.484 ± 0.426
235.609	↓	15	141	5.55	2.428 ± 0.199
236.314	21:00	13	204	5.42	1.835 ± 0.083
236.440	00:00	11	216	4.98	1.807 ± 0.077
236.495	01:17	9	245	4.76	1.939 ± 0.086
236.518	01:50	26	307	5.11	1.934 ± 0.077
236.531	02:08	26	455	5.13	1.985 ± 0.066
236.541	02:23	25	303	5.35	1.922 ± 0.077
236.550	02:36	35	620	5.30	2.145 ± 0.069
236.560	02:50	37	735	5.11	2.231 ± 0.068
236.571	03:06	40	756	4.93	2.357 ± 0.077
236.581	03:20	41	682	5.10	2.148 ± 0.066
236.591	03:34	65	1251	5.15	2.181 ± 0.050
236.600	03:47	122	2263	5.16	2.333 ± 0.044
236.610	04:01	172	3430	5.15	2.348 ± 0.036
236.619	04:19	188	3991	5.06	2.527 ± 0.039
236.628	04:27	123	2213	5.03	2.492 ± 0.051
236.638	04:41	85	1204	5.02	2.515 ± 0.070
236.649	04:57	70	750	5.23	2.625 ± 0.098
236.658	05:10	64	449	5.55	2.352 ± 0.099
236.667	05:23	41	304	5.59	2.435 ± 0.133
236.681	05:43	38	306	5.82	2.366 ± 0.124
236.726	06:47	51	319	5.65	2.096 ± 0.092
236.787	08:14	32	436	4.91	1.902 ± 0.061
236.844	09:35	19	245	5.04	2.760 ± 0.190
236.857	09:54	14	206	4.86	3.246 ± 0.303
236.868	10:10	18	302	4.81	3.382 ± 0.268
236.878	10:24	29	362	5.14	3.053 ± 0.194
236.887	10:37	51	629	5.27	2.819 ± 0.125
236.896	10:50	58	887	5.35	2.807 ± 0.104
236.907	11:05	25	221	5.12	2.655 ± 0.188
236.920	11:24	15	203	5.36	2.657 ± 0.199
236.982	12:52	10	133	5.56	2.439 ± 0.207

These population indices can be converted into mass indices which describe the exponent of the power law of particle abundance versus particle mass. If the entire kinetic energy of particle entering the atmosphere is converted to radiation, the mass index s can be expressed simply by $s = 1 + 2.5 \lg r$. For the above values, we obtain $s = 2.0 \pm 0.1$ and $s = 2.3 \pm 0.1$. The efficiency will not be 100%, however; photographic observations rather suggest $s = 1 + 2.3 \lg r$. The resulting mass indices are thus roughly $s = 1.9 \pm 0.05$ and $s = 2.2 \pm 0.1$, respectively. Particles as fragile as the Leonids will certainly provide particularly low energy-conversion efficiencies.

The corresponding mass index profile of the 2002 Leonids is shown in Figure 14. The values are all derived by $s = 1 + 2.3 \lg r$. The error bars are obtained from the r-errors applying error transmission which leads to $\Delta s \approx (\Delta r/r) 2.3 \lg r$.

A future analysis of the activity of the 2002 Leonids will be based on the population index profile presented in Figure 13. More details about the radiant height dependence are planned for that study.

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Ongoing meteor work

Morphology of persistent trains is due to fragmentation

Peter Jenniskens [1]

Persistent trains often show two parallel bands of light, a morphology that until now has been interpreted as due to a tubular structure and a phenomenon called 'limb brightening'. A problem with this interpretation is that the brightness between the two bands is less than expected. A recent study of meteoroid breakup now shows that fragmentation often leads to the survival of two relatively large fragments. Here, we show that this can explain the dominant morphological features of persistent trains.

1 Introduction

Persistent trains can be defined as all those luminous glows of meteors that linger due to chemiluminescence. They tend to last longer than several tens of seconds, because the time scale of the chemistry is limited by diffusion processes. Persistent trains were described as early as 1856 (Hind, 1866; Mann, 1856; Newton, 1869a; Newton, 1869b) and have since puzzled all those who witnessed or studied them. Spectacular trains were observed during the 1998 Leonids (Figure 1).

Proof that chemiluminescence was the luminous mechanism came only during the 1999 Leonid storm, when it was shown that most of the visible light is emission from the FeO (iron oxide) molecule and from sodium atoms (Jenniskens et al., 2000a). The light is produced as a result of chemical reactions that recombine the oxygen atoms in the train with ambient ozone molecules to form oxygen molecules, a process catalyzed by (amongst others) meteoric iron and sodium atoms (O_3 + Fe $\rightarrow$ FeO^* + O_2; FeO + O $\rightarrow$ Fe + O_2). Chapmann (1955) first proposed the mechanism. Other airglow-type mechanisms may be at work, especially in the near-IR, see Kruschwitz et al. (2001).

2 Train morphology

Drummond and co-workers (Drummond et al., 2001a, 2001b) have proposed a classification of persistent trains in two types: those that have two parallel bands of luminosity (Type II) and those that show abundant billowing structure (Type I). However, on closer inspection it is clear that even the trains with strong billowing (Figure 1) sometimes show two parallel bands.

That morphology of persistent trains has always been a puzzle. The simplest explanation is that the glow comes from the edge of a cylinder, where ambient ozone molecules gradually diffuse into the oxygen atom rich meteor path (Trowbridge, 1911; Hawkins, 1957). At the edge of the cylinder, the line of sight is parallel to that zone, causing limb brightening, while at the center it cuts perpendicularly through that zone, causing a factor of two lower brightness (Jenniskens et al., 2000b; Kruschwitz et al., 2001). On closer inspection, one finds that the void between the two bands is too dark, a point illustrated nicely by the ROTSE meteor in Figure 1, which shows a high contrast.

Alternative explanations include wing-tip vortices, such as those observed in the wake of an aircraft (Gerz and Holzapfel, 1999). Wingtip vortices are created be-

Figure 1 – Three well-studied Leonid persistent trains from 1998 Nov 17, all showing parallel bands with various levels of turbulent billowing. **Left:** A magnitude −10 Leonid at 01^h31^m UT left the 'Chippenham' train with two parallel bands along its entire path (Jenniskens et al., 2000b); **Middle:** a magnitude −11 Leonid left the 'ROTSE' train close to the radiant at 08^h32^m UT, which shows an abrupt change from little to much turbulence along its path (Zinn et al., 1999); **Right:** the product of a magnitude −14 Leonid at 10^h05^m UT studied by lidar (the diagonal streaks) with much billowing along its entire length (Chu et al., 2000). See also the discussion in (Kelley et al., 2000).

[1] *SETI Institute, 2035 Landings Drive, Mountain View, CA 94043. E-mail:* pjenniskens@mail.arc.nasa.gov

cause air is pushed down by the wings and rolls upward at its wing tips, thus creating a corkscrew shaped flow of air made visible on occasion by moisture in the air. If meteoroids flatten out to structures larger than the mean-free path in air, they could cause similar vortices. However, this explanation runs into problems because the bands have a large separation at the onset. In the case of the Chippenham meteor, we found an initial separation of 136 m at 86 km (Jenniskens et al., 2000b). The meteoroids responsible for bright Leonid meteors are thought to be much smaller, of order 5–20 cm.

3 Fragmentation as the cause for persistent train morphology

The observations point to both bands being independent trails caused by individual fragments (Kruschwitz et al., 2001), but how can there typically be only two fragments? In a recent study of video records of the Morávka fireball (Borovička et al., 2002), Jiri Borovička and colleagues made an important observation that, I believe, has relevance for cometary meteoroids and persistent trains. They found that many structurally strong meteoroid fragments during the breakup were lost abruptly at different altitudes. They concluded that during these breakups much of the mass is lost in the form of dust. If something survived big enough to cause a meteor, it was frequently two large fragments, with masses of 10%–30% of the initial mass. Only very rarely are there three fragments remaining. In particular, the measured frequency of one, two, three and four fragments was 8, 6, 1, and 0, respectively (Borovička et al., 2002). In my opinion, this could be a feature of catastrophic fragmentation in a collision with the air at the point of breakup pressure, where pieces on the back of the rock are typically spared. In collision experiments, a rock hitting a solid surface at high enough speed for a catastrophic fragmentation tends to break into smaller pieces at the front and spares larger fragments at the back (Fujiwara et al., 1989). This could also be the case for a rock hitting the air layer where the pressure exceeds the breakup pressure.

If comet dust too breaks apart early in flight and one or two dominant fragments remain, then the origin of the two bands in many persistent trains is explained. Because, just as in the luminous light during the descent, the fainter fragments will contribute little to the persistent train emission.

