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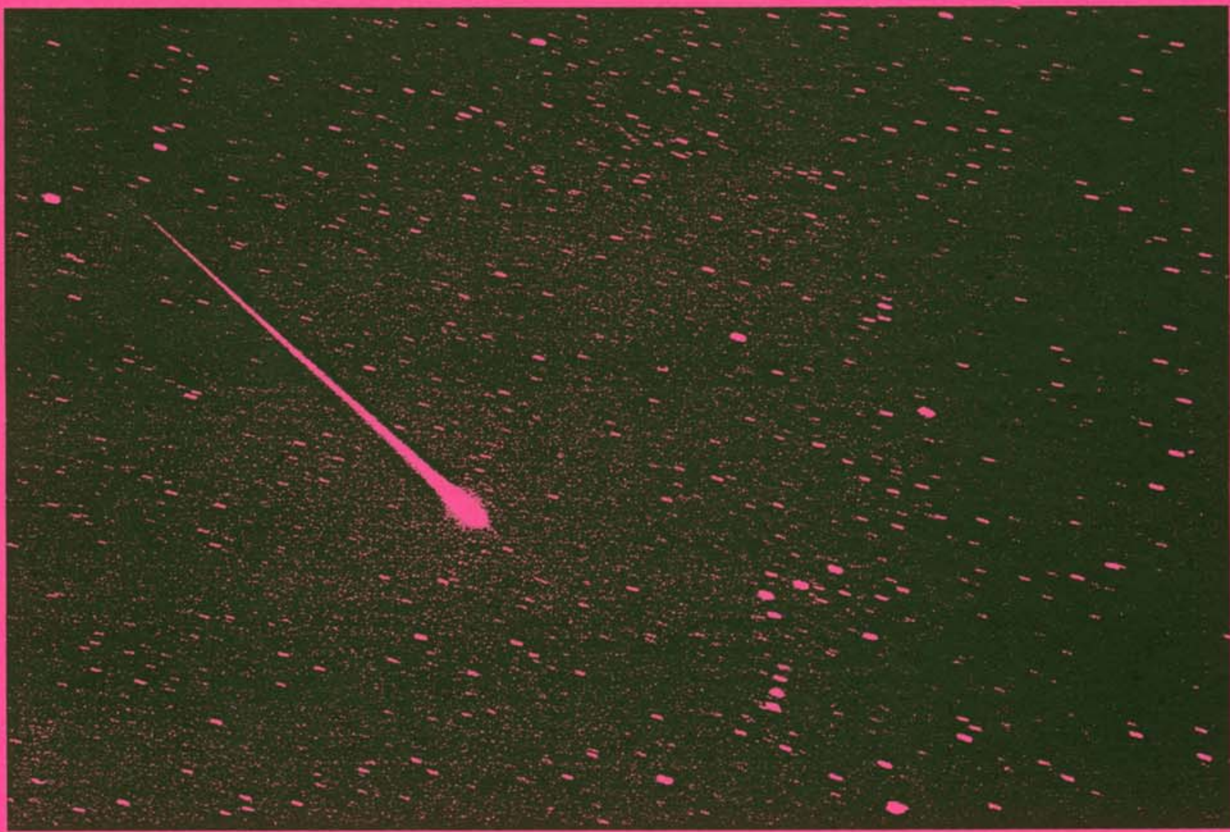

An impressive image of a magnitude −10 Leonid fireball obtained by Sergio de Miguel of the *Spanish Photographic Meteor Network* in 1998. The photo was taken from Valladolid (Spain) on November 17, 1998, at $3^h15^m$ UT.



In case of non-delivery, return postage guaranteed. Please return to:
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*WGN, Vol. 26, No. 6, October 2000, pp. 185-240*

## Contents



## Useful Information

### The February issue *(WGN 29:1)*

The *February issue* will be mailed around the middle of February. Contributions should be sent as soon as possible to *Marc Gyssens*.

### Subscriptions and ordering of publications

Volume 29 (2000) of *WGN* is expected to contain at least 240 pages and costs 35 DEM or 17.90 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription/membership fees. Subscription/membership information can be found in this issue, on p. 187. Changes of address and complaints about not receiving *WGN* should be addressed to the Treasurer, Ina Rendtel.

All addresses can be found on the inside of the back cover.

# In Memoriam
# Vasily V. Martynenko, 1930–2000

*Michael Boschat*

On November 27, 2000, I received a very sad e-mail on the passing of my dear friend, Vasily V. Martynenko. He was born on July 31, 1930, in the Crimea, then USSR.

I had known Vasily since the early 1970s when we began corresponding by letter mail on many astronomical events. Vasily was in charge of teaching students at the Crimean Station of Young Technicians in Simferopol. He was primarily interested in visual meteor observing and he and his students would mount expeditions for many weeks to various parts of the USSR to record major and minor meteor showers using visual and sometimes optical observations. After the expeditions were finished they would return to reduce the data which took quite a bit of time. My small part was recording my observations which Vasily used to determine any increases in meteor activity as seen from our two countries. Vasily's papers were published in the journals *Science in the USSR* and *Earth and Universe*. On one correspondence, I proposed that we should check if there were more meteors seen during high solar activity. He replied that it was an interesting idea and gave it room for thought. Of course, we never did find anything.

When not observing, Vasily had an interest in oil painting of various scenic areas of the Crimea. They were very nice, he put himself into the paintings and brought out the colorful glory of the places he loved to go to. He also made some paintings of astronomical objects.

Then, in the mid 1980s, Vasily began to feel unwell at times, and had two heart attacks, but he rebounded from them to continue his work, he always wrote that he could not stand doing nothing and sometimes against his doctors' orders went back to work at the observatory. But, at times, he had to miss a few meteor expeditions because of his health. I was surprised that he was more concerned about my health, which was poor since 1975, rather than his!

When I first attended university he always told me "Study is number one—is it not?" He gave me encouragement to keep going and to study as hard as possible, he always wished he could do more to help, but he said, "We are so far away, I wish I could help more."

Then, he suffered more various illnesses and was becoming tired and limited in his work, he kept trying to keep his students involved in observing, and, by now, the meteor expeditions were not the same anymore. In his letters he always told his students of me and my cooperation and said he would not know how the observatory would have ever run without my help in sending them magazines and books. He told me to continue to write and work with them.

The last letter I received from Vasily was written on October 8, 2000, from the hospital he was in. In the letter, he said he had received my astronomy calendar for 2001 and was happy, he went on to say he had been again surprised by being awarded a medal and diploma by the Supreme Soviet of the Crimean Autonomous Republic for *Meritorious Worker of Education of the Crimean Autonomous Republic*. But what he said in the last part of the letter, gave me a sense of sadness. He said that his students and workers hoped he would come back soon to the observatory, but added, "They do not know I will never be back." After reading that letter, I had sent him a gift and told him how glad I was he was awarded that honor, but, the next day, I received the devastating e-mail of his passing.

He had celebrated his 70th birthday on July 31 of this year.

Vasily Martynenko was a Founding Member of the *International Meteor Organization* and served on its first Council. He was a regular contributor to *WGN* in the period 1981–1990.

He will be missed by all who knew and studied with him.

# From the Editor-in-Chief

*Marc Gyssens*

*I never had the opportunity of meeting Vasily Martynenko in person, but his passing is certainly a great loss, not only for those who knew and loved him, but also for the meteor community, especially in the Crimea, where he was a driving force. I can only hope his colleagues and former students will continue meteor work in his spirit, and, in this respect, it is quite fitting, I think, that this issue contains a report on Crimean Leonid observations.*

*A second point I want to make, concerns* WGN. *As you will read in the notice below,* FIDAC News *will be discontinued as a printed bulletin for a combination of reasons, the most important of which being that the ever increasing availability of the internet to meteor observers makes this electronic medium a far more suitable one for the information contained in* FIDAC News.

*However,* FIDAC News *did not only contain numeric data, but also articles, which used to appear in the "Fireballs and Meteorites" section of* WGN *before. With the introduction of* FIDAC News, *this section did not altogether disappear from* WGN, *but became of considerably less importance. With the disappearance of* FIDAC News, *the "Fireballs and Meteorites" section of* WGN *will resume its full former role, and we re-invite our readers to submit articles for this section, which they may have submitted to* FIDAC News *the last few years.*

*As last year, the* IMO *set up a rapid-communication network for the Leonids. Again, Rainer Arlt was the driving logistic force behind this network, and I coordinated "headquarters" during the night of the main expected peaks as well as the night before and the night after. Several observers in Europe and America accepted to act as primary node of our network and phone or e-mail me their results as soon as possible after the event. Their reports, together with reports of other observers that reached me, were of course instrumental in our efforts. I wish to thank all observers who contributed to the network; their names are mentioned in the electronic circulars that were sent out. Should some names have been omitted, we apologize. We received so many observations, that we had to cut off data input at some point to avoid delaying the circulars!*

*Anyway, the project took considerably more effort than last year. There were several reasons. First, we decided to monitor three peaks (one on November 16-17; two on November 17-18) instead of one last year. Second, the peaks were far less pronounced than last year, so more observations were required to confirm them. And, third, of course, there was the Moon which caused large scatter in the observational data, which again required more observations than last year to average out this scatter. However, we managed to get results out of the observations, the three peaks we were looking for did occur, although some of them were early by several tens of minutes and less pronounced than last year's storm peak. More details can be found elsewhere in this issue.*

*The big lesson from this experience which we must keep in mind for the future is that observations of major showers under moonlight conditions can be meaningful! In particular, we hope to learn from the 2000 Leonid observations how we can perfect observing techniques to deal with these circumstances.*

*The excitement over the Leonids was hardly over as several meteor workers, in particular Richard Taibi and Peter Jenniskens just to mention those who mentioned it to me personally, pointed our attention to the possibility of an Ursid outburst in 2000. In particular, Peter Jenniskens and Esko Lyytinen wrote an article for* WGN *which can be found in this issue, but, unfortunately, it was not possible to publish this issue before the event. Anyway, the message was sent out via the internet and reached the observers. First reports indicate that the predicted outburst may indeed have occurred with an activity of several tens of meteors per hour.*

*Next year will be a year with major expectations for the Leonids, so a lot of excitement lies ahead of us. First though, enjoy this issue!*

# FIDAC News Discontinued as Printed Bulletin

*Jürgen Rendtel and André Knöfel*

*FIDAC News* was introduced when the *Global Volcanic Network* (*GVN*; formerly *Scientific Event Alert Network, SEAN*) stopped the collection and publication of fireball data in 1992. In fact, the mailing of a printed summary of fireball observations does not seem to meet the needs as currently most of such observations are disseminated via e-mail and should be available on the internet. This is also the case with the DoD fireball detections. Furthermore, almost the entire input of fireball data (i.e., time, positions, locations, etc.) is done by just one person. Events such as the 1998 Leonid fireball display and personal circumstances caused long delays in the data input alone. In view of these circumstances, we concluded to discontinue the publication of a printed *FIDAC News* bulletin. Instead, the available data shall become available on the internet, starting on January 1, 2001. Earlier data will be added subsequently. Reports about specific events are to be published in the *IMO* Journal *WGN*.

People who subscribed to *FIDAC News* (or paid the "combined subscription"), may choose between prolonging their *WGN* with an additional year, a volume of the *Report Series* of their choosing, a volume of the *IMC Proceedings* of their choosing, or a volume of *WGN* back issues of their choosing. Finally, of course, we also offer a re-funding of the paid subscription as an alternative. We apologize for this inconvenience, but hope that the proposed solution is satisfactory. Please let our Treasurer, Ina Rendtel, know which option you prefer!

# Renew Your IMO Membership/WGN Subscription Now!

*Ina Rendtel*

### Do I have to pay now?

For quite some time now, we offer the possibility to pay for two consecutive years, but people seem to forget whether or not they did so. **If the address label on the envelope mentions 2000, you should renew now!** People seeing a later year either have already renewed or paid for two years last year!

### Can I also pay for two consecutive years?

Yes, you can! In this way, you avoid a likely increase in dues next year! In addition, you do not have to bother about renewing next year (the address label will remind you that you paid for two years) and you save on bank costs by transferring larger amounts.

### Can I combine my renewal with ordering publications?

Yes, you can! The price list of *IMO* publications is on the outside back cover. Also mind that one international payment is always cheaper than two! *New* IMO *publications* are Report 12 containing the 1999 visual observations, and the Proceedings of the 1999 and 2000 *IMC*s, the latter of which will appear shortly and can already be ordered.

### How can I do something extra for the IMO?

You can **become a supporting member** by adding at least 15 DEM (7.67 EUR) or 10 USD per year to your membership.

### Why should I not delay my renewal?

By renewing right now, you ensure that your subscription is processed well in time before the February issue has to be sent out and you save the already overloaded *IMO* officers to have to run on and off to the post office to mail back issues.

### Payment instructions

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

- **in Europe:** pay in *German Marks* or *Euro* to *Ina Rendtel* by transferring to the postal giro account number 547234107 at Postbank Berlin, bank code 10010010. (Please send **no bank checks!**—If you must pay by check, pay to Robert Lunsford as indicated below.)
- **in the United Kingdom:** 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 *US Dollars* to *Robert Lunsford*, 161 Vance Street, Chula Vista, California 91910, USA.

**All people insisting on paying by check should pay to Robert Lunsford in US Dollars, as indicated above. Make checks payable to Robert Lunsford, not to the IMO!**

### Price list

Prices in German Marks (and Euros) remain unchanged. **To reflect currency rate changes, we decreased the equivalent amounts in US Dollars!**

| *Type of subscription* | 2001 | 2001 + 2002 |
|---|---|---|
| Regular subscription (*WGN*) | 35 DEM (17.90 EUR) or 20 USD | 70 DEM ( 35.79 EUR) or 40 USD |
| Combined subscription (*WGN*, Report) | 55 DEM (28.12 EUR) or 35 USD | 110 DEM ( 56.24 EUR) or 65 USD |
| *Also possible outside Europe:* | | |
| Regular subscription with airmail delivery | 70 DEM (35.79 EUR) or 40 USD | 140 DEM ( 71.58 EUR) or 80 USD |
| Combined subscription with airmail delivery for *WGN* only | 95 DEM (48.57 EUR) or 60 USD | 190 DEM ( 97.14 EUR) or 115 USD |

# The 2001 International Meteor Conference

## Cerkno, Slovenia, September 20–23, 2001

*Mihaela Triglav*

The first *International Meteor Conference* in the third millennium will be held in a small town called Cerkno in Slovenia. The conference will take place in Hotel Cerkno, which is situated in the center of this small town. It starts in the afternoon of September 20 and closes after lunch on September 23. It will be organized by the *Astronomical Association Javornik* with the help of the *Association for Technical Culture of Slovenia.*

First, just a few words about Slovenia. Slovenia is a small country with a population of around 2 million people, located at the convergence point of several major geographic areas: the Alps, the Adriatic See, the Karst and the Panonia Basin. It borders Austria to the north, Italy to the west, Croatia to the south, and Hungary to the east. It is independent since 1991. For most countries, no visa is required for a stay.

Cerkno is a small town with no more than 2000 inhabitants. It is located about 60 km northwest of the capital Ljubljana and 15 km north from Idrija. There are no direct train connections to this region and the bus frequency is low, too. Therefore, we will provide a shuttle service from Ljubljana railroad station and Brnik airport to the conference site. For this reason, I appeal to all those planning to come by train or plane to inform us as soon as possible about their exact time of arrival.

The regions of Idrija and Cerkno are nested in narrow green valleys in hills at the feet of the Julian Alps, at the meeting point of the Alps and the Karst. The regions are world-famous because of the 500-year old mercury mine in Idrija and a history of lace manufacturing that goes back 300 years. The local lace makers have an annual lace-making festival. Nearby Cerkno, there is the Franja Partisan Hospital from World War II.

Hotel Cerkno has 180 beds in different types of rooms. Therefore, we can offer you two different rates for hotel accommodation. For the standard participation fee of 200 DEM, you will be accommodated in second-category rooms with 2 to 4 beds (you can see a picture on the web page mentioned at the end of this article). These rooms include toilet, shower cabin, and a telephone. For those who want to enjoy some more luxury, we can offer a first-class room for an additional fee of 45 DEM (so, for 245 DEM altogether). These rooms also have a TV, hair dryer and mini-bar (again, you can see a picture on the web page). If you want to be accommodated in a first-class room, you should contact the organizers.

All meals will be served at the hotel restaurant. Above the hotel's swimming pool, there is a big lecture room for the main lectures, with a capacity of around 100 people. Speakers will have at their disposal a computer, a digital projector, a video projector, an overhead projector, and a slide projector. Workshops will be organized in smaller rooms which can accommodate 30 to 40 people each and in which a computer will be installed. In this way, you will have a chance to participate in a workshop and get in closer touch to a speaker or join those that are not interested in this workshop in a (meteor) chat at a hotel bar which will be opened especially for us.

At this moment, the destination of the traditional excursion on Saturday afternoon is still a secret that will be revealed some months before the *IMC*.

Of course, in order to make a very interesting conference program, we need your contributions. So, indicate on your registration form your contribution (lectures, posters, workshops, group sessions, etc.) and the equipment required for this purpose. E-mail us for any questions, additional information, or special requests. If you want to stay a few days longer in Slovenia to see our Alps, the Karst, or ..., we can help you in making the arrangements.

Please send your registration form as soon as possible to *IMO* Treasurer Ina Rendtel and simultaneously inform the organizers via e-mail. The full participation fee is 200 DEM (245 DEM for accommodation in first-class bedrooms).

A tendency of the last few years is that participants were registering rather late. Since this meant the local organizers had a lot of additional work and worries (blocking off a sufficient number of hotel rooms, organizing local transportation, ...), the *IMO* Council has decided to set a **registration deadline: July 1, 2001. Late registrants will pay an additional fee of 40 DEM; thus, after July 1, the standard registration fee amounts to 240 DEM!**

At this moment, we cannot yet offer any reduced fee for people who might have problems with paying the full fee. Anyway, you should contact the local organizers, if you have such problems, to let us know how many people wish to get a reduction. We expect to know how much reduction we can offer, if any, around July 1, 2001. Also, it is likely that the *IMO* will offer grants, similar to the last two years. Announcements will be published in *WGN* later.

For more information on this conference, a great opportunity to meet meteor lovers from all over the world, see the 2001 *IMC* web page at `http://www2.arnes.si/~sopezakr/IMC2001/` or contact the organizers via e-mail at `mtriglav@yahoo.com` or `jure.zakrajsek@kiss.uni-lj.si`.

# International Meteor Conference

## Cerkno, Slovenia, September 20–23, 2001

### 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 100 DEM (51.13 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 2001 *IMC* from September 20 to 23;
- ○ 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 Cerkno;
- ○ I wish a 1st-category room (add 45 DEM or 23.01 EUR; also, contact the organizers).
- ○ I wish to stay in Slovenia 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 200 DEM (102.26 EUR) or a pre-payment of 100 DEM (51.13 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 100 DEM (51.13 EUR) in cash upon arrival in Cerkno. Participants desiring a 1st-category room must pay the entire fee of 245 DEM (125.27 EUR) to the Treasurer.

Date and signature: ______________________________

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

- in Europe: pay in DEM or 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.*

# Letters to WGN

*compiled by Marc Gyssens*

**On the Leonid observations made by Alexander von Humboldt from Venezuela**

When the eminent German naturalist Alexander von Humboldt visited the Spanish province Nueva Andalucía (now Venezuela), he witnessed a spectacular Leonid shower. His evocative description can be found in [1]:

> *"The night of the 11 to the 12 November was fresh and exceptionally pleasant. In the morning, from 2.30 am, most extraordinary fiery meteors were seen towards the east. Bonpland, who had got up in order to enjoy the chill on the gallery, noticed them first. Thousands of fireballs and shooting stars were falling one after another for four hours. Their direction was very regular from north to south. They filled a part of the sky stretching 30 degrees to either side of the true east direction. Along a distance of 60 degrees, meteors were seen rising from east-northeast and east above the horizon, describing large and small arcs and, after they pursued the direction of the meridian, fell down towards south. Some of them climbed up to 40 degrees; all of them higher than 25–30 degrees. The wind in the lower air masses was very weak and blew from east; no trace of clouds was visible. According to Bonpland, right in the beginning, there was no part of the sky as large as three lunar diameters, which was not crowded by fireballs and shooting stars. The former were fewer; since various sizes of them were visible, it was impossible to draw a distinction between these two classes of phenomena."*

(An estimate of ZHR $\geq$ 5000 was given in [2]).

The above description relates to the visit of von Humboldt to Cumaná in 1799 (one of the more ancient Venezuelan cities), and we give this citation here mainly since, in Chapter 1 of [3], it is indicated that von Humboldt *"observed the famous 1833 Leonid storm from South America."* The source of this reference, [4], makes a short note about the *"...investigation of the facts observed at those epochs when showers of shooting stars fell periodically in Cumaná in 1799, and in North America during the years 1833 and 1834, ...,"* this way leaving no doubt of the fact that von Humboldt actually observed the Leonids storm of 1799.

In fact, in [1], a note is added about the Leonids of 1766: *Almost all the inhabitants of Cumaná were witnesses of this phenomenon..."* (referring to the 1799 shower), and *"...the sight of fireballs was by no means immaterial to them; the eldest of them recalled the strong earthquake of 1766 being preceded by a very similar phenomenon."*

This last aspect is interesting since, in Chapter 6 of [3], it is indicated that *"The more recent appearances began with that on November 11, 1799, when a meteor storm appeared and was fairly well described by some competent witnesses..."* The idea here simply is to clarify these details, since the ancient records are an integral part of thorough studies of the ever-surprising Leonid meteor shower.


[1] A. von Humboldt, "Viaje a las Regiones Equinocciales del Nuevo Continente", Monteavila Editores, Caracas, 1987.

[2] M. Kidger, "Una historia de dos lluvias", *Tribuna de Astronomía*, No. 122, 1996, pp. 60–65.

[3] J. Rendtel, R. Arlt, A. McBeath (eds.), "Handbook for Visual Meteor Observers", IMO, Potsdam, 1995, 308 pages.

[4] A. von Humboldt, "Cosmos", Editorial Glem, Buenos Aires, 1944, 601 pages.


*Antonio Martínez Picar, October 24, 2000*

# Call for Observations: January 24, 2001

*Alastair McBeath and Roberto Gorelli*

A possible new minor shower, with a radiant perhaps only periodically active in Coma Berenices or a neighboring constellation, was described in [1]. This shower may be associated with the poorly-observed, only weakly active, Comet Lowe 1913 I, seen definitely and briefly at only a single return, but which may also have been observed, again rather badly, in 1750. The computed shower parameters suggest a radiant at $\alpha = 188°$ and $\delta = +22°$, producing maximum activity at $\lambda_\odot = 304.^\circ2$–$305.^\circ0$ (eq. J2000.0), equivalent to January 24.9–25.7, 2000. The meteors would be swift-moving, with an atmospheric velocity of 59 km/s. Determining more about this possible shower is important, since, as indicated in [1], Comet Lowe may have the potential to impact the Earth in the second half of the 21st century.

The currently-known minor Coma Berenicid shower may have similar orbital characteristics to this proposed new source (cf. the discussion in [1]), but its established activity seems to peter out by January 23 [2], and its extrapolated radiant would be over 15° west and slightly south of the above position by January 25. Such a discrepancy between computed and real radiant positions is not insurmountable, but the January 24–25 radiant could indeed be a separate, previously unobserved, minor shower.

Confirmation that unusual activity may occur around these dates from time to time is suggested by data in [3], where, in 1998, at least five fireballs of magnitudes −3 to −8 were seen between January 24, $19^h45^m$ UT to January 25, $2^h35^m$ UT ($\lambda_\odot = 304.^\circ65$–$304.^\circ94$) from sites in the UK and Germany. Unfortunately, insufficient data were available from the single casual witness reports in most cases to define even potential radiant regions for these meteors, but two at least could have had radiants in the area bounded by UMa-Leo-Vir-Boo/CrB. In the same report [3], January 24–25, $\lambda_\odot = 304°$–$305°$, was noted as producing a previously undetected minor echo count peak in radio meteor rates, which suggested the activity had resulted from a radiant somewhere between Dra-Her-Oph westwards to UMa-Leo-Hya. Further definition of the potential source than this was not possible. It is worth noting, however, that this radio echo count peak was not found in 1994–1997 data, and that, in 1999–2000, the peak was only recovered weakly, and not by all observers. Where it was found, there was a slight preference for it to appear in counts of longer-duration echoes, most likely due to somewhat brighter meteors.

Obviously, we need many more observations to seek out this possible shower, and we would particularly welcome video and photographic data which would enable us to compute orbital information on this source, since that is the only way we can be sure it is real, not simply a chance alignment of some visually-plotted meteors. Carefully made visual plots would be very useful too, however, since we need to confirm whether the shower is visually detectable or not. The reports of casual fireballs, and another unconfirmed report by two Slovenian observers, Nikolaj Štritof and Igor Grom, of a small outburst of meteors possibly radiating from near Corona Borealis on January 21-22, 1999, after $1^h$ UT [4], suggest visual observations should be possible.

Whether this is connected to the probable video radiants in Serpens and Corona Borealis found in February 2000 [5,6] is unknown. The published video analysis, though including data from January 25 to February 17, 2000, was not designed to detect radiants this early or this far west. The apparently compact video radiant area around $\alpha = 186°$ and $\delta = +15°$ in Figure 1 of [5], using an assumed geocentric velocity of 50 km/s, and which shows a southeasterly drift in the later February 5–17 data (see Figure 4 of [5]), if not simply an artifact, might be linked to the January 24–25 source.

Kronk [7] provides a useful synopsis of the scant orbital data concerning the Coma Berenicids. We would urge everyone in the professional or amateur meteor science communities with access to the appropriate material to check for any fresh information on meteors from this Coma source, or the January 24–25 one. Past visual radiants and associated data from near the Comet's 1912–1913 return and later not in [1] or [7], or any new orbital parameters would be especially valuable, along with a search of photographic plates from December 1912 covering the Virgo region where Comet Lowe was seen, to secure pre-discovery images which may be used to better refine the Comet's orbit. A second encounter with the January 24–25 stream may occur about six months later, and although unlikely, this cannot yet be excluded. Any new results could help us understand whether we need be concerned about a potential Earth-impacting comet, or whether we can definitively rule out Comet Lowe as a present threat.

With New Moon on January 24, conditions are perfect for observing in 2001, and, although the nights of January 23-24 and 24-25 are probably the most important periods for watching ($\lambda_\odot = 304.^\circ2$–$305.^\circ0$ equates to January 24, $3^h30^m$–$22^h30^m$ UT in 2001), other dates around then should not be ignored if the sky is clear, since, as with most meteor showers, we would hope some low rates might still be seen a few days to either side of the maximum. This may not be the case if the shower produces only occasional outbursts however, since then only the maximum time might yield anything, as with the Draconids in October, for example. For reporting meteors from this possible new source, we would suggest using the provisional name *January Coma Berenicids* until a proper radiant determination has been achieved. For northern hemisphere sites, the proposed radiant is well on-view from about $22^h30^m$ to $23^h$ local time, culminating shortly before dawn. Some of the 1998 fireballs were recorded soon after the radiant rose, however, and, if they were January Coma Berenicids, that could suggest observing even earlier in the night might still be worthwhile, if a bright meteor outburst occurs.

Good luck and clear skies!

### References


[1] R. Gorelli, "The Case of Comet Lowe 1913 I", in *Proceedings of the 1999 IMC*, Frasso Sabino, R. Arlt, ed., IMO, 2000, pp. 121–126.

[2] J. Rendtel, R. Arlt, R. Koschack, A. McBeath, P. Roggemans and J. Wood, "Meteor Shower Descriptions: Coma Berenicids", in *Handbook for Visual Meteor Observers*, J. Rendtel, R. Arlt and A. McBeath (eds.), IMO, 1995, pp. 270–272.

[3] A. McBeath, "SPA Meteor Section Results: January–February 1998", *WGN* 26:4, August 1998, pp. 184–188.

[4] M. Triglav, *IMO-News*, January 27, 1999. We are indebted to Mihaela Triglav for providing us with this information, and also the follow-up discussion messages she received relating to this event.

[5] J. Rendtel, G.W. Gliba, "Possible New Radiant in Early February", *WGN* 28:1, February 2000, pp. 13–18.

[6] A. McBeath, "Some thoughts on the $\xi$-Bootids", letter, *WGN* 28:2/3, April-June 2000, pp. 43–44.

[7] G.W. Kronk, "Meteor Showers: A Descriptive Catalog", Enslow, 1988, pp. 243–245.