Fragmentation may increase the visibility of the train by increasing the volume of air involved in the chemistry. During the 2001 Leonid Multi-Instrument Aircraft Campaign, a slow (23 km/s), grazing, 12-second long, magnitude ~ -11 Taurid fireball was recorded on November 18 at $12^{h}52^{m}48^{s}$ UT by intensified video cameras (Figure 2). This fireball showed an unmistakable persistent train at a position early in the trajectory, when the fireball was only about magnitude -2. To our knowledge, this is the first time that a persistent train was reported for such a slow meteor. The train was visible for more than 14 minutes, until the plane turned away. It showed all the typical features, such as an initial increase in brightness (Jenniskens et al., 2000b), a long duration, and changes in shape due to the strong upper atmosphere winds. Hence, persistent trains are not unique to very fast and very bright fireballs! We can only understand why this particular slow meteor had a persistent train, when it was not so bright, by assuming that it was the fragile nature of cometary dust that helped create a number of fragments and make it bright. Taurids derive from comet Encke. I have found that Perseid fireballs, too, show persistent trains when viewed by a small telescope, although they tend not to be visible by the naked eye.

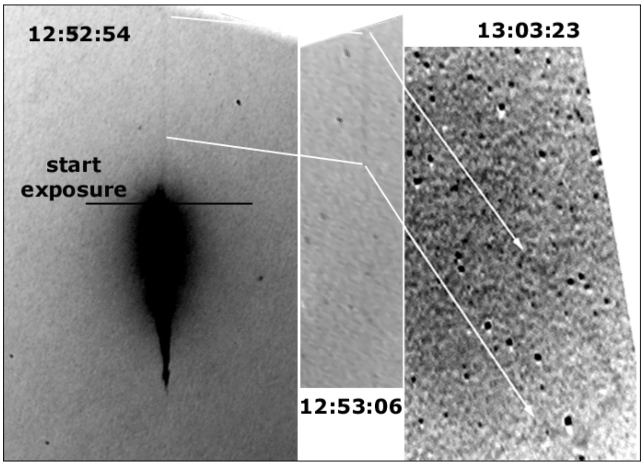

Figure 2 – The November 18, $12^{h}52^{m}48^{s}$ UT Taurid fireball, in a 10^{s} exposure by Dean W. Armstrong from Las Vegas, Nevada. The exposure was started while the meteor was in flight, moving top to bottom. The pictures to the right show the persistent train as seen from the FISTA aircraft at $+38^{s}$ and $+7^{m}$.

Further support for this hypothesis comes from a unique photograph that was obtained by Robert Haas of the Dutch Meteor Society during the Sino-Dutch Leonid campaign in China, which provided support to the 2001 Leonid MAC (Haas, 2001). Following a magnitude -6 earth-grazer at 2001 November 19, $16^{h}03^{m}58^{s}$ UT, he obtained a guided exposure of a persistent train that appears to consist of three parallel bands of light (Figure 3). Each band develops billows at a different rate, just as expected if three fragments survived the early breakup and were of different sizes.

4 Discussion

The breakup of the original Leonid meteoroid must have occurred above the $\sim$ 90–75 km altitude range where persistent trains are observed. The separation of the fragments is driven by the breakup and pressure generated in the process. As the fragments fall, they should continue to separate. I have re-examined the Chippenham data to see if the initial band separation increases with decreasing altitude as would be expected. Indeed, there is such an increase, which points to an initial separation of the fragments at an altitude of 130–160 km, with a horizontal velocity component of $\pm$100 m/s (Figure 4). The bands drift apart at a rate of 10.5 m/s, possibly due to pressure generated by the expanding heated air columns.

The breakup occurred just at the time of, or just

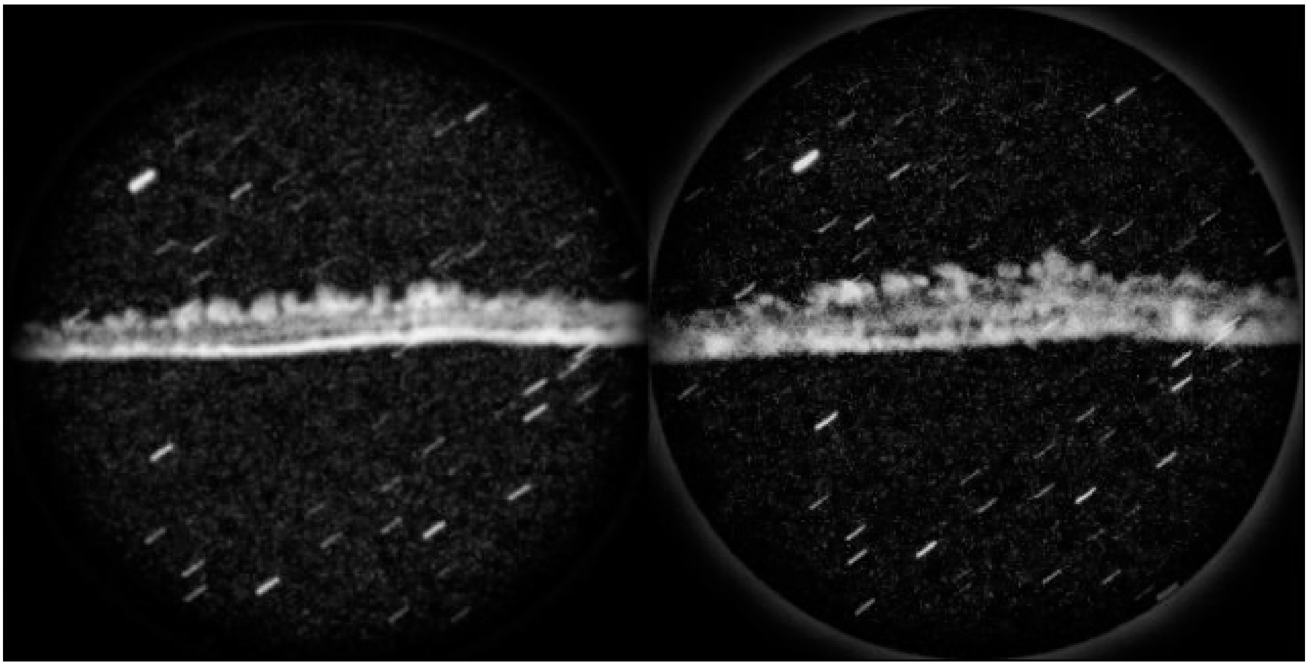

Figure 3 – Composite of two photographs of the magnitude −6 Leonid persistent train on 2001 November 19, $16^h03^m58^s$, showing three bands. Photograph by Robert Haas, Dutch Meteor Society (Haas, 2001).

before, the onset of the massive evaporation of silicates at ∼ 135 km altitude (Spurný et al., 2000; Popova et al., 2000). The mechanism of the fragmentation can not be the same as that for structurally strong meteoroids, because the pressure is still very low at 135 km. Rather, it is believed that the heating of the meteoroid by air collisions leads to the evaporation of a volatile 'glue' at an altitude higher than 120 km (Hawkes and Jones, 1975). Cometary meteoroids include many organic volatiles with boiling points of 400–600 K. These will presumably boil before minerals do. This evaporation process can be rather violent and the breakup could also be catastrophic in nature, with one or two large fragments remaining if the heating occurs preferentially at the front. Alternatively, stresses caused by heating could lead to a catastrophic breakup in these rather fragile meteoroids. It is not clear if the sudden increase in the total surface area would already be noticed if the breakup occurs before the main minerals start to evaporate. The catastrophic nature of the breakup is key to understanding why there are typically only (one or) two large fragments.

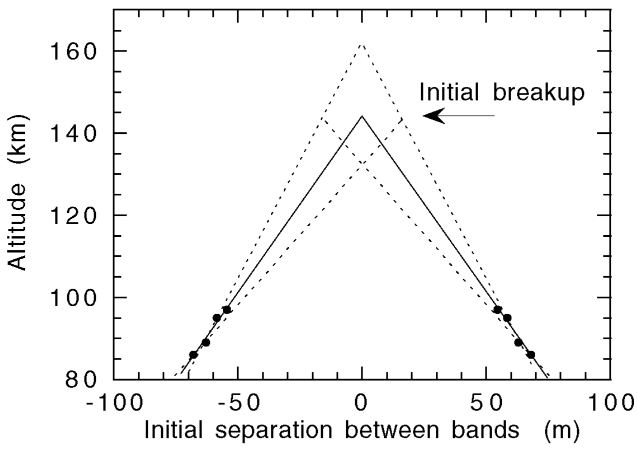

Figure 4 – Separation of the Chippenham bands just after deposition. Each set of dots represents the separation of the bands extrapolated back in time the drift of the persistent train to the time of formation. I measured this initial separation at four altitudes. The solid lines are the best fit, the dotted lines are the most extreme cases that will fit in 1-σ accuracy of all points of each quartet.

It is often observed that the two bands have different brightnesses. The intensity of each band depends on the rate of mixing between oxygen atoms created in the meteor's path and ambient ozone molecules, and mixing is enhanced by turbulence.