# Meteor Shower Calendar: January–March 2001

*compiled by Alastair McBeath and Rainer Arlt*

## 1. January to March

The year's first quarter brings several low activity showers, including the diffuse ecliptical stream complex of the Virginids, active from late January to mid-April. Of the major showers, the northern-hemisphere Quadrantids just survive the waxing Moon, but the southern-hemisphere $\alpha$-Centaurids (maximum due around February 7, $22^h$ UT) are lost to Full Moon. The minor $\delta$-Cancrids may peak on either January 11 (badly moonlit) or 17 (Moon-free till after local midnight), though the even weaker $\delta$-Leonids in late February are much better placed. In mid-March, the $\gamma$-Normids, with a maximum on March 13 or perhaps March 17 (this latter time based on 1999 data), are lost to moonlight in either case. Daylight radio peaks are theoretically due from the Capricornid/Sagittarids around $8^h$ UT on February 1, and the $\chi$-Capricornids on February 13, around $9^h$ UT. Recent radio results suggest the Capricornid/Sagittarid peak may fall 2–3 days later than this, however, while no significant enhancement in radio rates was found near the expected $\chi$-Capricornid peak between 1994 and 1999. As both showers have radiants less than 10° to 15° west of the Sun at maximum, they cannot be regarded as visual targets even from the southern hemisphere.

*Quadrantids*

Active: January 1–5; Maximum: January 3, $12^h$ UT ($\lambda_\odot = 283\overset{\circ}{.}16$);
ZHR = 120 (can vary ~ 60–200);
Radiant: $\alpha = 230°$, $\delta = +49°$; Radiant drift: see Table 2; $V_\infty = 41$ km/s; $r = 2.1$ at maximum, but variable;
TFC: $\alpha = 242°$, $\delta = +75°$ and $\alpha = 198°$, $\delta = +40°$ ($\beta > 40°$ N);
PFC: $\alpha = 150°$, $\delta = +70°$ before $0^h$ local time;
$\alpha = 180°$, $\delta = +40°$ and $\alpha = 240°$, $\delta = +70°$ after $0^h$ local time ($\beta > 40°$ N).

The year opens with a reasonable return of the Quadrantids for northern hemisphere observers, as the waxing gibbous Moon will set shortly after local midnight on January 2-3, and by $1^h30^m$ local time on January 3-4. This is beneficial, since the shower's radiant in northern Bootes is circumpolar for many northern locations, but attains a useful elevation only after local midnight, rising higher towards morning twilight. An interesting challenge is to try spotting the occasional long-pathed shower member from the southern hemisphere around dawn, but sensible Quadrantid watching cannot be carried out from such places.

The maximum time given above is based on the best-observed return of the shower ever analyzed, from *IMO* 1992 data, confirmed by radio results in 1996, 1997, and 1999. A repeat of this time in 2001 would especially favor central and western North America. The peak itself is normally short-lived, and can be easily missed in just a few hours of poor winter weather in the north, which may be why the ZHR level apparently fluctuates from year to year, but some genuine variability is probably present, too. For instance, visual ZHRs in 1998 persisted for over two hours at their best. An added level of complexity comes from the fact that mass-sorting of particles across the meteoroid stream may make fainter objects (radio and telescopic meteors) reach maximum several hours before the brighter (visual and photographic) ones, so observers should be alert throughout the shower!

Past observations have suggested the radiant is very diffuse away from the maximum, contracting notably during the peak itself, although this may be a result of the very low activity normally seen away from the hours near maximum. Photographic and video observations from January 1–5 would be particularly welcomed by those investigating this topic, using the PFCs and TFCs given above, along with telescopic and visual plotting results.

*$\delta$-Leonids*

Active: February 15–March 10; Maximum: February 24 ($\lambda_\odot = 336°$); ZHR = 2;
Radiant: $\alpha = 168°$, $\delta = +16°$, Radiant drift: see Table 2; $V_\infty = 23$ km/s; $r = 3.0$;
TFC: $\alpha = 140°$, $\delta = +37°$ and $\alpha = 151°$, $\delta = +22°$ ($\beta > 10°$ N);
$\alpha = 140°$, $\delta = -10°$ and $\alpha = 160°$, $\delta = 00°$ ($\beta < 10°$ N).

The resemblance of the $\delta$-Leonids' orbits and that of the asteroid (4450) Pan might prove their distinguished origin apart from the general ecliptical (Virginid) background activity. Rates are normally low, and meteors are predominantly faint, so the shower is a prime candidate for telescopic investigation. Visual observers must make very accurate plots of the meteors to distinguish them from the nearby Virginids and the sporadics. Northern hemisphere sites have an advantage for covering this stream, though southern hemisphere watchers should not ignore it, as they are better-placed to note many of the other Virginid radiants. The one-day-old Moon presents a perfect observing opportunity in 2001, and the $\delta$-Leonid radiant is well on view for most of the night near its weekend peak.

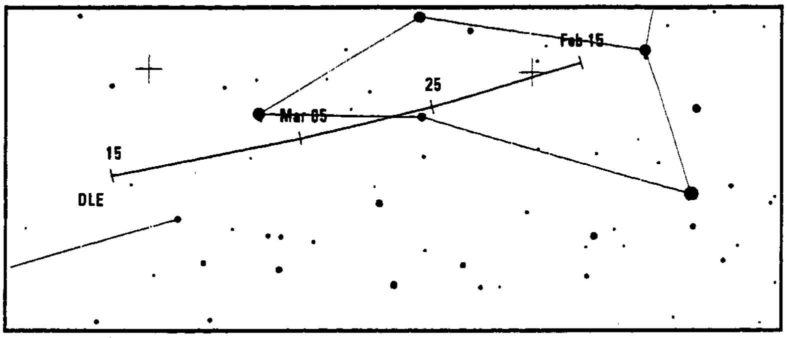


Figure 1 – Radiant position and drift of the δ-Leonids.

## 2. Working list of meteor showers

Table 1 – Working list of meteor showers for the period January–March 2001. Streams marked with an asterisk are periodically or occasionally active, and therefore no ZHR is cited. The "maximum" date cited for the Virginids should be seen as a reference date rather than a true maximum.

| Shower | Activity | Maximum | | Radiant | | $V_\infty$ | $r$ | ZHR |
|---|---|---|---|---|---|---|---|---|
| | | Date | $\lambda_\odot$ | $\alpha$ | $\delta$ | (km/s) | | |
| Quadrantids (QUA) | Jan 01–Jan 05 | Jan 03 | 283.°2 | 230° | +49° | 41 | 2.1 | 120 |
| δ-Cancrids (DCA) | Jan 01–Jan 24 | Jan 17 | 297° | 130° | +20° | 28 | 3.0 | 4 |
| α-Centaurids (ACE) | Jan 28–Feb 21 | Feb 07 | 319.°2 | 210° | −59° | 56 | 2.0 | 6 |
| δ-Leonids (DLE) | Feb 15–Mar 10 | Feb 24 | 336° | 168° | +16° | 23 | 3.0 | 2 |
| γ-Normids (GNO) | Feb 25–Mar 22 | Mar 13 | 353° | 249° | −51° | 56 | 2.4 | 8 |
| Virginids (VIR) | Jan 25–Apr 15 | Mar 24 | 4° | 195° | −04° | 30 | 3.0 | 5 |

Table 2 – Radiant positions in $\alpha$ and $\delta$.

| | COM | QUA | DCA | ACE | VIR | DLE | GNO |
|---|---|---|---|---|---|---|---|
| Jan 0 | 186° +20° | 228° +50° | 112° +22° | | | | |
| Jan 5 | 190° +18° | 231° +49° | 116° +22° | | | | |
| Jan 10 | 194° +17° | | 121° +21° | | | | |
| Jan 20 | 202° +13° | | 130° +19° | | | | |
| Jan 30 | | | | 200° −57° | 157° +16° | | |
| Feb 10 | | | | 214° −60° | 165° +10° | 155° +20° | |
| Feb 20 | | | | 225° −63° | 172° +06° | 164° +18° | 225° −53° |
| Feb 28 | | | | | 178° +03° | 171° +15° | 234° −52° |
| Mar 10 | | | | | 186° 00° | 180° +12° | 245° −51° |
| Mar 20 | | | | | 192° −03° | | 256° −50° |
| Mar 30 | | | | | 198° −05° | | |

## 3. Radiant sizes and meteor plotting

If you are not observing during a major-shower maximum, it is much more essential to associate meteors with their radiants correctly, since the total numbers will be small. Meteor plotting allows the shower association by more objective criteria than the prolongation of paths under the sky. As you plotted the meteors on gnomonic maps, you can trace the radiant by straight lines. If the radiant lies on another chart, you should find common stars on an adjacent chart to extend the backward prolongation there. How large should the radiant be assumed for shower association? The physical radiant size is very small; visual plotting errors cause many true shower meteors to pass the radiant outside this area. We have to assume a larger radiant. The opposite behavior is caused by sporadic meteors—more and more sporadics line up accidentally upon enlarging the radiant. Hence, we have to apply an optimum radiant diameter compensating the loss due to plotting errors, and the sporadic meteor pollution. Table 3 gives the optimum diameter in function of the distance of the meteor from the radiant.

Table 3 – Optimum radiant diameters ("Diameter") to be assumed for shower association of minor-shower meteors as a function of the radiant distance ("$D$") of the meteor.

| $D$ | Diameter | $D$ | Diameter |
|---|---|---|---|
| 15° | 14° | 50° | 20° |
| 30° | 17° | 70° | 23° |

The direction of the path is not the only criterion for shower association. The angular velocity of the meteor should match the expected speed of the shower meteors according to the geocentric velocity of the meteoroids. Angular velocity estimates should be made in degrees per second (°/s). In your imagination, you make the meteors move for one second. The path length of this imaginary meteor is the angular velocity in °/s. Note that typical speeds are in the range 3°/s–25°/s. Typical errors of such estimates are given in Table 4.

Table 4 – Error limits for the angular velocity.

| Angular velocity (°/s) | 5 | 10 | 15 | 20 | 30 |
|---|---|---|---|---|---|
| Permitted error (°/s) | 3 | 5 | 6 | 7 | 8 |

Table 5 gives the angular speeds for a few geocentric velocities, which can be looked up in Table 1 for each shower.

Table 5 – Angular velocities as a function of the radiant distance and the elevation of a meteor for three different geocentric velocities. All velocities are in °/s. The tables are symmetric: you can read radiant distance horizontally and elevation vertically, or vice-versa.

| $h \backslash D$ | $v_\infty = 25$ km/s | | | | | $v_\infty = 40$ km/s | | | | | $v_\infty = 60$ km/s | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10° | 20° | 40° | 60° | 90° | 10° | 20° | 40° | 60° | 90° | 10° | 20° | 40° | 60° | 90° |
| 10° | 0.4 | 0.9 | 1.6 | 2.2 | 2.5 | 0.7 | 1.4 | 2.6 | 3.5 | 4.0 | 0.9 | 1.8 | 3.7 | 4.6 | 5.3 |
| 20° | 0.9 | 1.7 | 3.2 | 4.3 | 4.9 | 1.4 | 2.7 | 5.0 | 6.8 | 7.9 | 1.8 | 3.5 | 6.7 | 9.0 | 10 |
| 40° | 1.6 | 3.2 | 5.9 | 8.0 | 9.3 | 2.6 | 5.0 | 9.5 | 13 | 15 | 3.7 | 6.7 | 13 | 17 | 20 |
| 60° | 2.2 | 4.3 | 8.0 | 11 | 13 | 3.5 | 6.8 | 13 | 17 | 20 | 4.6 | 9.0 | 17 | 23 | 26 |
| 90° | 2.5 | 4.9 | 9.3 | 13 | 14 | 4.0 | 7.9 | 15 | 20 | 23 | 5.3 | 10 | 20 | 26 | 30 |

## 4. Lunar phases

It will be New Moon on January 24, February 23, and March 25; First Quarter on January 2, February 1, March 3, and April 1; Full Moon on January 9, February 8, March 9, and April 8; and Last Quarter on January 16, February 15, March 16.

## 5. Daytime radio meteor streams

Table 6 – Working list of daytime radio meteor streams. The "Best Observed" columns give the approximate local mean times between which a four-element antenna at an elevation of 45° receiving a signal from a 30-kW transmitter 1000 km away should record at least 85% of any suitably positioned radio-reflecting meteor trails for the appropriate latitudes. Note that this is often heavily dependent on the compass direction in which the antenna is pointing, however, and applies only to dates near the shower's maximum.

| Shower | Activity | Max | $\lambda_\odot$ | Radiant | | Best Observed | | Rate |
|---|---|---|---|---|---|---|---|---|
| | | Date | 2000.0 | $\alpha$ | $\delta$ | 50° N | 35° S | |
| Cap/Sagittarids | Jan 13–Feb 04 | Feb 02 | 312°5 | 299° | −15° | $11^h$–$14^h$ | $09^h$–$14^h$ | medium |
| $\chi$-Capricornids | Jan 29–Feb 28 | Feb 14 | 324°7 | 315° | −24° | $10^h$–$13^h$ | $08^h$–$15^h$ | low |

Leonids

# Bulletin 16 of the International Leonid Watch: Results of the 2000 Leonid Meteor Shower

*Rainer Arlt and Marc Gyssens*

A set of $614^{\rm h}.22$ observing hours covering the activity of the Leonid meteor shower as logged by 230 observers was used to determine the population index and activity profiles of the 2000 Leonids. Three clear maxima in terms of Zenithal Hourly Rates (ZHR) are found. The first peak at $\lambda_\odot = 235^\circ.28 \pm 0^\circ.01$ (November 17, $8^{\rm h}07^{\rm m}$ UT) falls about 15 minutes after the predicted passage time of the 1932 dust trail of Comet 55P/Tempel-Tuttle. The activity level was ZHR $= 130 \pm 20$. The second maximum is broad and is best described by a 1-hour plateau of activity with a maximum possibly centered at $\lambda_\odot = 236^\circ.09 \pm 0^\circ.01$ (November 18, $3^{\rm h}24^{\rm m}$ UT) with ZHR $= 290 \pm 20$. This enhancement covers the predicted time of the dust trail of the 1733 perihelion passage of the Comet. The third maximum is found near $\lambda_\odot = 236^\circ.25 \pm 0^\circ.01$ (November 18, $7^{\rm h}12^{\rm m}$ UT) with ZHR $= 480 \pm 20$ occurring about 40 minutes before the predicted 1866 dust trail passage. The population index $r$, however, reaches a maximum value of 2.2 at exactly the predicted time—40 minutes after the ZHR maximum. The $r$-value was almost constant for four hours between $3^{\rm h}$ and $7^{\rm h}$ UT on November 18.