The source of turbulence could be the flow around the body, or the instability of the column of heated air in its path. The flow around the body has too low a Reynolds number (Re ∼ 800) and too high a Knudsen number (Kn ∼ 1) to generate turbulence, but roughness, heat, and ablation vapor can disrupt the flow. The most likely explanation for the observed billowing, however, is that the heated air column behind each fragment becomes unstable. The size of the column behind each fragment is about 10 mean-free paths wide, which amounts to a few meters at 95 km, and various fluid dynamical processes can occur. Shortly after the collisions heat the air in the meteor's path, the plasma will tend to expand to pressure equilibrium with its surroundings. When the hot gas in the meteor's path accelerates against the colder heavy ambient environment there will be Rayleigh-Taylor (R-T) instabilities. Small irregularities in the interface quickly grow to larger structures, when the hot gas penetrates the denser and colder ambient air. Indeed, the images by Haas (Figure 3) appear to show a preferred expansion of the air in upward direction, as expected for R-T instabilities in an environment with gravity.

A characteristic of R-T instabilities is that, after an initial exponential growth, at larger amplitudes the hot gas penetrates linearly with time into the ambient medium in the form of fingers or bubbles (Taylor, 1950). Those fingers then merge into larger structures before dissipating when the pressure difference that drives the instability is gone. The observed width of the Chippenham bands does seem to increase linearly in time at 3 m/s before slowing down, although a (square root with time) diffusion-like expansion cannot be excluded (Jenniskens et al., 2000b).

The amount of vorticity created during the initial exponential growth (which determines the appearance of the pattern shortly after) is a function of the pressure and density of the heated gas. Larger fragments should create more heated air plasma, producing billowing trains. Indeed, very bright (magnitude −12 to −14) Leonids tend to show larger billows (Figure 1). Turbulence should be more prominent during peak brightness when ablation rates are high deeper in the atmosphere. Abrupt changes in the brightness of the meteor can explain the sudden increase in billowing observed in the ROTSE meteor (Zinn et al., 1999). In other cases, the trains can remain relatively free from turbulence (such as the Chippenham train) if much of the light results from the ablation of dust in the flow and the persistent trains are caused by relatively small fragments.

Kelvin-Helmholtz instability can perhaps play a role as well in creating initial irregularities. K-H instabilities are caused by velocity shears between the heated plasma and the ambient atmosphere. In bright fireballs, it has been shown that such velocity shears do exist immediately after the passage of the meteor, as a result of kinetic energy of the meteor being imparted on the meteor plasma (Borovička and Jenniskens, 2000).

5 Conclusion

In conclusion, the multi-band morphology of persistent trains is not due to limb brightening of a tubular train, but a result of fragmentation of meteoroids at high altitudes, after which each fragment creates its own turbulent wake.

The implication is that persistent trains may be used to study the stresses that cometary matter can be subjected to before breaking, which is important information for future comet landing missions. The surface of comets is thought to consist of fallen back meteoroids. Studies of the onset of meteors too may teach us when and how cometary meteoroids first fall apart.

Acknowledgments

I thank John Plane for helpful discussions over the years. Mike Koop operated the intensified cameras onboard the FISTA aircraft during the 2001 Leonid MAC mission. The deployment of FISTA was made possible by grants from NASA's Astrobiology and Planetary Astronomy programs. The mission was executed by the 418th Flight Test Squadron at Edwards AFB in California. This paper supports the goals of the ProAmat Working Group of IAU commission 22.

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On the existence of the September Taurid shower

Arkadiusz Olech [1]

An analysis of the paths of 1906 meteors observed in the middle of September 1996–2000 during almost 400 hours collected by the Polish Comets and Meteors Workshop (CMW) shows no trace of September Taurid activity. The maps computed by RADIANT and COMZHR software show the existence of δ-Aurigid and α-Triangulid radiants but no signature of the September Taurids. Moreover, the ZHR profile computed using the radiant position given in the original discovery announcement shows only random variation at the level of ZHR ≈ 1 with no clear enhancement around the predicted maximum of the activity of the shower.

1 Introduction

Recently, S.J. O'Meara (2002) reported the discovery of a new meteor shower. In the middle of 2001 September he observed quite fast meteors radiating from the area around $\alpha = 61°$ and $\delta = +22°$.

This shower, called the September Taurids, attracted the attention of two Bulgarian observers who witnessed quite strong activity during the night of 2002 September 14/15. Among 35 plotted meteors, as many as 9 seemed to come from the radiant at $\alpha = 61°$ and $\delta = +21°$ (Velkov, 2003).

Both these investigations derived similar parameters of the stream independently, suggesting that the September Taurid shower indeed exists. On the other hand, the small number of observed meteors, the small number of analyzed observations and the vicinity of large radiants of sporadic meteors connected with northern and southern branches of the apex source made this discovery questionable.

We decided to verify the results described in (O'Meara, 2002; Velkov, 2003) using the data from the Polish Visual Meteor Database (PVMDB) (Olech et al., 2001). Besides the data already published from 1996–1998, we also used unpublished entries from the interval 1999–2000 (Złoczewski et al., 2003).

2 Observations

We investigated the behavior of the September Taurids in the period September 5–25. There are 397.56 hours of effective observation time and 1906 meteors recorded in the PVMDB in the years 1996–2000 for this interval. These observations were collected by 25 observers whose names with effective observation times are listed below:

> Paweł Brewczak (2.00), Dariusz Dorosz (32.66), Ewa Dygos (31.10), Jarosław Dygos (40.92), Tomasz Fajfer (76.50), Izabela Fitoł (5.00), Michał Jurek (6.84), Maciej Kwinta (21.83), Mariusz Lemiecha (16.00), Krzysztof Mularczyk (37.00), Jarosław Nocoń (6.22), Arkadiusz Olech (8.50), Dorota Pietruszko (3.41), Łukasz Pospieszny (1.00), Karolina Pyrek (23.00), Andrzej Skoczewski (14.76), Krzysztof Socha (13.63), Dominik Stelmach (5.68), Piotr Szakacz (6.43), Konrad Szaruga (11.24), Paweł Trybus (5.32), Mariusz Wiśniewski (6.94), Albert Witczak (18.08), Luiza Wojciechowska (2.00), Krzysztof Wtorek (1.50)

Based on this material we obtained 410 hourly rate estimates.

3 The radiant

All meteors from the PVMDB were transformed into the DBF format and then analyzed using the RADIANT software (Arlt, 1992). This software takes into account the properties of the observed meteors such as angular velocities and coordinates of the beginning and the end of the meteor path, and computes maps of probability for the presence of a radiant (hereafter PPR maps).

We have chosen maps centered at the radiant of the September Taurids and having a size of $60° \times 60°$ with a resolution of (50×50) pixels. The angular velocity of the meteors considered was in the range $(1–30)°/s$. We have analyzed only those meteors with a distance from the center of the map smaller than $90°$. The PPR maps were computed for geocentric velocities from 30 km/s to 55 km/s with steps equal to 5 km/s, and for solar longitude $\lambda_\odot = 172°$ corresponding approximately to September 15. The daily drift of the radiant was assumed to be $\Delta\lambda = 1.0°$.

The results are presented in Figure 1 where we show PPR maps for different geocentric velocities. All maps show the predicted positions of the other radiants active around September 15, i.e. the δ-Aurigids and σ-Orionids.

4 An alternative explanation for the original observations

Since the 1950s we have known that sporadic meteor radiants are not distributed uniformly over the celestial sphere, but that they are concentrated in particular regions which are similar to radiants with radii around $20°$ and positions approximately fixed relative to the Sun. The first three sources associated with the ecliptic plane were discovered by Hawkins (1956). According to the latest papers (Brown & Jones, 1995; Jones & Brown, 1993; Poole, 1997), we now identify six such sources. They are the antihelion, helion, northern and southern toroidal centers and also the northern and southern apex. In this work we focus only on the apex sources

[1] *Nicolaus Copernicus Astronomical Center, Polish Academy of Science, ul. Bartycka 18, 00-716 Warszawa, Poland.*
Email: `olech@camk.edu.pl`

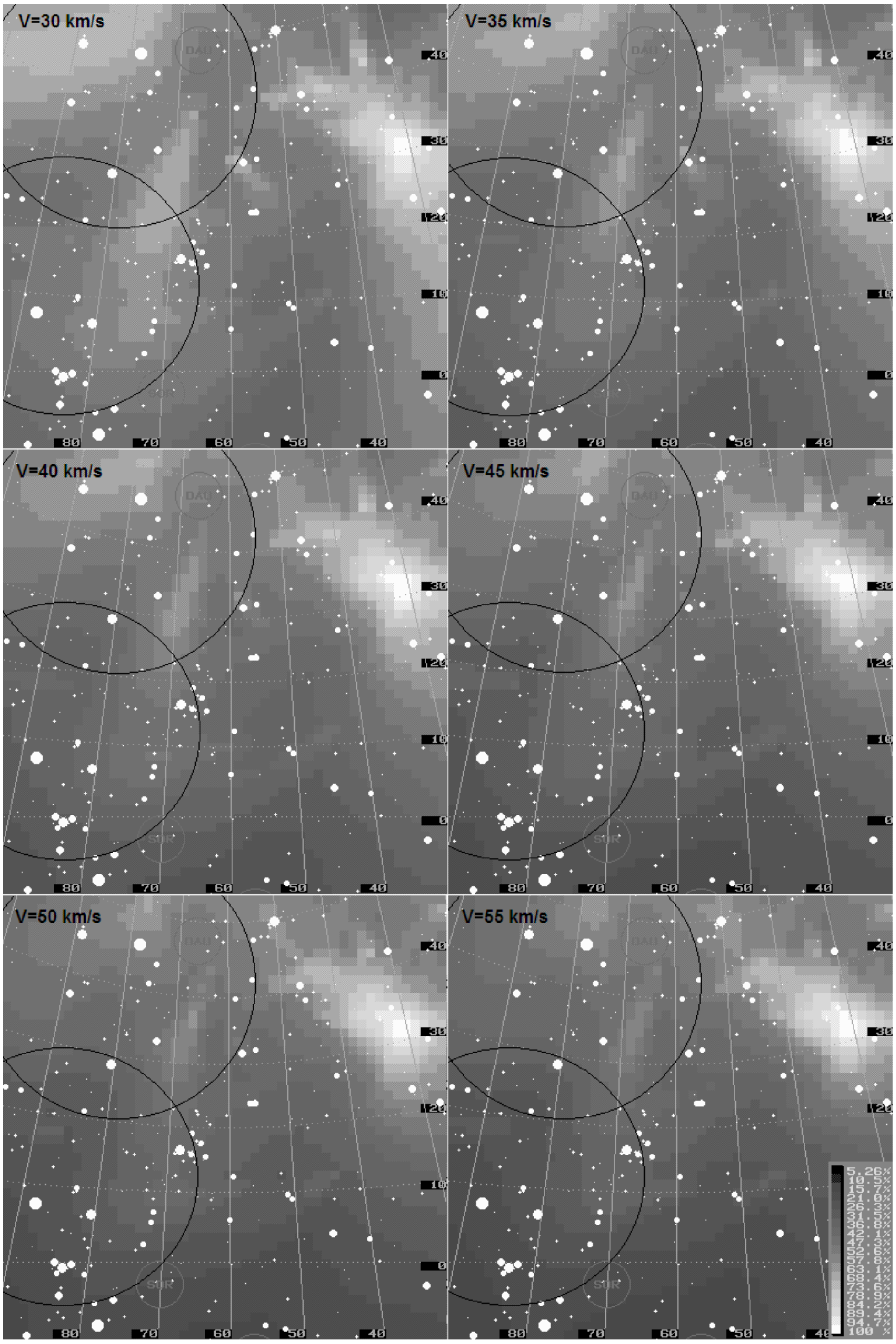

Figure 1 – PPR maps for a sample of 1906 meteors observed around September 15 in the years 1996–2000. All maps are computed for the following parameters: $\lambda_\odot = 172°$, $\Delta\lambda = 1.0°$. The maximum distance of the meteor from the radiant is 90°. The large circles denote the positions of the sporadic meteor sources connected with the Northern and Southern Apices. North is up and East is left.

since they are relatively close to the suggested position of the September Taurid radiant.

In Figure 1 the northern and southern apex sources are denoted by open circles with radius 20° (Jones & Brown, 1993). The highest PPR is observed on the border line between the Aries and Triangulum constellations (upper right of Figure 1) and can be connected with activity of the α-Triangulid shower (Currie, 1994; Wiśniewski, 2003). One can also detect a weak signature of the δ-Aurigid radiant (upper left of Figure 1), slightly shifted most probably due to the influence of the northern apex source.

There is no signature of any radiant close to the center of the map where we expect to find the radiant of the September Taurids.

Recently, Olech & Jurek (2003) introduced the new ComZHR software which, for a given geocentric velocity, computes maps of mean Zenithal Hourly Rates

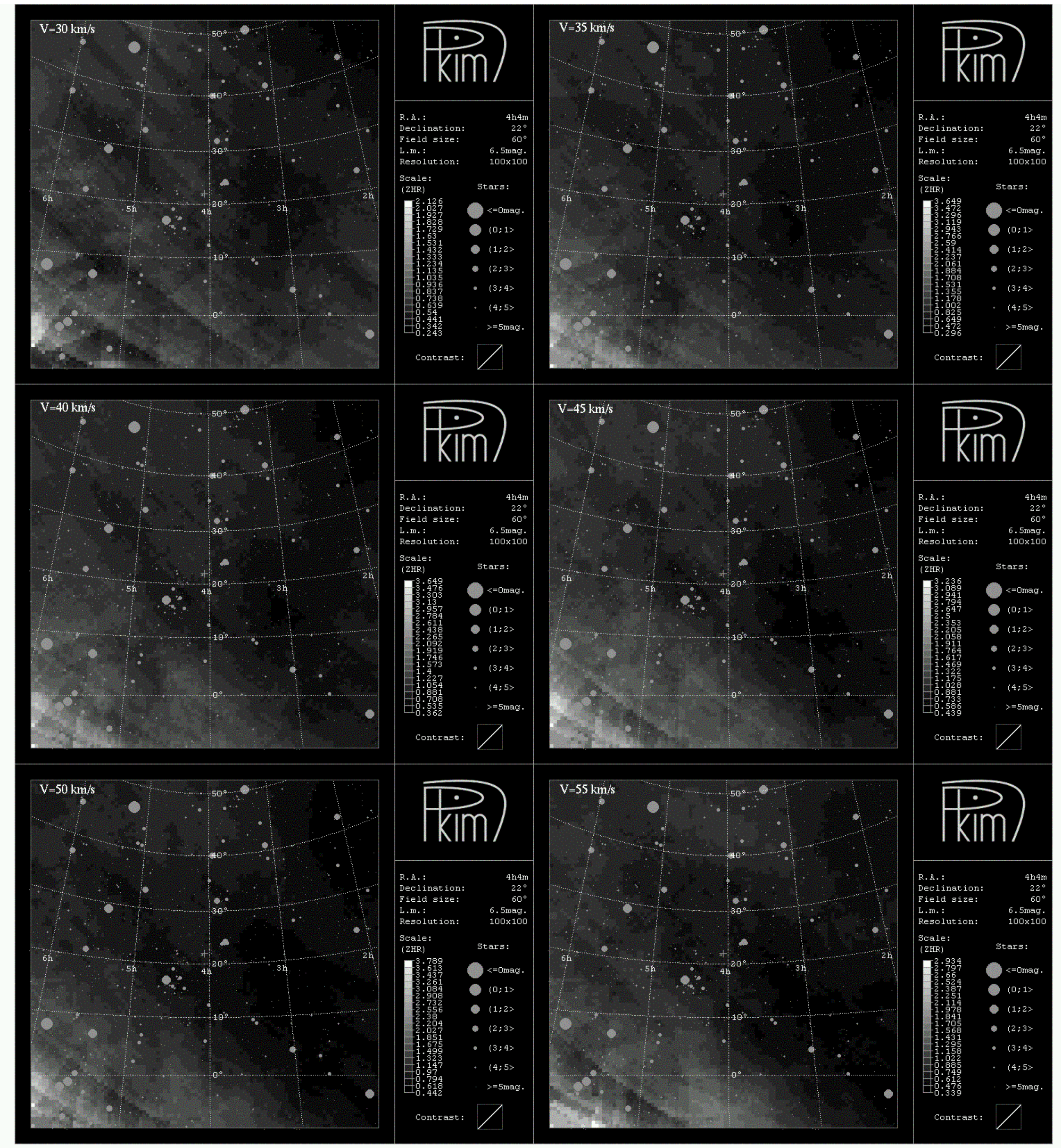

Figure 2 – ZHR maps for a sample of 1906 meteors observed around September 15 in the years 1996–2000. All maps are computed for the following parameters: time of maximum $\lambda_\odot = 172°$, daily drift $\Delta\lambda = 1.0°$. North is up and East is left.

(ZHRs) averaged over a given time interval. The pixels of this map where true radiants exist should have high mean ZHRs compared to others, making the detection of new showers possible.

We decided to use ComZHR to look for the September Taurid radiant. The maps we computed have the same parameters as in the case of the analysis performed using the Radiant software. However, the resolution was increased to (100×100) pixels. Pixels were considered for analysis only when their altitude during the time of observation was over 20°.

The results obtained using the ComZHR software are shown in Figure 2.

This time the strongest signature of the radiant is observed in the Orion constellation (bottom left of Figure 2). It could be a combination of two factors: activity of the Southern Apex and high ZHRs produced by the low elevation of this part of the map during September nights. Additionally, on all ComZHR maps one can see the same pattern with higher ZHRs at the left part of each map. These higher ZHRs are most probably connected with activity of both apex sources, which are characterized by spread in geocentric velocities and not by one almost exact value of entry velocity as with ordinary meteor showers. The lower-left corner of Figure 2 is always low over the horizon. This has major influence on two things: (1) The ZHRs computed for these points are artifically overestimated because the coefficient $1/\sin(h_{\rm R})$ is large. (2) Meteors are seen always far away from this area. ComZHR uses standard IMO criteria for shower association, and thus radiants from the lower-left corner are always very large and many meteors seem to radiate from this area contributing to the higher ZHRs.