## 1. Introduction

Another return of the Leonid meteor shower with prolific visual meteor rates was monitored in 2000, despite the unfavorable conditions with a Last Quarter Moon interfering with the peak nights. Its close position to the Leonid radiant caused difficulties in finding a suitable observing field. Problems with shower association may arise from a field located too far from the radiant. A major shower like the Leonids these years, however, is not so much affected by the problems of shower association because of the relatively large meteor numbers compared with the sporadic background activity.

Two major peaks were predicted by the dust trail orbital integrations of McNaught and Asher [1]. Such a dust trail is produced by the parent comet, 55P/Tempel-Tuttle, at each perihelion passage. A first maximum was expected at $3^{\rm h}44^{\rm m}$ UT on November 18, caused by the 1733 dust trail after 8 orbital revolutions. A second peak was expected at $7^{\rm h}51^{\rm m}$ UT on the same day, caused by the 1866 trail after 4 orbital revolutions. The prediction of peak ZHRs was more uncertain than for 1999, since comparable encounters with these dust trails covered by observations were missing. A possible enhancement of Leonid activity was also predicted for the 2-revolution trail of 1932 for $7^{\rm h}51^{\rm m}$ UT on November 17, which is exactly one day before the 4-revolution trail. The predicted peak times correspond to $\lambda_\odot = 235^\circ.270$, $\lambda_\odot = 236^\circ.104$, and $\lambda_\odot = 236^\circ.278$, respectively; all solar longitudes refer to equinox J2000.0.

Estimates of ZHR predictions in [1] were 100 for the two peaks on November 18, annotated with a comment on the uncertainty of these numbers for the 2000 Leonid return. The dust trail computations by Lyytinen and van Flandern [2] resulted in more optimistic values of 700 for the two November 18 peaks and 215 for the November 17 peak of the 4-revolution trail. More predictions were given by other authors, but we restrict ourselves to the forecasts based on the apparently most accurate dust-trail integrations.

We are most grateful to all the observers who have put their efforts in recording visual data for the 2000 Leonid meteor shower and who quickly submitted their reports for the utilization in the *Visual Meteor Database*. The following is an alphabetical list of all contributors for the activity period of the Leonids:

George Akrivas (AKRGE, $0^{\rm h}.83$), José Alvarellos (ALVJO, $1^{\rm h}.57$), Raquel Alvarez Franco (ALVRA, $3^{\rm h}.65$), Esther Amor Pérez (AMOES, $1^{\rm h}.12$), Birger Andresen (ANDBI, $2^{\rm h}.14$), Rainer Arlt (ARLRA, $1^{\rm h}.04$), Joseph D. Assmus (ASSJO, $6^{\rm h}.29$), Jure Atanackov (ATAJU, $2^{\rm h}.72$), Rachel Aubuchon (AUBRA, $1^{\rm h}.30$), Julia Babina (BABJL, $4^{\rm h}.74$), Pierre Bader (BADPI, $1^{\rm h}.87$), Istvan Balogh (BALIS, $3^{\rm h}.69$), Nicolás Barrile (BARNI, $1^{\rm h}.50$), Orlando Benítez Sanchez (BENOR, $4^{\rm h}.31$), Felix Bettonvil (BETFE, $2^{\rm h}.23$), Fuyan Bian

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(VETMI, $0^h.70$), William Watson (WATWI, $0^h.78$), Thomas Weiland (WEITH, $4^h.25$), Anne Williams (WILAN, $3^h.25$), Glenn Williams (WILGL, $3^h.25$), Jean-Marc Wislez (WISJE, $4^h.14$), Oliver Wusk (WUSOL, $1^h.41$), Dan Xia (XIADA, $1^h.35$), Karen Young (YOUKA, $2^h.00$), Robert Young (YOURO, $2^h.50$), Jure Zakrajsek (ZAKJU, $2^h.08$), Zorana Zeravcić (ZERZO, $0^h.67$), Cunli Zhang (ZHACU, $2^h.75$), Dongyan Zha (ZHADO, $1^h.25$), Ju Zhao (ZHAJU, $2^h.55$), Zhou-sheng Zhang (ZHAZH, $9^h.66$), Jing Zhong (ZHOJI, $0^h.60$), Jin Zhu (ZHUJI, $2^h.33$), Xiaojin Zhu (ZHUXI, $0^h.52$), Ron Zincone (ZINRO, $3^h.62$), Kamil Złoczewski (ZLOKA, $4^h.50$)

from the following 38 countries:

Argentina, Austria, Australia, Belgium, Brazil, Bulgaria, Canada, Chile, China, Croatia, Cuba, Czech Republic, Finland, France, Germany, Greece, Hungary, India, Israel, Italy, Japan, Malta, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, Spain, Switzerland, UK, Ukraine, USA, Venezuela, Yugoslavia.

## 2. The population index profile

The various dust trails might be detectable not only through the activity profile, but upon inspection of the population index variations as well. A total number of 535 magnitude distributions of Leonids were available, of which 525 could be used for the analysis. The remaining 10 distributions contained hundreds of meteors covering the entire observation of many hours. They were not applicable to this study.

The method used here to obtain population indices converts the average meteor magnitude *distance* from the limiting magnitude into a population index ($r$-value). This average magnitude distance $\langle \Delta m \rangle$ is a unique function of $r$. Idealized magnitude distributions for various population indices hence deliver a set of corresponding $\langle \Delta m \rangle$. Rough steps of this conversion are given in Table 1. The method is based on the simulations by Richter [3]; a comparison with the regression-line method delivered no serious differences (despite the larger error margins of the latter) unlike the magnitude analysis of the 1999 Leonids.

Table 1 – Conversion of the average meteor magnitude distance from the limiting magnitude, $\langle \Delta m \rangle$, into population indices. Note that a large value for $\langle \Delta m \rangle$ denotes a low average magnitude.

| $r$ | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\langle \Delta m \rangle$ | 5.301 | 4.568 | 4.069 | 3.700 | 3.413 | 3.180 | 2.987 | 2.823 | 2.682 | 2.559 |

The binning here is adaptive; the algorithm uses as many magnitude distributions successively in time as necessary to gather a given minimum meteor number. It derives $r$ and starts with the next hitherto unused distribution. There is thus no additional smoothing involved. Natural smoothing occurs due to the length of the magnitude-distribution interval which may "hang out" of the binning interval.

For the period between $\lambda_\odot = 236^\circ.00$ and $\lambda_\odot = 236^\circ.20$, a minimum meteor number of 500 was adopted, whereas this limit was lowered to 200 for the adjacent periods before and after the two strongest peaks on November 18. The pre-set meteor number is the reason for the virtually invariable size of the error margins in each of these three periods. The final profile is shown in Figure 1; the numerical details are given in Table 2. In order to detect possible small-scale features, we chose the smaller bins (i.e., smaller minimum meteor number) for the encounter time with the 1866 dust trail, despite the limited number of magnitude distributions compared with the 1733 trail encounter. As the sample of individual observers is thus very small, we also give averages of the period after $\lambda_\odot = 236^\circ.20$ with a 500-meteor minimum in Table 3.

Young dust trails are typically attributed with a higher population index than the annual background activity of the shower. A slight hint on a maximum of the population index is visible very close to the time which will be favored by the activity profile as being the 8-revolution dust trail peak which was observed from Europe and Africa (precisely, at $\lambda_\odot = 236^\circ.085$ or $3^h16^m$ UT on November 18 with $r = 2.06$).

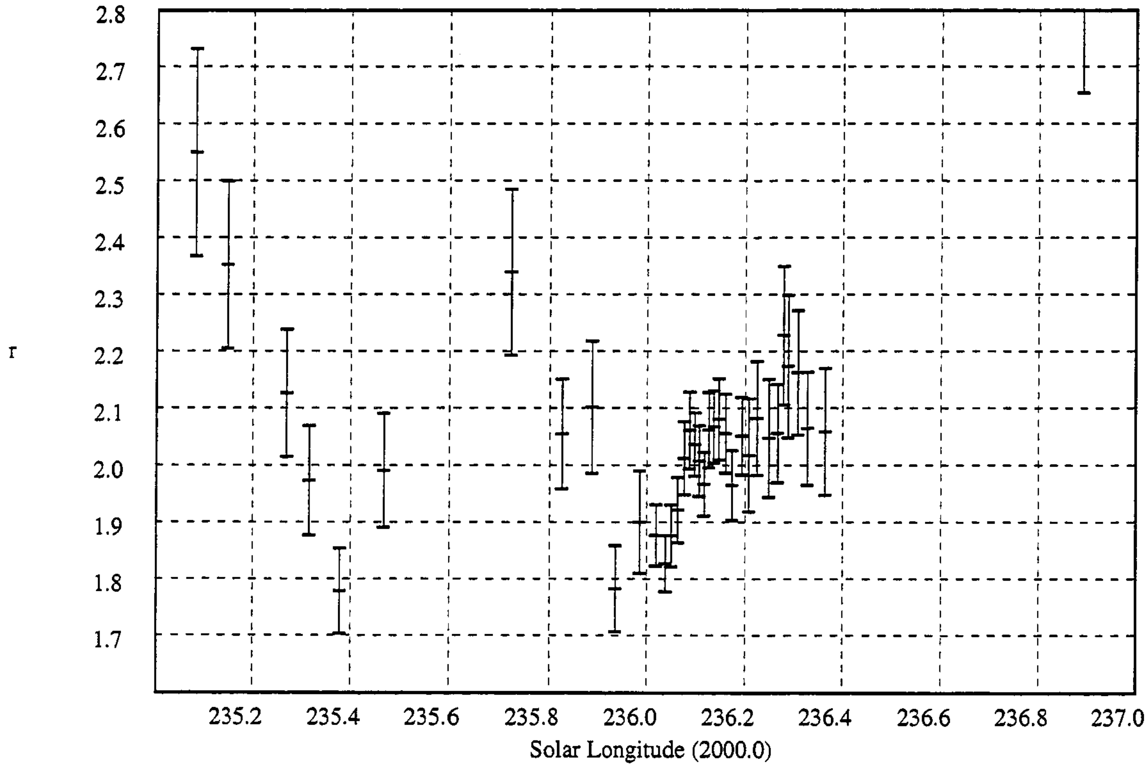


Figure 1 – Population index profile of the 2000 Leonids. The time period covered by this diagram runs from November 17, $1^h$ UT to November 19, $1^h$ UT.

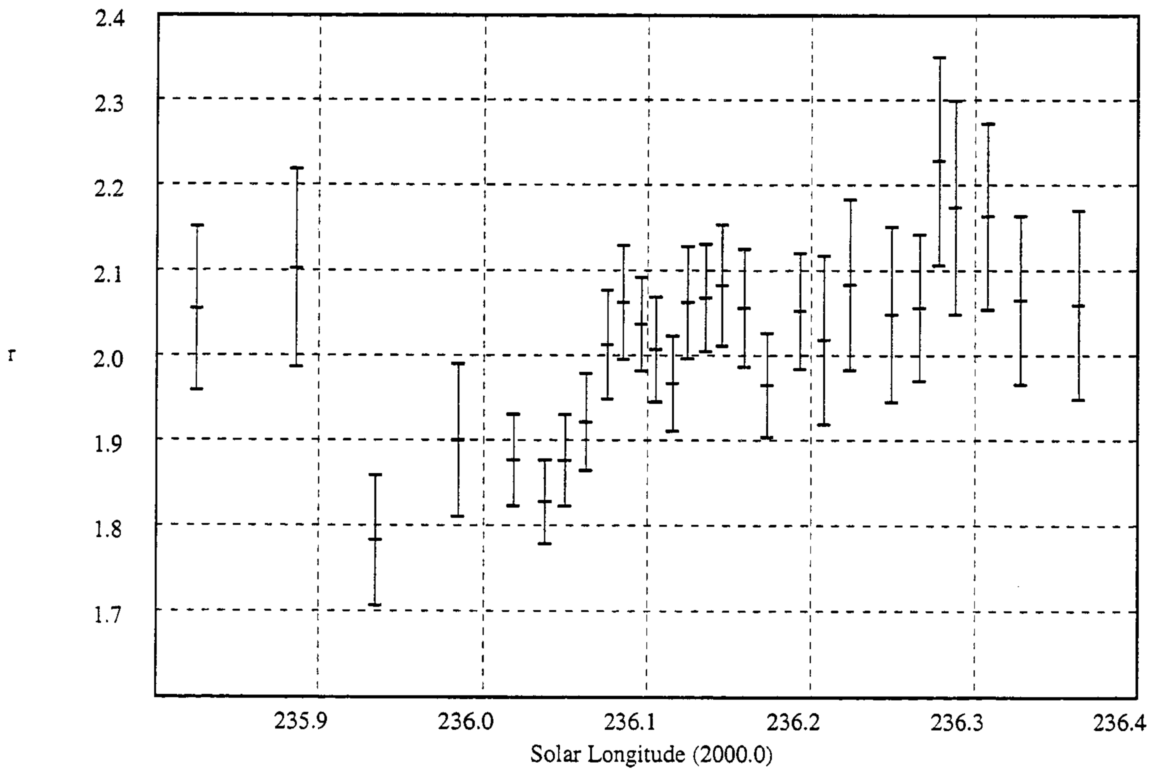


Figure 2 – Magnification of the population index profile of the 2000 Leonids for the period November 17, $20^h30^m$ to November 18, $10^h50^m$ UT.

Table 2 – Averaged population index. Despite the smaller number of magnitude distributions, the period of the encounter with the 4-revolution dust trail is shown applying the lower limit of minimum meteor number. Table 3 shows that period with the same 500-meteor limit as was used for the 8-revolution encounter.

| $\lambda_\odot$(J2000.0) | Obs | $n$ | $r$ | $\overline{\mathrm{lm}}$ |
|---|---|---|---|---|
| 234.705 | 18 | 229 | $2.391 \pm 0.147$ | 5.19 |
| 235.081 | 14 | 204 | $2.551 \pm 0.182$ | 5.25 |
| 235.147 | 6 | 215 | $2.354 \pm 0.147$ | 6.03 |
| 235.269 | 8 | 231 | $2.128 \pm 0.112$ | 5.28 |
| 235.315 | 9 | 218 | $1.974 \pm 0.096$ | 5.64 |
| 235.378 | 10 | 213 | $1.780 \pm 0.075$ | 5.31 |
| 235.468 | 12 | 207 | $1.992 \pm 0.100$ | 4.94 |
| 235.722 | 12 | 212 | $2.340 \pm 0.146$ | 5.47 |
| 235.825 | 9 | 264 | $2.056 \pm 0.096$ | 4.72 |
| 235.886 | 8 | 207 | $2.103 \pm 0.116$ | 5.43 |
| 235.935 | 8 | 206 | $1.784 \pm 0.076$ | 5.73 |
| 235.985 | 9 | 213 | $1.901 \pm 0.090$ | 5.65 |
| 236.018 | 20 | 510 | $1.878 \pm 0.054$ | 5.65 |
| 236.037 | 18 | 537 | $1.829 \pm 0.049$ | 5.77 |
| 236.049 | 20 | 512 | $1.877 \pm 0.054$ | 5.67 |
| 236.062 | 20 | 516 | $1.923 \pm 0.057$ | 5.62 |
| 236.075 | 19 | 513 | $2.014 \pm 0.064$ | 5.55 |
| 236.085 | 20 | 541 | $2.063 \pm 0.067$ | 5.59 |
| 236.096 | 27 | 761 | $2.038 \pm 0.055$ | 5.74 |
| 236.105 | 23 | 540 | $2.008 \pm 0.062$ | 5.28 |
| 236.115 | 26 | 597 | $1.968 \pm 0.056$ | 5.74 |
| 236.124 | 19 | 563 | $2.063 \pm 0.066$ | 5.64 |
| 236.135 | 19 | 643 | $2.069 \pm 0.063$ | 5.62 |
| 236.145 | 23 | 516 | $2.083 \pm 0.071$ | 5.72 |
| 236.159 | 20 | 510 | $2.057 \pm 0.069$ | 5.79 |
| 236.173 | 19 | 503 | $1.966 \pm 0.061$ | 5.72 |
| 236.193 | 16 | 521 | $2.053 \pm 0.068$ | 5.79 |
| 236.208 | 7 | 225 | $2.019 \pm 0.099$ | 5.66 |
| 236.224 | 6 | 263 | $2.084 \pm 0.100$ | 5.41 |
| 236.249 | 9 | 226 | $2.049 \pm 0.103$ | 5.15 |
| 236.266 | 9 | 329 | $2.057 \pm 0.086$ | 5.18 |
| 236.278 | 7 | 240 | $2.229 \pm 0.122$ | 5.52 |
| 236.288 | 8 | 203 | $2.175 \pm 0.125$ | 5.10 |
| 236.308 | 7 | 265 | $2.164 \pm 0.109$ | 5.32 |
| 236.328 | 7 | 252 | $2.066 \pm 0.099$ | 5.44 |
| 236.364 | 11 | 202 | $2.060 \pm 0.111$ | 5.25 |
| 236.891 | 13 | 204 | $2.899 \pm 0.244$ | 5.50 |
| 237.272 | 6 | 33 | $2.030 \pm 0.309$ | 5.87 |

The enhancement has, however, only marginal significance. Moreover, as there is also a minimum in $r$ for $\lambda_\odot = 236\overset{\circ}{.}115$ or $3^h59^m$ UT on November 18 with $r = 1.97$, we consider these extrema to be statistical fluctuations and find the population index fairly constant over a long period of more than four hours in the UT-morning hours of November 18.

A maximum $r$-value occurs again for the 4-revolution trail as seen from the Americas, centered on $\lambda_\odot = 236\overset{\circ}{.}278$ or $7^h52^m$ UT on November 18 with $r = 2.23$. The maximum is still visible in the coarser binning as given in Table 3, but the time is less well defined there, of course.

Table 3 – Averaged population index of larger bins for the period $\lambda_\odot = 236^\circ\!.2$–$237^\circ\!.0$.

| $\lambda_\odot$(J2000.0) | Obs | $n$ | $r$ | $\overline{\text{lm}}$ |
|---|---|---|---|---|
| 236°222 | 15 | 506 | $2.137 \pm 0.076$ | +5.34 |
| 236°264 | 17 | 576 | $2.020 \pm 0.061$ | +5.30 |
| 236°291 | 18 | 511 | $2.211 \pm 0.081$ | +5.19 |
| 236°329 | 14 | 511 | $2.053 \pm 0.068$ | +5.46 |
| 236°364 | 11 | 202 | $2.060 \pm 0.111$ | +5.25 |
| 236°805 | 8 | 133 | $2.795 \pm 0.283$ | +5.49 |

No population index extremum appears for the 2-revolution trail, which may be supposed to be richest in faint meteors, because it is younger than any other trail encountered. What is visible there is a gradual, almost linear decrease of $r$ from $\lambda_\odot = 235^\circ\!.1$ to $\lambda_\odot = 235^\circ\!.4$ while the peak was expected near $\lambda_\odot = 235^\circ\!.27$.

### 3. Activity profile

We use the population index profile of Table 2 and Figure 1 to correct observations for their limiting magnitude to the standard value of lm = +6.5. Given the limiting magnitude lm, possible field obstruction factors $F$, and the elevation of the Leonid radiant, $h_\text{R}$, the total correction for an individual (index $i$) observing period amounts to

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

Averages of the ZHR are weighed by that correction and the effective observing time $T_{\text{eff},i}$ such that

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

Again, no additional smoothing is applied apart from the overlap of periods due to $T_{\text{eff},i} > 0$. Observing periods longer than the bin size are excluded from the average. That means that the maximum effective bin size due to interval overlap is twice the given bin size. A time correction to topocentric stream encounter [4] was not applied; the resolution of the profiles will not be as low as five minutes, which is the typical correction between geographical locations used here.

Table 4 lists the bin sizes used to cover the period of maximum Leonid activity with meaningful averages. Note that one hour corresponds to a solar-longitude difference of $\Delta\lambda_\odot = 0^\circ\!.0420$ in those nights. A significant number of observations was divided in intervals of about one hour, and the bin size of 0°045 was explicitly chosen to include these observations. Similarly, for the high-resolution part, the bin size of 0°011 was chosen to include the numerous 15-minute observing periods.

Table 4 – Bin sizes.

| Period | Bin size |
|---|---|
| 234°60–235°10 | 0°045 |
| 235°10–235°35 | 0°022 |
| 235°35–235°95 | 0°090 |
| 235°95–236°37 | 0°011 |
| 236°37–237°50 | 0°050 |

Table 5 – Detailed numerical data of the averaged ZHRs obtained from records with a minimum radiant elevation of $h_R = 15°$.

| $\lambda_\odot$(J2000.0) | Obs | $n$ | $\overline{\mathrm{ZHR}}$ | $\overline{\mathrm{lm}}$ | $\lambda_\odot$(J2000.0) | Obs | $n$ | $\overline{\mathrm{ZHR}}$ | $\overline{\mathrm{lm}}$ |
|---|---|---|---|---|---|---|---|---|---|
| 234°6818 | 4 | 13 | 34.0 ± 9.1 | 5.71 | 236°1160 | 91 | 972 | 252.0 ± 8.1 | 5.65 |
| 234°8280 | 5 | 26 | 49.7 ± 9.6 | 5.34 | 236°1277 | 68 | 739 | 235°9 ± 8.7 | 5.62 |
| 234°8578 | 4 | 27 | 35.8 ± 6.8 | 5.49 | 236°1382 | 56 | 536 | 191.1 ± 8.2 | 5.68 |
| 234°9551 | 7 | 18 | 25.8 ± 5.9 | 5.46 | 236°1486 | 42 | 457 | 211.4 ± 9.9 | 5.82 |
| 234°9935 | 6 | 20 | 39.1 ± 8.5 | 5.12 | 236°1605 | 38 | 443 | 230.3 ± 10.9 | 5.80 |
| 235°0447 | 13 | 57 | 50.3 ± 6.6 | 5.12 | 236°1709 | 29 | 435 | 263.1 ± 12.6 | 5.72 |
| 235°0847 | 9 | 32 | 40.6 ± 7.1 | 5.29 | 236°1819 | 22 | 380 | 275.6 ± 14.1 | 5.65 |
| 235°1066 | 8 | 24 | 28.5 ± 5.7 | 5.68 | 236°1922 | 18 | 238 | 323.0 ± 20.9 | 5.63 |
| 235°1217 | 10 | 66 | 61.6 ± 7.5 | 5.70 | 236°2035 | 14 | 214 | 332.6 ± 22.7 | 5.41 |
| 235°1470 | 6 | 43 | 46.1 ± 6.9 | 5.84 | 236°2151 | 18 | 261 | 396.1 ± 24.5 | 5.42 |
| 235°1674 | 5 | 34 | 32.1 ± 5.4 | 5.88 | 236°2271 | 20 | 207 | 326.1 ± 22.6 | 5.56 |
| 235°1890 | 6 | 27 | 76.4 ± 14.4 | 5.28 | 236°2372 | 19 | 196 | 323.6 ± 23.1 | 5.52 |
| 235°2126 | 7 | 33 | 83.6 ± 14.3 | 5.31 | 236°2484 | 30 | 469 | 483.1 ± 22.3 | 5.54 |
| 235°2360 | 7 | 17 | 51.8 ± 12.2 | 5.73 | 236°2593 | 34 | 483 | 437.9 ± 19.9 | 5.47 |
| 235°2540 | 7 | 20 | 54.1 ± 11.8 | 5.87 | 236°2703 | 43 | 650 | 419.5 ± 16.4 | 5.47 |
| 235°2782 | 10 | 59 | 132.5 ± 17.1 | 5.46 | 236°2813 | 40 | 504 | 362.7 ± 16.1 | 5.43 |
| 235°2984 | 9 | 41 | 80.8 ± 12.5 | 5.36 | 236°2921 | 38 | 397 | 247.1 ± 12.4 | 5.51 |
| 235°3186 | 8 | 27 | 69.9 ± 13.2 | 5.23 | 236°3030 | 29 | 277 | 215.2 ± 12.9 | 5.50 |
| 235°3393 | 9 | 23 | 30.3 ± 6.2 | 5.12 | 236°3136 | 26 | 218 | 170.0 ± 11.5 | 5.51 |
| 235°3717 | 11 | 33 | 30.1 ± 5.2 | 5.10 | 236°3247 | 19 | 162 | 163.3 ± 12.8 | 5.50 |
| 235°4383 | 3 | 23 | 54.2 ± 11.1 | 5.38 | 236°3340 | 11 | 68 | 105.5 ± 12.7 | 5.46 |
| 235°7142 | 19 | 175 | 61.4 ± 4.6 | 5.39 | 236°3463 | 7 | 62 | 109.2 ± 13.8 | 5.59 |
| 235°8052 | 17 | 236 | 49.2 ± 3.2 | 5.47 | 236°3565 | 4 | 31 | 89.8 ± 15.9 | 5.62 |
| 235°8837 | 15 | 279 | 85.6 ± 5.1 | 5.68 | 236°3663 | 4 | 33 | 93.2 ± 16.0 | 5.59 |
| 235°9630 | 6 | 37 | 118.7 ± 19.3 | 5.55 | 236°3820 | 9 | 56 | 49.5 ± 6.6 | 5.83 |
| 235°9740 | 5 | 43 | 124.9 ± 18.8 | 5.64 | 236°4114 | 14 | 75 | 38.0 ± 4.4 | 5.79 |
| 235°9836 | 10 | 49 | 125.5 ± 17.8 | 5.89 | 236°4727 | 3 | 43 | 37.0 ± 5.6 | 6.01 |
| 235°9957 | 12 | 72 | 143.4 ± 16.8 | 5.37 | 236°6174 | 5 | 27 | 35.6 ± 6.7 | 5.78 |
| 236°0058 | 17 | 113 | 144.7 ± 13.6 | 5.51 | 236°6687 | 7 | 28 | 28.2 ± 5.2 | 5.72 |
| 236°0173 | 21 | 145 | 177.6 ± 14.7 | 5.64 | 236°7673 | 4 | 28 | 34.9 ± 6.5 | 5.17 |
| 236°0274 | 27 | 330 | 237.0 ± 13.0 | 5.69 | 236°9248 | 4 | 10 | 31.4 ± 9.5 | 5.65 |
| 236°0389 | 45 | 512 | 244.3 ± 10.8 | 5.63 | 236°9646 | 11 | 27 | 24.5 ± 4.6 | 5.58 |
| 236°0495 | 49 | 517 | 232.6 ± 10.2 | 5.59 | 237°0153 | 6 | 28 | 26.9 ± 5.0 | 5.43 |
| 236°0605 | 66 | 654 | 243.9 ± 9.5 | 5.56 | 237°0760 | 8 | 33 | 21.0 ± 3.6 | 5.69 |
| 236°0716 | 54 | 667 | 269.5 ± 10.4 | 5.57 | 237°1100 | 5 | 20 | 17.6 ± 3.8 | 5.64 |
| 236°0832 | 68 | 783 | 256.9 ± 9.2 | 5.70 | 237°1753 | 3 | 10 | 11.3 ± 3.4 | 5.51 |
| 236°0936 | 101 | 1019 | 287.9 ± 9.0 | 5.62 | 237°3188 | 5 | 2 | 19.4 ± 11.2 | 5.55 |
| 236°1052 | 115 | 1067 | 250.0 ± 7.6 | 5.59 | 237°3613 | 3 | 1 | 15.7 ± 11.1 | 5.46 |

In this analysis, we did not compute individual perception coefficients. Such coefficients account for systematic properties of observers. They can be obtained from *systematic* deviations of an individual observer's ZHRs or corrected sporadic rates from the average. A few exceptional cases were specially treated here, however.

Veteran observer Norman McLeod (MCLNO) has a remarkable ability to spot faint stars; his corrected meteor rates settled very consistently at about 50% of the average rates seen by other observers. We applied a perception coefficient of $c_p = 0.5$ to observer MCLNO.

Japanese observer Kazuhiro Osada (OSAKA) has a very effective perception of meteors. His reports are not easy to correct for that effect, as the meteor perception appears to increase when more meteors are visible anyway. This is expressed by enhanced sporadic rates which climbed up to about 80 (!) for the Leonid maximum. If no major shower is active, sporadic rates lie between 40 and 50 for OSAKA. We chose a tentative perception factor of $c_p = 4$ to normalize his data, although his observations are atypical.

Finally, Mikiya Sato's (SATMK) data are reduced by $c_p = 2$ based on the generally higher-than-average sporadic and shower rates.