There is a weak signature of the radiant at the center of the map but its weakness does not allow us to derive any valuable conclusions about its connection with the September Taurids.

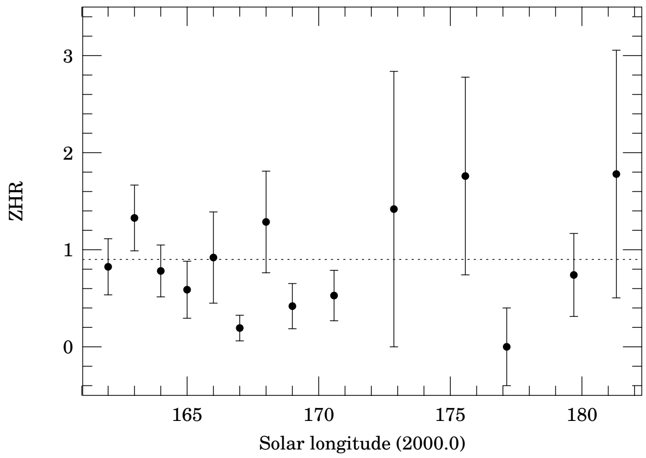

Figure 3 – The activity profile of the September Taurids resulting from the CMW data. The dotted line denotes mean ZHR value for all points in the graph.

5 The activity profile

Knowing the position of the September Taurid radiant given in (O'Meara, 2002; Velkov, 2003), we can compute the activity profile of the shower. We have assumed that the geocentric velocity and population index r are equal to 40 km/s and 2.6, respectively. A velocity of 40 km/s is a quite safe assumption taking into account that we in fact do not know the exact value of V_∞ for any possible September Taurids. We point, however, out that our conclusions do not differ at all for velocities of 50 km/s and 60 km/s.

The resulting activity profile for the September Taurid shower for the period September 5–25 is shown in Figure 3. There is no clear trend visible on this graph and one can see only a random scatter around the mean value of ZHR ≈ 1. The lack of the enhancement of the ZHRs around the predicted time of the maximum ($\lambda_\odot \approx 172°$) is another argument for the non-existence of the September Taurids. Of course another but less plausible explanation is that the shower might be real but not really present in the years 1996–2000.

6 Conclusions

Our analysis of the paths of 1906 meteors observed in the middle of September 1996–2000 during almost 400 hours collected by the Polish Comets and Meteors Workshop shows no trace of September Taurid activity. The maps computed by RADIANT and COMZHR software show the existence of δ-Aurigid and α-Triangulid radiants but no signature of the September Taurids. Moreover, the ZHR profile computed using the radiant position given in O'Meara (2002) and Velkov (2003) shows only a random scatter at the level of ZHR ≈ 1 with no clear enhancement around the predicted maximum of the activity of the shower.

Thus we conclude that currently available observational data does not give any proof for the existence of the September Taurid shower. The conclusions about its presence described in O'Meara (2002) and Velkov (2003) were based on very modest observational material and were, in our opinion, too eager.

Acknowledgments

I would like to thank to Konrad Szaruga and Michał Jurek for their great efforts inputing the 1999–2000 data.

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The Lyrids in 2003

Audrius Dubietis[1] *and Rainer Arlt*[2]

An analysis of the 2003 Lyrid meteor shower is presented. Due to the moonlight interference, fewer Lyrids were seen than in other years. However, the normalized activity in terms of a Zenithal Hourly Rate (ZHR) has reached the annual level. The shower peaked at $\lambda_\odot = 32\overset{\circ}{.}32$ (J2000.0) with ZHR $= 18.5 \pm 1.7$ which is in good agreement with the combined profile derived by the authors from more than a decade of observations. The population index was $r = 2.36 \pm 0.11$.

1 Introduction

The activity of the Lyrid meteor shower extends from $\lambda_\odot = 25°$ to $\lambda_\odot = 38°$ (April 15–28) with a sharp maximum at solar longitude $\lambda_\odot = 32\overset{\circ}{.}3$ with ZHR $= 18$ (Dubietis & Arlt, 2001). All solar longitudes in this Paper refer to eq. J2000.0. The Lyrid meteor shower is produced by a long-period comet, C/1861 G1 (Thatcher), which has a period of ≈ 415 yr. The annual activity of the Lyrid meteor shower is characterized by almost constant hourly rates recorded from year to year. Nevertheless, the Lyrids are known for several unexpected outbursts (Jenniskens, 1995, 1997), which make the shower an interesting target for observing. Arter & Williams (1997) showed that the Lyrid meteoroid stream forms a ring structure as a consequence of perturbations caused by Jupiter and suggested a 12-year periodicity, explaining the times of outbursts in the past rather well. Only one intersection with the hollow stream is being observed, however. The 12-year periodicity would make 2006 a promising year of enhanced activity. Lyytinen & Jenniskens (2003) related these outbursts to the perturbations of the one-revolution trail, predicting the forthcoming outburst of the Lyrids in 2040.

2 Observations

The observing conditions for 2003 Lyrids were not ideal, a full moon by April 16 having changed to a last-quarter on April 23, so part of the observations were affected by moonlight. For northerly locations moonlight was a less disturbing factor, with the Moon at very southerly declinations rising well after local midnight. The shower maximum was expected at $21^{\rm h}$–$22^{\rm h}$ UT on April 22 ($\lambda_\odot = 32\overset{\circ}{.}3$), favoring sites located in the Near East and Eastern Europe. In the period of April 16–26, a total of 1072 meteors (455 Lyrids, 45 Sagittarids, 1 η-Aquarid and 571 sporadics) were observed in 120.48 hours of net observing time. We highly appreciate the efforts of the following 44 observers:

> Bojan Besednik, Andreas Buchmann, Jens T. Carlsen, Mitar Ceranić, Tibor Csörgei, Danijela Cuić, Shlomi Eini, Daniel Grüen, Darja Golikowa, Shy Halatzi, Takema Hashimoto, Harri Haukka, Carl Johannink, Anna Levina, Robert Lunsford, Hartwig Lüthen, Marina Marinković, Alastair McBeath, Bruce McCurdy, Alex Mikishev, Emil Neata, Brian Nilsson, Markku Nissinen, Andrijana Obradović, Arkadiusz Olech, Jens O. Olesen, Daniel van Os, Milena Popova, Branislav Savić, Ivan M. Sergey, Hristo Stoev, Tibot Szeiff, Richard Taibi, Michel Vandeputte, Kristina Veljković, Valentin Velkov, Suzana Vicentić, Marija Vranić, Ilkka Yrjölä, Kim S. Youmans, Quanzhi Ye, and the authors

who are from the following countries:

> Belarus, Belgium, Bulgaria, Canada, China, Denmark, Finland, Israel, Japan, Lithuania, the Netherlands, Poland, Romania, Slovakia, Switzerland, the UK and the USA.

3 Analysis

The population index r was derived from 62 magnitude distributions reporting 389 Lyrids. Since the mean limiting magnitude for the entire set of observations was only $\overline{\rm LM} = +5.6$, the set of magnitude distributions used for the population index determination was reduced to LM $\geq +5.0$, with 333 shower meteors still being available. A standard method was applied, which involved a calculation of differences LM $- m$ and subsequent conversion into the population index. The method and conversion tables are given in Arlt (2003). Additional effects of individual perception characteristics such as are derived therein are neglected here. The analysis yielded $r = 2.36 \pm 0.11$.

The ZHR was computed using the standard procedure

$$\overline{\rm ZHR} = \left(1 + \sum_i n_i\right) \Big/ \sum_i \frac{T_{{\rm eff},i}}{C_i} ,$$

where n_i is the individual number of shower meteors observed during a time period $T_{{\rm eff},i}$, and C_i is the total correction for a limiting magnitude LM, field obstruction factor F, and the radiant elevation $h_{\rm R}$:

$$C_i = r^{(6.5-{\rm LM})}\, F \Big/ \sin h_{\rm R}.$$

Because of the interference from the moonlight, somewhat relaxed data selection by using $C_i \leq 10$ instead of $C_i \leq 5$, was applied. The error margins were estimated as

$$\Delta{\rm ZHR} = \overline{\rm ZHR} / \sqrt{1 + \sum_i n_i}.$$

The preliminary analysis given in an IMO shower circular (Dubietis & Arlt, 2003) was based on less than