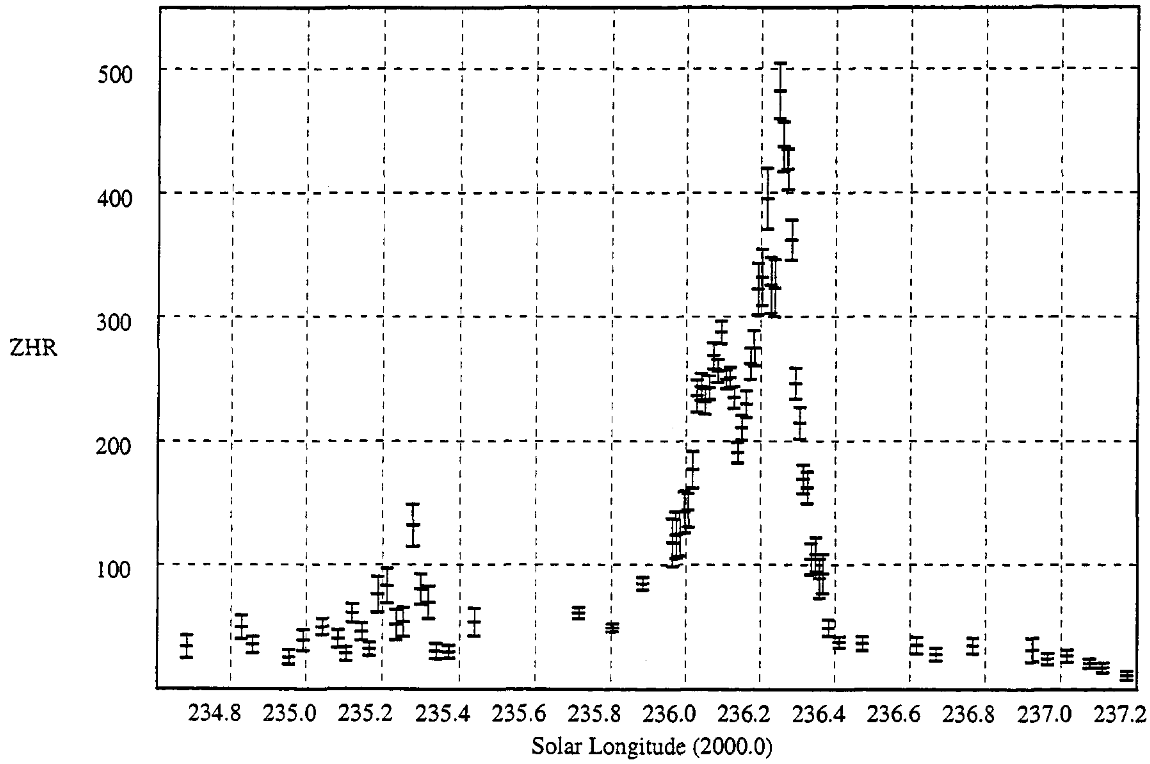


Figure 3 – Entire ZHR profile of the 2000 Leonids. The minimum radiant elevation was 15°; observing periods longer than the bin size are excluded.

The general influence of corrections can be checked by varying the quality limits for the individual records. While the graphs in Figures 3 and 4 were produced with a minimum radiant elevation of $h_R = 15°$, the graph of Figure 5 involves more rigorous restrictions, namely $h_R \geq 20°$ and $C \leq 8$, with $C$ the total correction factor. This means that, even if the radiant was high enough, limitations are imposed to the limiting-magnitude and cloud correction. The two graphs in Figures 4 and 5 are satisfactorily similar. Nevertheless, we will go into detail of observing effects in the following sections.

## 4. Limiting magnitude influence

The relatively poor conditions with the Moon high in the sky may have a systematic effect on the height of the ZHR maxima. We divided the observations into two samples, one with $\text{lm} \geq +5.6$ and the other with $\text{lm} < +5.6$. The second sample is a little more comprehensive with respect to the number of individual records, but was chosen deliberately in order to compensate for the lower meteor numbers due to poorer conditions. Indeed the graph of the second data set (Figure 8) shows somewhat higher ZHRs than the high-lm set (Figure 7), but the good news is that the shape of the profile is not drastically altered. The change in ZHR level can have two reasons: (*i*) the lm correction overestimates the loss of meteors, or (*ii*) the observers underestimated their limiting magnitude.

Table 6 – Distribution of observing periods and effective observing time versus limiting magnitude.

| Limiting magnitude | 4.0–4.5 | 4.5–5.0 | 5.0–5.5 | 5.5–6.0 | 6.0–6.5 | 6.5–7.0 |
|---|---|---|---|---|---|---|
| Records | 92 | 225 | 586 | 609 | 444 | 18 |
| $T_{\text{eff}}$ | 37ʰ22 | 88ʰ22 | 171ʰ18 | 203ʰ42 | 103ʰ91 | 10ʰ27 |

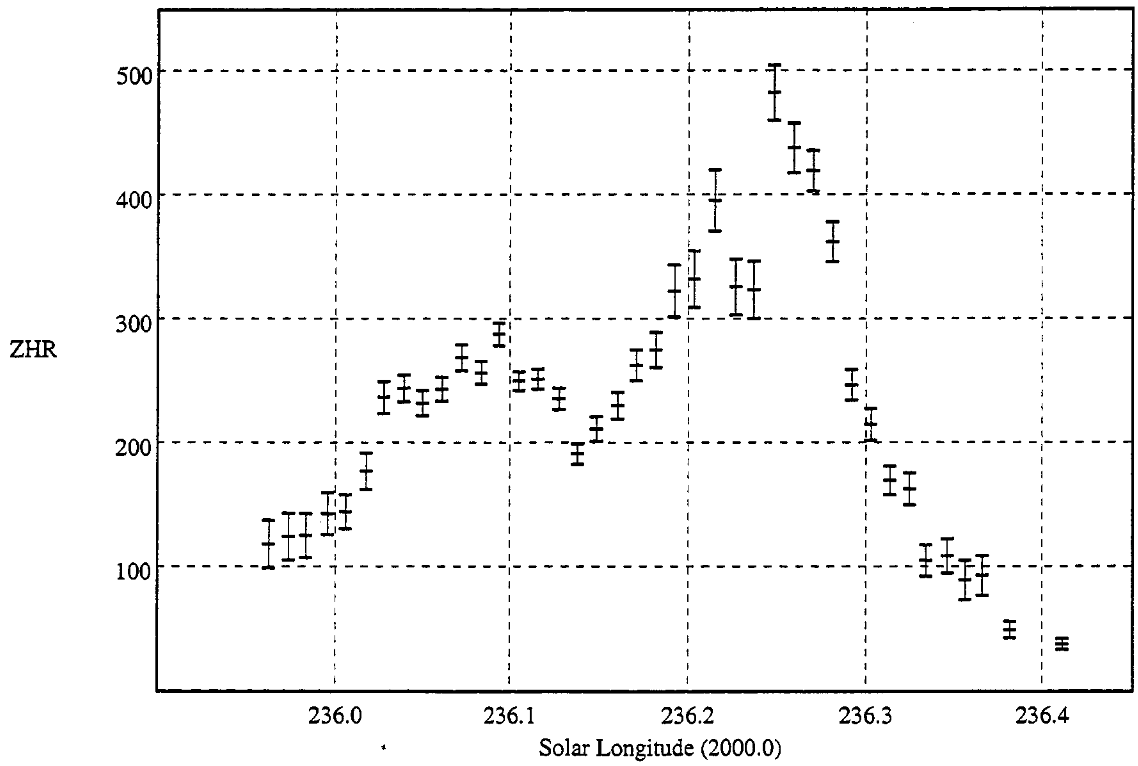


Figure 4 – Magnification of the ZHR profile of the 2000 Leonids near the peaks of the 8-revolution and 4-revolution trails. The period shown corresponds to November 17, $22^h50^m$ to November 18, $12^h00^m$ UT.

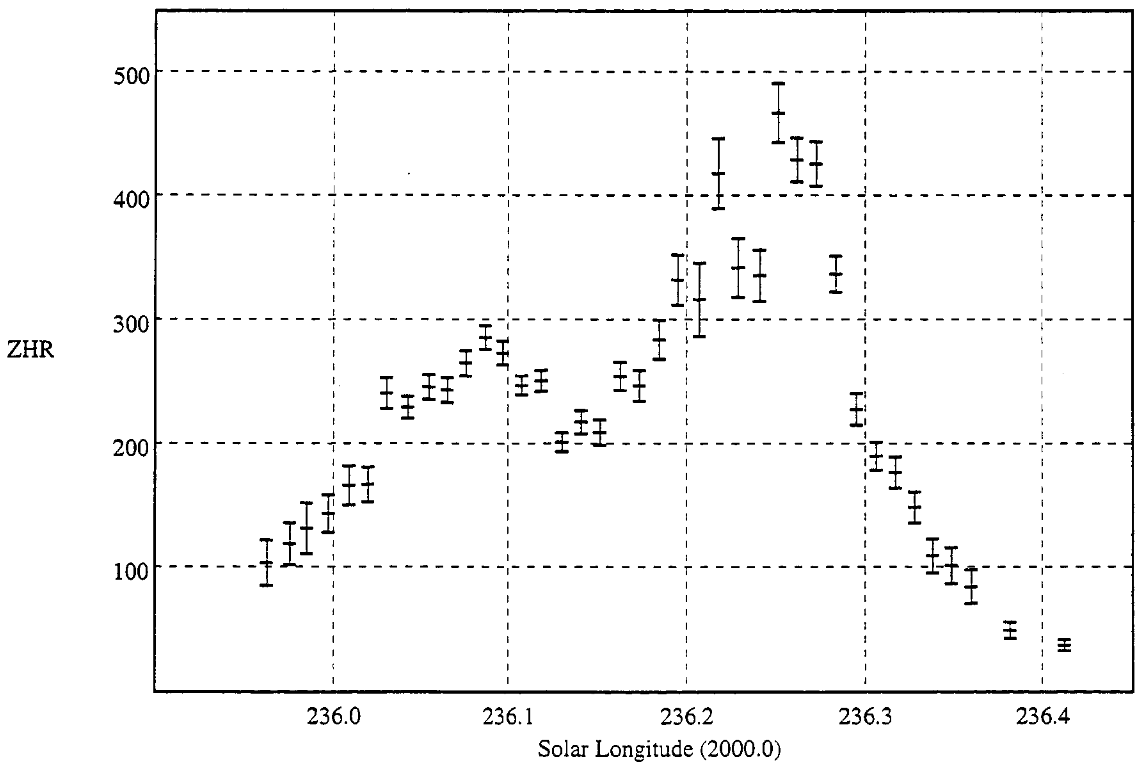


Figure 5 – Restricted profile of the 2000 Leonids near the peaks of the 8-revolution and 4-revolution trails with a maximum total correction of 8.0 and a minimum radiant elevation of 20°.

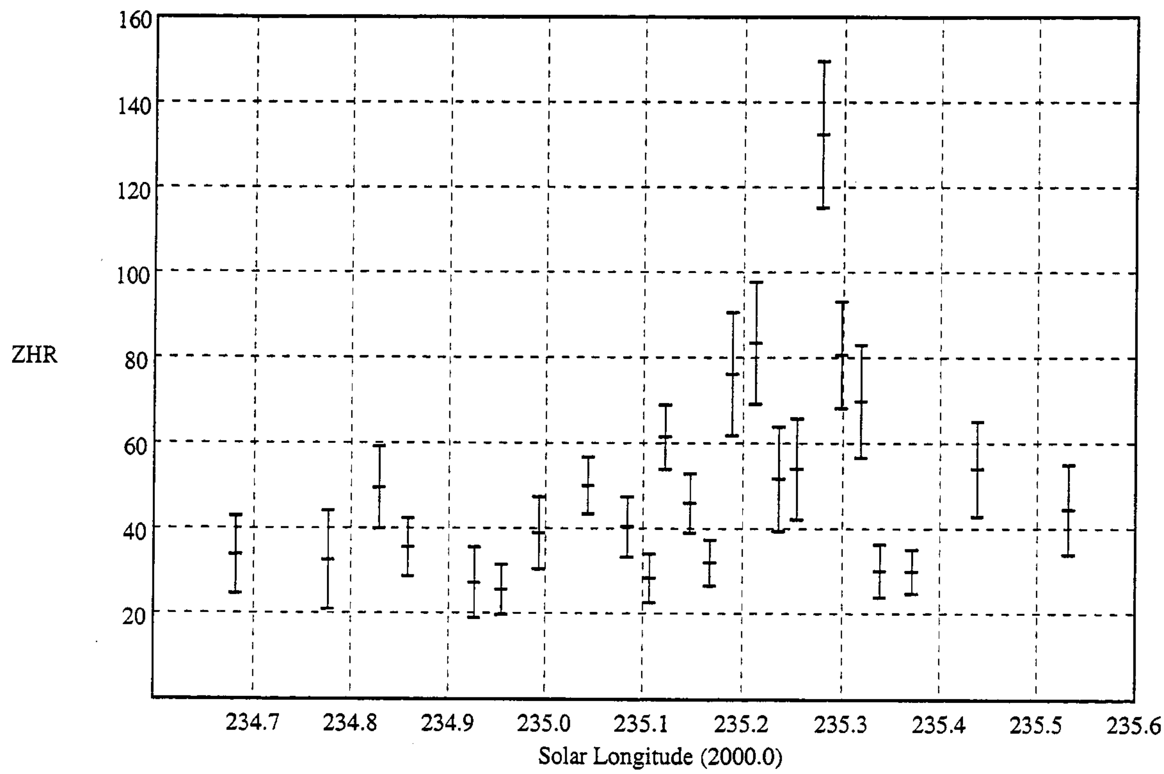


Figure 6 – Magnification of the ZHR profile of the 2000 Leonids near the peak of the 2-revolution trail. The graph is discussed in Section 6.

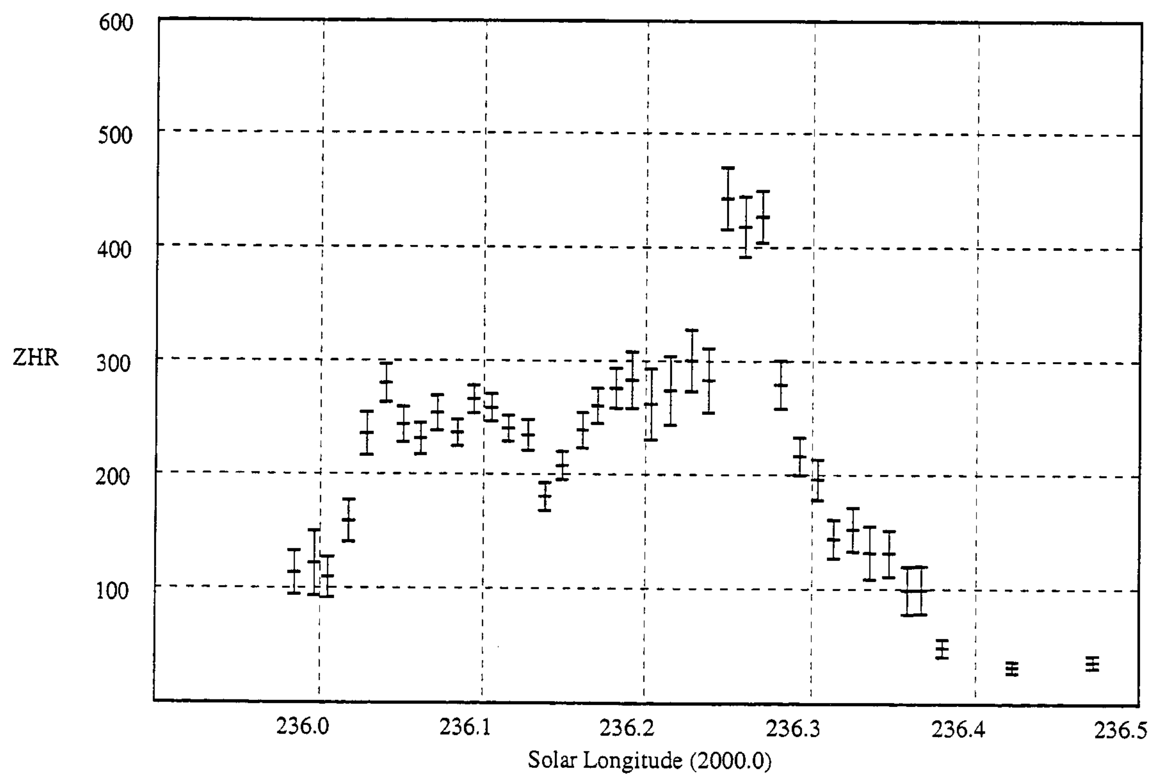


Figure 7 – Maximum part of the ZHR profile of the 2000 Leonids from observations with lm $\geq +5.6$.

The total graph of Figure 3 is closer to the high-lm Figure 7 with respect to ZHR amplitudes, since the averages are weighed with the inverse of the total correction, and periods under poor conditions—explicitly extracted for Figure 8—have less weight than those recorded under good skies.

## 5. Cloud interference

In spite of a relatively broad but clear maximum for the 8-revolution trail between $3^h$ and $4^h$ UT on November 18, observers who were lucky to have good conditions for a long period in that night independently mentioned the obvious absence of a distinct peak according to both their impression and data. We have, therefore, split the data set into two other samples: one containing only long-duration observations from sites from where, at worst, occasional cloud cover of no more than 10% were reported; the second containing the remaining observations. The dataset of (European) long-term observers was formed by BADPI, BETFE, JIMMN, JOHCA, KIDMA, LANMA, MARDA, MASED, MISKO, MOMIV, OKODR, QUEFR, PLADU, RODFR, RUIVI, SERMI, VERCI, and WISJE.

The amazing result of splitting the data set in this way is shown in Figure 9, with the long-term observations at the *left* side and the "cloud-gap" observations at the *right* side. Indeed, the impression of the long-term watchers that the activity curve lacked a clear peak for the 8-revolution prediction features also in the analysis. The observers more or less being disturbed by clouds produce a graph with clear rise, peak, and fall of activity, with the maximum at $\lambda_\odot = 236.^\circ09$ ($3^h24^m$ UT) being within a 20-minute error margin from the predicted passage of the 1733 trail. The long-term observers saw constant activity (with just a slight, downward trend) between $\lambda_\odot = 236.^\circ06$ and $\lambda_\odot = 236.^\circ13$ (between $2^h41^m$ and $4^h21^m$ UT). The level of activity is 230–250 for the long-term observers—the same as seen by the cloud-gap watchers who essentially topped this graph by "their" peak.

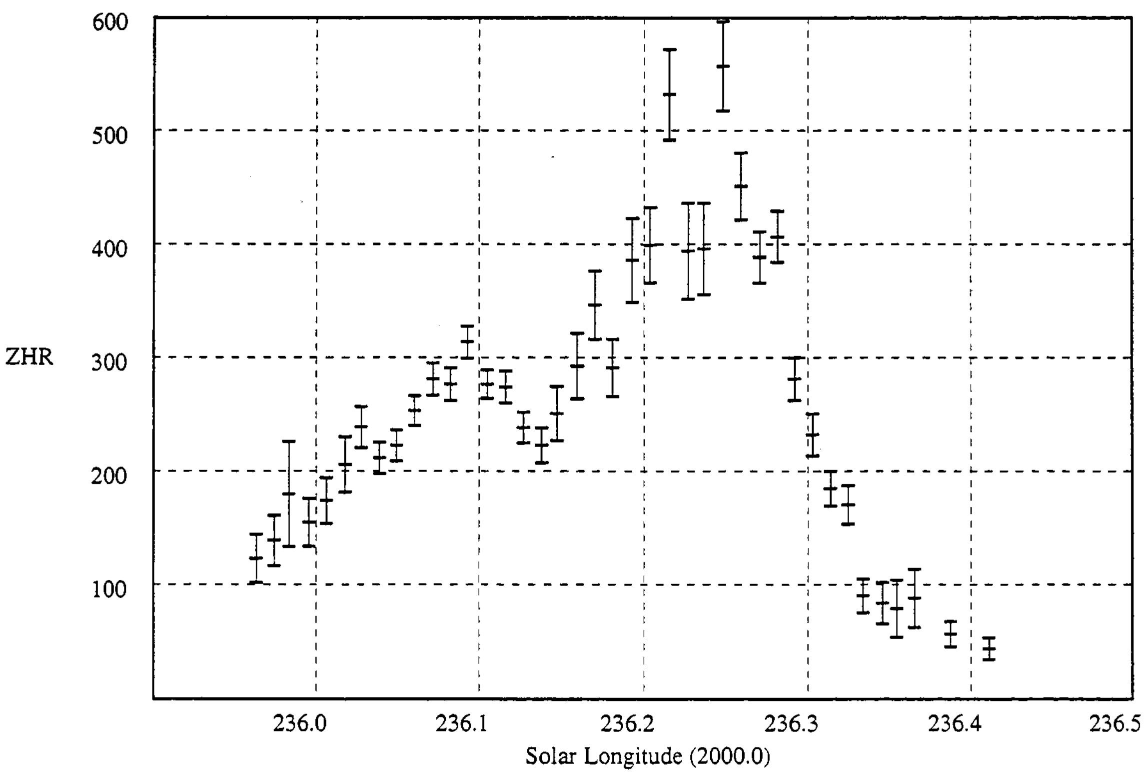


Figure 8 – Maximum part of the ZHR profile of the 2000 Leonids from observations with lm < +5.6.

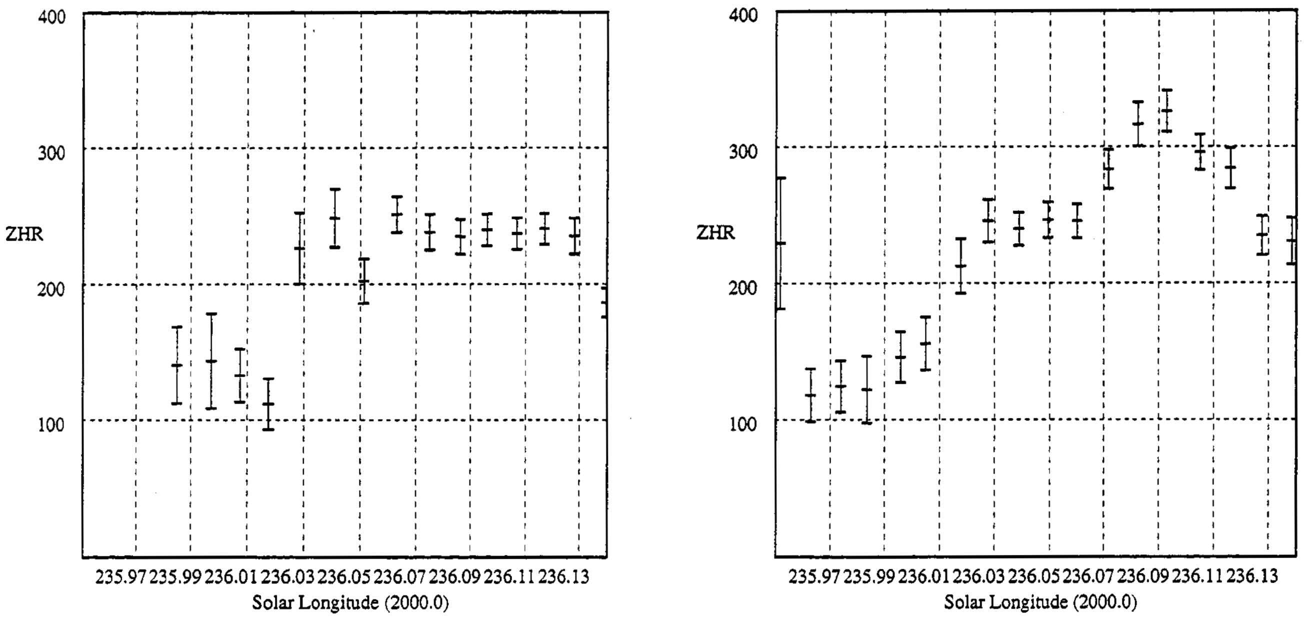


Figure 9 – *Left*: Maximum part of the 2000 Leonids from long-duration observations with no more than occasional 10% obstruction. *Right*: Complementary part of the observations.

These two profiles of Figure 9 call for possible explanations. It is not unlikely that a psychological effect plays a role here. Expectations were high, and an observer waiting for a cloud gap may tend to "reward" his waiting by recording a good meteoric display. If the psychology during exciting events has such an impact, we would have to consider much larger error margins for other outbursts, which were covered by poor-condition data *only*.

We note that it may be more satisfactory to find other explanations maintaining the confidence in the observers that they try to *record what they see* rather than what is expected. Naturally, the expectations of the peak may lead to an increased number of observations with poor conditions. "If nothing worked out this night," the observer may have said, "these ten minutes round the peak will be recorded, however poor the sky is, however small the cloud-gap is." Together with the fact that low-lm data tend to produce higher ZHRs, a peak can be expected just as an indirect consequence of the expectations.

Our considerations would not be complete, however, if we would not also search for explanations the other way round: Were long-term observers possibly fatigued by the time the 1733 peak was expected? In this investigation, "fatigue" is meant in a very broad sense: when using this term, we do not so much think of fatigue caused by a need for sleep after several hours of concentrated observing, but rather of fatigue to the eyes and their ability to adapt to the darkness, because of their constant exposure to the moonlit sky background, although the two effects may reinforce each other, of course.

The observers did not start at the same time, and by the time one observer might have become fatigued, another just started fresh. The distribution of beginning times (UT) is: MOMIV, $23^h24^m$; SERMI, $0^h05^m$; QUEFR, $0^h25^m$; JOHCA, $1^h17^m$; MISKO, $1^h18^m$; MASED, $1^h21^m$; LANMA, $1^h29^m$; JIMMN, $1^h55^m$; WISJE, $2^h00^m$; VERCI, $2^h12^m$; MARDA, $2^h15^m$; PLADU, $2^h30^m$; KIDMA, $2^h40^m$; RODFR, $2^h42^m$; OKODR, $2^h50^m$; RUIVI, $3^h05^m$; BETFE, $3^h16^m$; and BADPI, $3^h25^m$.

We have two ways to tentatively check for possible fatigue. First we consider the temporal development of averaged sporadic rates of the two categories of observers. Indeed, we find a gradual decrease of $HR_{spor}$ for the all-night observers with values of 23.7, 13.8, 9.6, 8.9, and 7.1 for $0^\circ\!.05$ steps between $1^h15^m$ and $7^h10^m$ UT. The observer class with cloud interferences delivers 7.0, 5.5, 6.8, 9.5, and 15.6—rather showing a rising tendency, as it would be expected approaching the culmination of the apex near $6^h$ local time. This may indeed be an indication of fatigue for the former group.

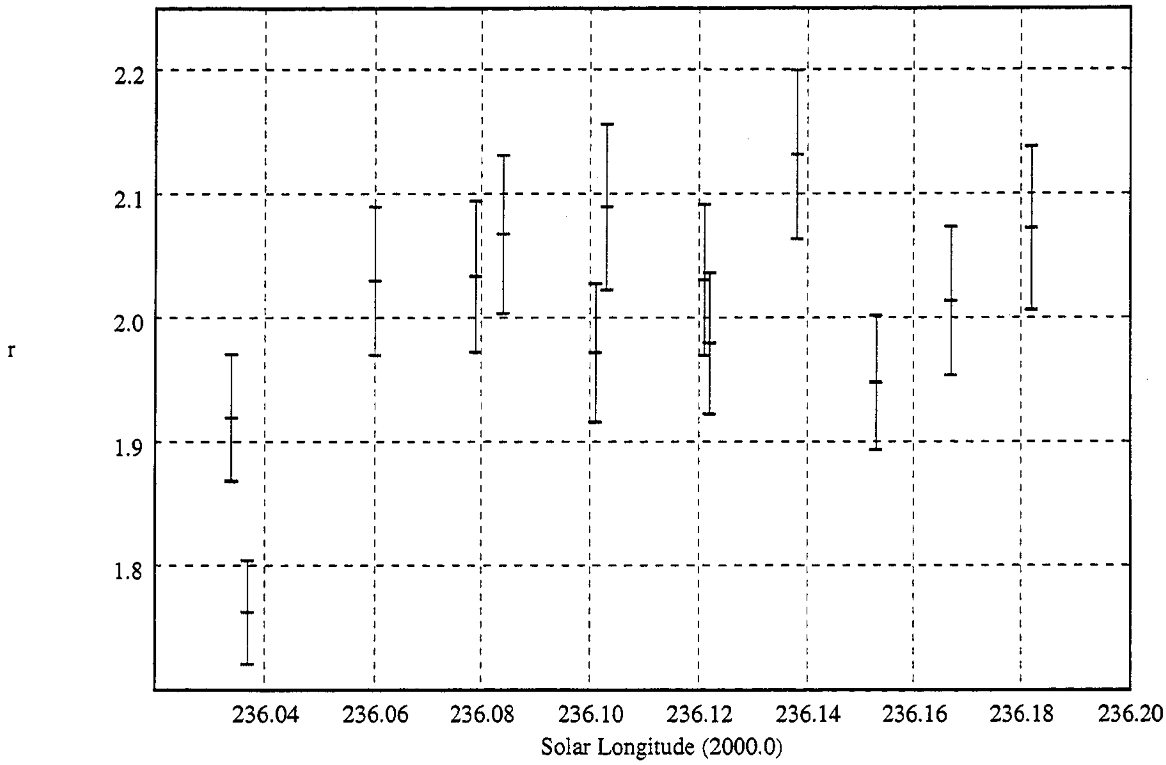


Figure 10 – Population index profiles for two groups of observers: black data refer to long-term observations with no cloud interference, grey values refer to the remaining observations with more or less cloud interference and breaks.