[1] *Baltupio 101-2, LT-2057 Vilnius, Lithuania. E-mail:* audrius.dubietis@ff.vu.lt
[2] *Friedenstr. 5, D-14109 Berlin, Germany. E-mail:* rarlt@aip.de

half of the shower meteors available at present. Nevertheless, it provided a correct impression of the Lyrid activity in 2003. More data related to maximum and post-maximum periods arrived, and the maximum time was well covered by European observations reporting almost 300 Lyrids in a short time interval of $\lambda_\odot = 32\overset{\circ}{.}25$ to $32\overset{\circ}{.}50$. Figure 1 depicts the whole activity profile of the 2003 Lyrids. The softened data selection criterion allowed almost the entire rate dataset to be used, and 115 observing periods reporting 436 Lyrid meteors contributed to the activity graph. The scarce observational data of April 16–18 were omitted, since they comprised three observing periods only. A variable bin size for averaging was applied, depending on the amount of data available. There is still no reliable average ZHR of the pre-maximum time (within the interval of $\lambda_\odot = 31\overset{\circ}{.}6$ to $32\overset{\circ}{.}1$), which corresponds to $10^{\rm h}$–$20^{\rm h}$ UT of April 22. However, the average of only two pre-maximum observing periods is 14 at $\lambda_\odot = 32\overset{\circ}{.}25$. This is why we will assume that the maximum should not have occurred more than $0\overset{\circ}{.}1$ earlier than that shown in Figure 1. The peak rate of ZHR $= 18.5 \pm 1.7$ was thus observed at $\lambda_\odot = 32\overset{\circ}{.}32^{+0.05}_{-0.1}$, which coincides almost exactly with the time of the annual maximum derived from the long-period activity profile (Dubietis & Arlt, 2001). Because of the data gap before this peak value, we cannot exclude an earlier maximum time and we thus give a large lower margin for the $\lambda_\odot$-error.

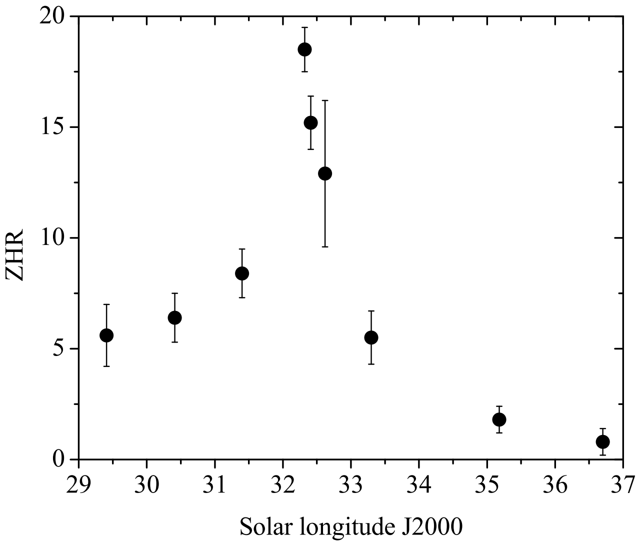

Figure 1 – Activity profile of Lyrids in 2003.

The post-maximum activity drops almost exponentially, whereas there is a characteristic plateau extending from $\lambda_\odot = 29°$ to $\lambda_\odot = 31\overset{\circ}{.}5$. A similar trend has been observed with the Lyrids on many occasions during the past decade; the origin of the plateau, however, is still being discussed. In 2003 the amplitude of the plateau was somewhat higher than usual, and this difference can be partly attributed to the disturbing factor of the moonlight.

Table 1 – Activity data of the 2003 Lyrids. $N_{\rm ind}$ is the number of individual periods and $N_{\rm LYR}$ is the number of meteors contributing to ZHR estimates.

$\lambda_\odot$	$N_{\rm ind}$	$N_{\rm LYR}$	ZHR
29.41	6	15	5.6 ± 1.4
30.41	10	32	6.4 ± 1.1
31.40	16	56	8.4 ± 1.1
32.32	23	124	18.5 ± 1.7
32.41	35	165	15.2 ± 1.2
32.62	3	14	12.9 ± 3.3
33.30	11	21	5.5 ± 1.2
35.18	9	8	1.8 ± 0.6
36.70	2	1	0.8 ± 0.5

4 Conclusions

The activity of the 2003 Lyrids was just slightly above the annual level, which has been established by more than a decade of observations. The shower peaked on 2003 April 22, at $23^{\rm h}$ UT ($\lambda_\odot = 32\overset{\circ}{.}32$) with ZHR $= 18.5 \pm 1.7$. More data, especially from Asia, will be needed to reach conclusions about the exact maximum time. We would be grateful if more still Lyrid observations were submitted.

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History

Meteor Beliefs Project: Three Meteoric Similes in *The Argonautica* of Apollonius of Rhodes

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

Three passages from Apollonius Rhodius' *Argonautica* which draw on meteoric imagery are discussed. Two different translations are given for each, to show some variations that may occur, which hint at problems of interpretation that may be found when trying to use such materials.

1 Introduction

In the first Meteor Beliefs Project article (McBeath & Gheorghe, 2003) we set out the basic guidelines for the Project, and presented some brief inaugural examples from the last 350 years, to give a flavour of what the Project is about. This time, we intend to delve back further into the past, looking at three meteoric similes used in *The Argonautica* written by Apollonius of Rhodes.

Apollonius is believed to have been born sometime between 296 and 260 BC in Alexandria in Egypt, where he lived and wrote his *Argonautica* in his youth, probably before the middle of the third century BC. Comments by other surviving authors from the period and after indicate the work was known of and quoted by circa 247/8 BC. Anciently written biographies suggest the poor reception of his epic composition in its original form disheartened him so much that he retired to the island of Rhodes to teach rhetoric. There, he continued to work on his poem, and later reissued it to critical acclaim and honour by the Rhodians, hence he became 'of Rhodes'. How much of this is true is uncertain. As with many ancient authors, little of their life and work has survived, and although there are hints in the extant 'later' version of the poem that it could have been revised, too little of the 'original' is preserved by other authors to give us any clues as to how different or similar the two versions were. No complete version of Apollonius' first attempt has reached us modernly.

The mythical voyage of Jason and the Argonauts to recover the golden fleece from the land of Colchis (modernly Georgia on the Black Sea) was well known in ancient times, and it is likely that numerous different versions existed. Certainly several other variants after Apollonius' time are known. Homer (or perhaps more accurately, the authors whom we know today as Homer), probably writing around the 8th century BC, refers to it in passing, and it is clear that it was believed to have occurred some time before the events surrounding the siege of Troy as recounted semi-mythologically in *The Iliad*. If true, as the historical siege of Troy probably occurred in the late 13th century BC, this could make any real voyage of this kind earlier still, but this is unknown. As with most myths, there is no single 'correct' version. The overall storyline often remains more or less intact, but episodes within it may vary with each retelling or reworking, and may take on a different political or philosophical slant to suit the tastes of different audiences. Even modernly, different translators have different opinions as to how the same phrases or words should be interpreted, and this can create confusion or problems for those unfamiliar with such facts.

To give a flavour of some of these variations in translation, we have used two different versions of Apollonius' poem here, (Seaton, 1912) and (Rieu, 1959). Both are prose translations, but only Seaton's text includes the Greek original as well. As usual, we would urge those interested to read the texts in full. Apollonius uses a number of other astronomical similes and descriptions and, allowing for poetic license in places, seems to have been well informed about astronomical thinking of the period. The tale includes far more than all this, however.

2 Meteoric similes in *The Argonautica*

There are three meteoric similes used in Apollonius' poem, which we shall give in order of appearance in Books III and IV, along with some comments to fit them into context. The line numbering refers to the specific quotes used, not this additional contextual information.

Book III, lines 132–141: Jason's actions in the myth are partly under the guidance of the goddesses Hera (Zeus' wife, and queen of the gods) and Athene (wisdom and war goddess, sometimes called Pallas Athene). Athene helps fashion the ship Argo, allowing the journey to happen. Acting at the request of these two goddesses, the love goddess Aphrodite — here called Cypris, one of her pseudonyms — is offering a bribe to her young son Eros to shoot one of his love-arrows into Medea's heart, so she will fall in love with Jason and aid him to retrieve the golden fleece safely. Medea is the daughter of King Aeetes of Colchis, high priestess of the underworld and magic goddess Hecate, and a powerful sorceress.

Aphrodite is speaking: *Come, be ready to perform for me the task I will tell thee of, and I will give thee*

[1] *12a Prior's Walk, Morpeth, Northumberland, NE61 2RF, England, UK. Email:* meteor@popastro.com
[2] *Bd. Tineretului 53, bl. 65, ap. 40, sect. 4, Bucureşti, Romania. Email:* sarm@minisat.ro

Zeus' all-beauteous plaything — the one which his dear nurse Adrasteia made for him, while he still lived a child, with childish ways, in the Idaean cave — a well-rounded ball; no better toy wilt thou get from the hands of Hephaestus. All of gold are its zones, and round each double seams run in a circle; but the stitches are hidden, and a dark blue spiral overlays them all. But if thou shouldst cast it with thy hands, lo, like a star, it sends a flaming track through the sky. (Seaton, 1912, pp. 202–203).

The same passage from (Rieu, 1959, pp. 112–113) runs: *Will you be good and do me a favour I am going to ask of you? Then I will give you one of Zeus's lovely toys, the one that his fond nurse Adrasteia made for him in the Idaean cave when he was still a child and liked to play. It is a perfect ball; Hephaestus himself could not make you a better toy. It is made of golden hoops laced together all the way round with double stitching; but the seams are hidden by a winding, dark blue band. When you throw it up, it will leave a fiery trail behind it like a meteor in the sky.*

As we see, the two versions effectively say similar things, but in general the language of the second is more modern, and more concise. The star with a flaming track has now been more clearly defined as a meteor, although the language of the first is closer to a literal translation of the Greek, where 'meteor' is not used.

Book III, lines 1377–1380: Jason is set a series of apparently impossible tasks by King Aeetes before he will release the golden fleece to Jason, including ploughing the Field of Ares with an adamantine plough and two bronze-hooved, fire-breathing bulls, then sowing it with dragon's teeth, from which will spring a host of spear-armed, armoured, men. These teeth were left over from those Cadmus had sowed earlier at the founding of Thebes, after killing the dragon which guarded Ares' spring there. Athene had brought them to Aeetes. Medea, now in love with Jason, provides practical and magical aid so Jason accomplishes these tasks, to the amazement of all. The dragon's-teeth warriors appear (Book III, lines 1359–1363):

And as when abundant snow has fallen on the earth and the storm blasts have dispersed the wintry clouds under the murky night, and all the hosts of stars appear shining through the gloom; so did those warriors shine springing up above the earth. (Seaton, 1912, pp. 286–287).

Jason has been told what to do next to save himself from the warriors. Magically assisted, he lifts up a huge, round boulder, a Quoit of Ares, too big for four stout young men to lift, and flings it into the midst of the warriors growing from the soil, then takes cover behind his shield. The dragon's-teeth men attack one another, felling each other like trees in a gale. With his enemies weakened, it is time for Jason (whose father is Aeson) to act; thus we reach the meteoric quote:

And even as a fiery star leaps from heaven, trailing a furrow of light, a portent to men, whoever see it darting with a gleam through the dusky sky; in such wise did Aeson's son rush upon the earthborn men (Seaton, 1912, pp. 286–287).

And now, like a bright meteor that leaps from heaven and leaves a fiery trail behind it, portentous to all who see it flash across the night, the son of Aeson hurled himself on them (Rieu, 1959, p. 145).

Jason successfully defeats the remaining warriors, and returns to the city in triumph as the sun sets, his tasks completed. Eventually, after further adventures to overcome Aeetes' treachery, the fleece is taken and the Argonauts with Medea return to Greece by a long, circuitous route, trying to avoid the pursuing Colchian ships.

Book IV, lines 294–297: At one point in the return journey around the Black Sea, the Argonauts are uncertain which way to go, so they land and make sacrifices to Hecate to ask for help:

... and to them the goddess granted a happy portent, and all at the sight shouted approval, that this was their appointed path. For before them appeared a trail of heavenly light, a sign where they might pass. (Seaton, 1912, pp. 314–315).

... and the goddess gave her blessing to the route he had proposed by sending them a sign. With cries of joy they saw ahead of them a trail of heavenly light, showing them the way to go. (Rieu, 1959, p. 155).

Thus guided, they return to the Argo and sail on. Interestingly, although it is unlikely we will ever know if Apollonius intended it or not, each of these three meteoric similes feeds into the next, despite their relative separations in the text. The physical appearance of the ball-toy leaving a meteoric trail in the sky of the first example, leads into Jason's leap into combat like a meteoric portent, which in turn leads into the meteoric portent of the final noted point above. Although this last item is not specifically stated as being a meteor, and other things, perhaps an auroral ray or the appearance of the zodiacal light, could be being described, the portentous nature of the event suggests something meteoric, especially with what had gone before.

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Details of the Proceedings of IMC 2002, Frombork, Poland

Those who have attended an International Meteor Conference (IMC) will know that they present many high-quality papers on a wide range of meteor subjects. This material is less well known outside the circle of conference-goers, however. To make it more widely available, we are publishing brief details of all IMC 2002 papers here.

Those who attended the Conference will soon receive the Proceedings. Others can order them from the IMO: details are in the lower half of the inside back cover of this Journal.

MBK Team — Leonids 2001 Expedition to Arizona

Javor Kac and Jure Atanackov

Members of the *MBK Team* observed the Leonid 2001 meteor storm from Arizona, employing both visual and photographic techniques. During the peak night more than 10 000 Leonids were recorded by three observers in just over 15 hours of observing time. The calculated peak ZHR of the Leonids was 4000 at $\lambda_\odot = 236\overset{\circ}{.}153$.

Preliminary Results of Video Observations from Sino-Dutch 2001 Leonids Expedition

Min Guan, Marc de Lignie, Jin Zhu, Sietse Dijkstra, Jian Gao, Robert Haas, Casper ter Kuile, Wenzhong Liu, Huan Meng, Koen Miskotte, Jos Nijland, Rui Qi, Arnold Tukkers, Michel VandePutte, Dan Xia and Bin Yang

The preliminary 2001 Leonids results of multi-station video observations are presented. The observations were obtained at Miyun, Panshan, Xinglong and Huairou in China during 2001 November 18–20. Thirty Leonid meteors are reduced. The co-ordinates of the radiant are $\alpha = 154\overset{\circ}{.}49 \pm 1\overset{\circ}{.}80$ and $\delta = 21\overset{\circ}{.}32 \pm 0\overset{\circ}{.}74$ (J2000.0) for a mean solar longitude of $236\overset{\circ}{.}486$ based on these 30 Leonids.

Leonid Persistent Trains

Eliza Trandafir and Valentin Grigore

Perseids 2002 in Poland

Aleksander Trofimowicz

The recent results of the Polish *Comets and Meteors Workshop (CMW)* on Perseid activity are presented. Analyzing the data obtained during the night of the maximum, we concluded that the peak occurred on August 13 at $01^{\mathrm{h}}07^{\mathrm{m}}$ UT with ZHR $= 91 \pm 13$, assuming $\gamma = 1$. Additionally we present the ZHR evolution as well as the population index evolution.

Perseid Observations at SPECTER 2002 Astronomical Camp

Javor Kac

A specialized meteor camp was organized by the *Orion Astronomical Society* to cover the Perseid activity around maximum. Ten visual observers recorded 2576 meteors (1544 of them were Perseids) in 87 hours of effective observing time. The highest Perseid rate observed was ZHR = 47, with the maximum night clouded out. The Perseid activity was also covered using photographic and radio techniques.

Some Results of the Perseid Observations in Astroclub "Canopus", July–August, 2002

Valentin Velkov and Vladimir Krumov

Our most recent Perseid observations, in 2002, are presented. The data are not sufficient for accurate determination of the time of maximal activity. An unusual radiant drift is found and the result is compared with data from previous years.

Perseids 2002 Event in Romania

Valentin Grigore and Ştefan Berinde

The 10th PERSEIDE Astronomical Youth Camp is described. This took place in four locations and the activities are related. The observations made are outlined.

Radio Observations of 2002 Perseids and Correlation with Visual Observations

Tomislav Jurkić and Senca Pintarić

Simultaneous radio and visual observations of the 2002 Perseid meteor shower were performed. Radio observations were made using the forward scattering method with a commercial TV transmitter and two antennas — a Yagi and two stacked dipoles. We made visual observations using the *IMO* standard and recorded the appearance time of each meteor. We performed echo duration measurements and the radio-echo activity profile obtained shows the maximum activity at a solar longitude of 139.95° and no double peaks.

There is a good agreement between the radio observations and the visual observations, both in the activity profile and the population index. The population index distribution from radio observations was obtained with the minimum of $r = 1.71 \pm 0.03$ at the solar longitude of $140\overset{\circ}{.}10$, which corresponds to the visual and radio activity profile maximum. The mean population index of the Perseid shower for the night of the maximum is $r = 1.95 \pm 0.04$ for Perseids and $r = 2.75 \pm 0.07$ for sporadic pre-Perseid meteors. A correlation with the exponential dependence between the radio echo duration and the visual magnitude was established and the regression coefficients were calculated. An echo duration of 0.100 seconds corresponds to magnitude $+5.7 \pm 0.4$, with the limiting magnitude of 6.0 ± 0.6 for the experimental setup. A clustering analysis of 377 visual meteors showed a low level clustering effect, while an analysis of 1610 radio echoes showed strong clustering possibilities.

CCD Observations of Meteor Showers

Mariusz Wiśniewski

The preliminary results of using a CCD camera for meteor observations are described. The data were collected during 21 nights between April 22 and August 13 at Ostrowik Station of the Warsaw University Observatory. During the first 17 nights we used the Cousins *I* filter. During these nights we captured 31 meteors. Observations made during four nights near the Perseid maximum were performed with the rotating shutter and without any filter. During these nights we captured 17 meteors.

Weak Meteor Showers in Photographic and TV Databases

Piotr Kędzierski and Krzysztof Mularczyk

We present the results of an analysis of photographic and TV observations of the meteors from four databases combined into one uniform database. The total number of meteors used in the analysis is 7538 observed in the period 1952–2002. We wanted to demonstrate the possible existence of some minor meteor showers listed in the *IMO Working List of Visual Meteor Showers* and other lists of photographic radiants of minor meteor showers mentioned in some recent papers. Our analysis was done using special software which checks for the existence of almost 30 showers, but in this report we present the results of only those for which we obtained interesting output.

Small Bodies of the Solar System in the Data of the ASAS Project

A. Olech, M. Wiśniewski, M. Jurek, K. Złoczewski, P. Kędzierski, K. Mularczyk, A. Skoczewski and A. Trofimowicz

The data collected during the three stages of the All Sky Automated Survey (ASAS) project are reviewed from the point of view of searching for traces of small Solar System bodies. There are over 150 000 frames collected during the first five years of the project. There are many traces of meteors, asteroids and comets in these images. They are a potential source of valuable information about meteor showers of the southern hemisphere and orbital elements of newly discovered asteroids and comets. We point out on the possibility of discovering new comets and Near-Earth asteroids by analyzing the ASAS data using a newly developed image subtraction method.

Further Investigation of the β-Ursa-Minorids

Kamil Złoczewski

This work analyzes the data collected by observers of the Polish *Comets and Meteors Workshop* in August 1999–2001 with the aim of looking for the β-Ursa-Minorid shower. The radiant of this shower is clearly visible and its coordinates are $\alpha = 202°$ and $\delta = +65°$. The activity period of the shower lasts from around August 5 to August 11 with maximum around August 9. The best radiant picture is obtained from a geocentric velocity $V_\infty = 13$ km/s.

Video Meteor Observations from Slovenia — the First Test

Mihaela Triglav and Stane Slavec

The first video observations from Slovenia made by Stane Slavec of the *Astronomical Association Javornik* from his observing site in Ljubljana are described. The analysis of video data from the Perseid period is made with the Radiant program. The radiants of the Perseids, κ-Cygnids and Aquarids are drawn.

A Possible New Shower — September Taurids

Valentin Velkov

Observing results in connection with a publication of an American meteor observer are presented.

Summer Observations of the Astroclub "Canopus" in 2002

Valentin Velkov and Vladimir Krumov

A short review of the results of last summer's observing campaigns is presented.

More Information about the Probable Meteor Shower Related to C/1999 J3 (LINEAR)

Mihail Mihov

A short history of the investigation is given. Some new results are also mentioned. They are based on photographic, visual and video data. Unfortunately, the radiant of the Linearids near α Ursae Majoris cannot be clearly distinguished yet.

Looking for Weak Meteor Showers Using ComZHR Software

Arkadiusz Olech and Michał Jurek

This report describes new software of which the main goal is looking for the radiants of meteor showers and analyzing their structure. The software, for a given geocentric velocity, computes maps of mean Zenithal Hourly Rates (ZHRs) averaged over a given time interval. The pixels of this map where true radiants exist should have high mean ZHRs comparing to others, making the detection of new showers possible.

The Meteor Train Observing Project

Jan Verbert

The meteor train observing project, founded by M. Vints in 1991, has been restarted and extended. In the years 1992–1996 many observations were sent in, but after 1997 the rate dropped. Past observations have been entered in the database and further investigations can be started. Our goals are to study the differences in train formation between showers, during the night, and during the year.

Quantum Processes Accompanying the Development of Meteoric Phenomena in the Atmosphere

V. A. Smirnov

The theory and mechanism of double radiation of fast shower meteors are considered.

Mathematical Modeling of Meteoroid Stream Formation

Galina Ryabova

A brief description of mathematical models for the Geminid meteoroid stream and for the meteoroid streams of comet Halley and asteroid Geographos is presented.

Meteor Astronomy in Primary and Secondary Schools

Konrad Szaruga

The teaching of astronomy at school in Poland is described. The problems and opportunities are outlined; practical advice on keeping the attention and interest of children is given. Typical results are presented, indicating that an initial group of one or two dozen interested students may shrink to leave two or three with serious long-term interests. The need for expensive equipment is described, with some techniques for acquiring it.

Astronomical Youth Projects Supported by the European Union

Piotr Nawalkowski

The *Beskid Astronomical Club "Polaris"* and some of its activities are presented. The successful application for a European Community grant is described, and educational projects conducted with the grant are related. These involved astronomy camps to introduce Polish youth to the night sky and provide training in observation, especially of meteors.

Knowledge of Meteors by the Romanian Teenagers

Gelu-Claudiu Radu and Cornel Apetroaei

A survey of the astronomical knowledge of Romanian teenagers is described. The survey concentrated on knowledge of meteors and documented the declining level of astronomical teaching in schools.

World Meteor Poetry at the End of the Second Millennium

Andrei Dorian Gheorghe

A summary of meteor poetry from around the world is presented. Brief samples from the work of many poets are presented.

The Research of New Meteor Radiants

Ivan M. Sergey

Establishing the Existence of Theoretical Comet Radiants and Minor Planet Radiants.

Ivan M. Sergey

A total of 170 theoretical objects were selected from those listed by Artoos and checked on the basis of Belorussian visual meteor database covering the years 2000–2001, including 9236 meteors recorded by 34 observers of the *Belorussian Meteor Observers Network (BMON)*. The aim of the work was to check the existence of the theoretical comet radiants and minor planet radiants. The computer program Radiant 1.43 was used for the analysis of the situation of the corrected radiants. The recommendations on the use of this program were taken into account in this work.

Perseids 2000 in Belarus

Ivan M. Sergey

Perseids 2001 in Belarus

Ivan M. Sergey

The International Meteor Organization

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

Council

President: Jürgen Rendtel,
Seestraße 6, D-14476 Marquardt, Germany.
tel. +49 33208 50753
e-mail: `jrendtel@aip.de`

Vice-President Alastair McBeath
12A Prior's Walk, Morpeth,
Northumberland NE61 2RF, UK.
tel. +44 1670 518487
email: `mcbal.gwyvre@virgin.net`

Secretary-General: Robert Lunsford
Vance Street 161, Chula Vista,
CA 91910, USA. tel. +1 619 585 9642
e-mail: `lunro.imo.usa@cox.net`

Treasurer: Ina Rendtel
Mehlbeerenweg 5, D-14469 Potsdam, Germany
tel. +49 331 520 707
e-mail: `IRendtel@t-online.de`
postal (giro) account number: 5472 34-107
bank code: 100 100 10 Postbank Berlin
(bank code and postbank to be mentioned together with account number!)

Other council members:

Rainer Arlt, Friedenstraße 5, D-14109 Berlin, Germany. e-mail: `rarlt@aip.de`

David Asher, Armagh Observatory, College Hill, Armagh BT61 9DG, Northern Ireland, UK. email: `dja@star.arm.ac.uk`

Malcolm Currie, 25, Collett Way, Grove, Wantage, Oxfordshire OX12 0NT, UK. e-mail: `mjc@star.rl.ac.uk`

Marc Gyssens, Heerbaan 74, B-2530 Boechout, Belgium. email: `marc.gyssens@luc.ac.be`

André Knöfel, Saarbrücker Straße 8, D-40476 Düsseldorf, Germany. e-mail: `aknoefel@minorplanets.de`

Sirko Molau, Verbindungsweg 7, D-15366 Hönow, Germany. e-mail: `sirko@molau.de`

Mihaela Triglav, Podkraj 10c, SI-3320 Velenje, Slovenia. email: `mtriglav@yahoo.com`

Commission Directors

FIreball DAta Center: André Knöfel
Photographic Commission: Marc de Lignie
Prins Hendrikplein 42,
NL-2264 SN Leidschendam, the Netherlands
e-mail: `m.c.delignie@xs4all.nl`
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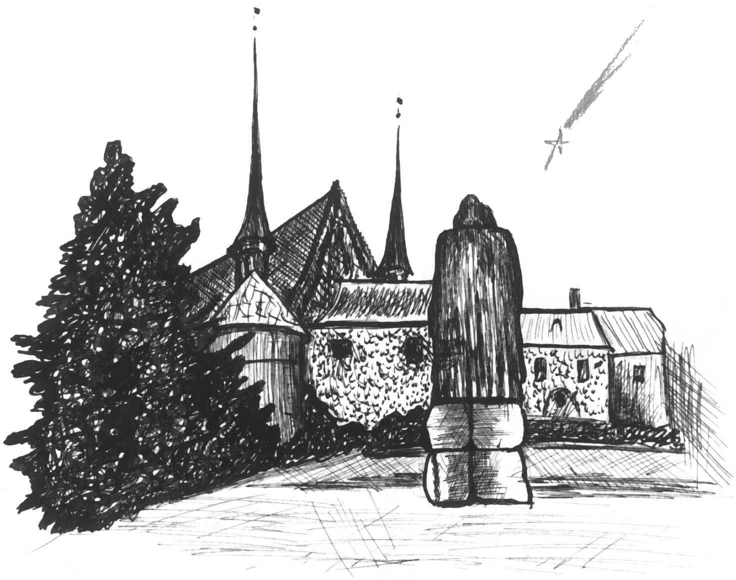

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