In a second attempt to check for possible fatigue, we computed the two independent population index profiles (for the Leonids, not the sporadics) for the two groups: fatigue would result in lower $r$-values because faint meteors are likely to be missed. This time, we applied a minimum meteor number of 600 in order to smear out small structures; we are only interested in the tendency over a period of several hours. The result is shown in Figure 10. Black values represent the all-night watchers' group, grey values refer to the "cloud group." Again, an opposite tendency with a decrease of $r$ for the all-night observers and an increasing $r$ for the "cloud-gappers" indicates fatigue as being important in long observations, at least under unfavorable circumstances. Note that these two tests are completely independent.

The distribution of locations is not significantly different for the two profiles, but the all-night observers' profile contains only locations in Bulgaria, Spain, Portugal, and Morocco. The remaining data set covers a much more extended area from the Crimea to the Canaries in longitude, and from Egypt to northern Norway in latitude. We consider it unlikely, though, that small-scale peculiarities within the dust trail caused southern Europe to see a flat profile instead of a peak, as suggested by the remaining European observations (partly from very similar locations, in fact).

## 6. The double peak of November 17

The dust trail integrations predicted a possible activity enhancement from the two-revolution trail ejected in 1932 for the UT-morning hours of November 17. Such an enhancement is indeed visible in Figure 3, with a ZHR level of about 130. As already noted in the *IMO Shower Circulars* [5], the profile exhibits a double peak near that time, with a somewhat lower, additional maximum preceding the peak close to the predicted time. The enlargement in Figure 6 shows the bimodal structure of this least prominent of the dust trail encounters. The times of the two maxima can be fixed at $\lambda_\odot = 235\overset{\circ}{.}21$ and $\lambda_\odot = 235\overset{\circ}{.}28$.

The average ZHR values given in Table 5 and shown in Figure 6 are not unproblematic, though. They are composed by individual reports of very high and very low activity. In fact, the numbers of individual reports involved in each of the averages in that part of the profile are not excitingly large, yet we decided not to smear out this feature of the graph by larger bins (cf., Table 4). Most of the observers contributing to the pre-1932 averages were experienced people, in alphabetical order ANDBI, BONNE, MCLNO, SEPTO, VANER, VERCI, and WISJE. Their ZHRs, however, range from 24 to 200 for the particular period between $6^h00^m$ and $6^h30^m$ UT. Possibly, more observing reports will help to clarify these contradictory activity values.

Particle integrations by Göckel and Jehn [6] indicate good activity from the 1932 trail in the morning of November 17. The particle numbers reaching Earth are small, but apart from the peak near $\lambda_\odot = 235.^\circ27$, we see another maximum with 75% of the strength of the former near $\lambda_\odot = 235.^\circ20$.

## 7. Conclusions

We present both population index profiles and ZHR profiles for the 2000 Leonids as derived from visual observations. Three major activity outbursts were found: $\lambda_\odot = 235.^\circ28$ (November 17, $8^h07^m$ UT) with ZHR = $130\pm20$, $\lambda_\odot = 236.^\circ09$ (November 18, $3^h24^m$ UT) with ZHR = $290\pm20$, and $\lambda_\odot = 236.^\circ25$ (November 18, $7^h12^m$ UT) with ZHR = $480 \pm 20$. With respect to the predictions by McNaught and Asher [1], the corresponding offsets of the visual maxima are +15 minutes for the 1932 trail, −20 minutes for the 1733 trail, and −40 minutes for the 1866 trail, all rounded to the nearest 5 minutes. Note that the accuracy of the observational peak times is no higher than ±15 minutes anyway. It is noteworthy that the population index reached its maximum precisely at the predicted time of the 4-revolution dust trail, that is about 40 minutes after the ZHR maximum. The older 8-revolution trail is characterized by a broad shape with almost flat top in both the ZHR and population index graphs. The error margin of its ZHR maximum is set to ±20 here in order to account for the systematic differences between two observer groups as described in Section 5.

We may also conclude that the influence of the Moon—although disturbing the joy of a nice meteor display—did not ruin the actual results. A few tests for the influence of the conditions on the ZHR graph showed that peak times and peak activity levels are not dominated by the choice of correction factors. Also, an in depth-study of the considerations made above about the possible influence of fatigue in long observations under poor circumstances may result in even more refined instructions for optimal observation of major showers under poor Moon conditions. From this perspective, we are confident to be able to present meaningful results also for the 2002 Leonid meteor shower which will suffer from an almost Full Moon.

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# The Rare 1932 Dust Trail Encounter of November 17, 2000, As Observed from Aircraft

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Both encounters with the 1932 and 1866 dust trails of Comet 55P/Tempel-Tuttle on November 17 and 18, 2000, respectively, were observed with intensified cameras from a twin-engine Cessna-130 aircraft over southern Florida. Here, preliminary results are presented for the 1932 dust trail encounter, which was most difficult to observe from the ground. Results are consistent with models that predict strong Leonid returns in November 2001 and 2002.

## 1. Introduction

Participants in the *Leonid Multi-Instrument Aircraft Campaign* negotiated this year's Leonid return from a number of ground-based locations in the USA, southern Europe, and Japan. New instruments and observing techniques were tested in preparation for possible future missions during the 2001 and 2002 returns. Airborne and ground-based observations addressed the intensity and width of this year's shower peaks. Of particular interest to the authors was the fact that both encounters with the 1932 and 1866 dust trails, inside, respectively, outside, of the trail center, would be observable from the eastern USA. Prior observations of the 1999 Leonid storm suggested to us that the dust trail pattern is shifted outward, enough to affect the predicted rates in future returns [1,2]. In that case, the 1932 encounter would be significantly more intense than the 1866 encounter, unlike predictions from theoretical models [3,4]. Also, the width of both trails should be significantly wider than for the 1899 storm.

## 2. The observations

Best observing conditions were expected from Florida. The authors worked from this location, in the company of Peter Gural and David Nugent. However, the low elevation of the state made the Last Quarter Moon a potential problem if haze or clouds would develop. An alternative site was chosen at Mount Lemon Observatory in Arizona from where Mike Koop, Rick Rairden, and Ray Russell observed. The more western longitude would lower the rates by a factor of two, but the high altitude promised better observing conditions and a climate different from that in Florida.

On November 16 and 17, we found ourselves trying to count meteors while all of the United States was in the ban of a presidential election, the outcome of which depended on the vote count in the state of Florida. Long before the elections, we had chosen our observing sites in, or near, the very counties that were contested. Sure enough, at both nights a cloud deck over northern Florida prevented meteor counts from our prime location at ISTEF, a BMDO facility at Kennedy Space Center. Peter and David continued observations at Mike Palimeti's observatory in the town of Jupiter near Palm Beach, but there, too, clouds occasionally interrupted the observations.

Figure 1 – The twin-engine Cessna-130 aircraft.

Pilot Pat Bainter was found willing to bring us to clear weather in a twin-engine Cessna-130 aircraft, with fuel tanks on the wing tips for stability (Figure 1). Such aircraft is relatively inexpensive to rent and perhaps within reach of amateur observers, but it does not bring the observer above clouds. Rather, the aircraft enabled us to fly to a region of clear weather, to be above ground haze (and scattered moonlight), and to point intensified cameras low on the horizon where meteor rates tend to be highest if extinction is low. Missions were flown on both nights, each out of Gainesville airport, in southern direction over the Everglades National Park, for a duration of 4.5 hours. We then landed in Fort Lauderdale for refueling.

## 3. Results

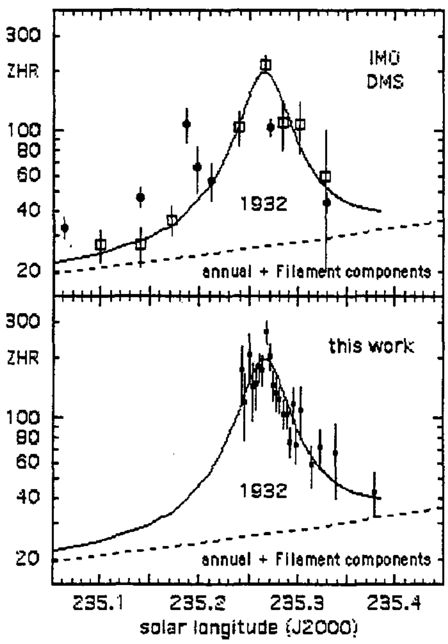


Figure 2 – Preliminary results.

Here, we will present preliminary results for the observations of November 16, when the Earth encountered the 1932 dust trail of parent comet 55P/Tempel-Tuttle. Average counts of three cameras in 5-minute intervals, corrected for radiant altitude [5], are shown in Figure 2.

The counts represent only a first visual scan of the tapes and then only around the peak of the shower. We have 640 Leonids and 40 sporadic meteors during 4.4 hours of effective observing time. This is sufficient to make the point that the observations differ from our expectations.

The peak is at $7^h48^m \pm 4^m$ UT, in agreement with predictions [3,4]. However, the airborne observations show a narrow profile that is wider than the 1999 Leonid storm, but by only 36%. The best fit Lorentzian curve in Figure 2 has a width of only $W = 0\overset{\circ}{.}049$ ($0\overset{\circ}{.}045$–$0\overset{\circ}{.}063$). Also, the peak of the 1932 encounter, with maximum ZHR of 170 (120–250) for the 1932 component alone, was significantly less intense than for the 1866 encounter, not more intense.

This outburst was not well observed from the ground, partially because there was a lack of bright meteors. From the video record, we measured a population index $r = N(m+1)/N(m) = 2.5 \pm 0.2$. It is not clear if that is high enough to be consistent with Lyytinen and Van Flandern [3], who pointed out that this shower was expected to consist of "mainly faint meteors."

Absolute calibration of the counts awaits the measurement of detection efficiency. Instead, the counts have been scaled to visual observations by Florida observer Norman McLeod and members of the *Dutch Meteor Society* who observed from Portugal and Spain (squares in Figure 2 indicate ZHRs as calculated by Marco Langbroek). The counts are also compared to data distributed by Marc Gyssens on behalf of the *International Meteor Organization* shortly after the event [6], derived from 373 visually observed Leonids (dots in Figure 2). Fortunately, the 1733 and 1866 maxima are much better described by the visual observations than this 1932 encounter, and define the level of the background activity (dashed line in Figure 2). That background contains a 1-day wide component consistent with the return of the Leonid Filament, much as we expected [7].

## 4. Discussion

The new observations for the first time enable a reliable measurement of the width of a dust trailet far from the trailet center, and thus calculate the width of the trailet perpendicular to the Earth's orbit. The measured width of $W = 0\overset{\circ}{.}045$–$0\overset{\circ}{.}063$ at a distance of $-0.0012$ AU from the center implies that the dust trailet is a factor of 4 wider in the plane of the comet orbit than in the path of the Earth. The 1932-dust shower is a factor of 2 narrower than the predicted $W = 0\overset{\circ}{.}10$. This puts in doubt our earlier measurements of three much less well-observed components far from the trailet center. If those measurements are in doubt, then there is no real basis for the trailet pattern to be significantly shifted [1,2]. Hence, it appears that we will pass close to the center of the trailets in November of 2001 and 2002 [3,4]. Comparison with results for the 1866 dust trail encounter will be postponed until all data are reduced. The many hours of ground-based observations will also help to further define the shape of the 1932 dust profile.

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# The 1999 Leonids from Crimea

*J. Babina, D. Karkach, and M. Kychyzhyeva*

Restricted-field visual observations of the Leonid meteor shower were carried out on November 18, 1999, using the method of multiple count in the zenith, near the horizon, and with binoculars to study the population index and spatial density of the stream. The population index was derived in the range of absolute magnitudes from −8 to +9. It was revealed that the population index turns out to be non-linear over a large interval of stellar magnitudes, and it is approximated by a second-order curve. The shape of the logarithm-of-the-stream-density curve suggests that particles yielding meteors fainter than magnitude +10 are absent in the stream. The shower reached maximum activity at solar longitude $\lambda_\odot = 235^\circ\!.287$ (J2000.0, at $2^h05^m$ UT). The maximum was characterized by a rapid increase in spatial density—6 times for half an hour only. The population index in the night of maximum does not show a regular course, and reflects the crossing of separated dust clouds by the Earth.

## 1. Introduction

When we had planned the study of the 1999 Leonid meteor shower, we decided to focus on the determination of the population index and the density in the meteoroid stream. These problems can be solved by using observations with a restricted field of view only. Besides the classical program applying circular frames that restrict the observers' field of view to a zenithal area, we decided to enlarge the range of meteor stellar magnitudes with observations of telescopic meteors and meteors near the horizon using special frames.

One of the interesting problems that can be solved by restricted-field observations is the study of the behavior of the population index $\kappa$ (*in most articles in* WGN *referred to as r, Ed.*) and the study of the deviation of the magnitude distribution from an exponential law. Observations show that the logarithm of the meteor number versus the magnitude $m$ increases approximately linearly with increasing $m$. In this case, the tangent of the angle between this function and the magnitude axis yields $\log \kappa$, which turns out to be independent of the magnitude, and the distribution of $N(m)$ is defined by the well-known formula [2]

$$N(m) = N(0)\kappa^m. \tag{1}$$

However, we have no fundamental reason to assume that $N(m)$ is behaving strictly corresponding to an exponential law. This law is a mere approximation only. The invariability of $\kappa$ in the range of visual meteors, that is for magnitudes 0 to +4, is a well-known fact verified by long-standing observations, and is confirmed with comprehensive statistical material. But the behavior of the population index outside this interval is unknown, whereas, from general considerations, it is clear that $\kappa$ cannot remain constant on a large interval of stellar magnitudes, since, in this case, the total density of the meteoroid stream would be infinite.

Let $f(m)$ be the differential law of the density distribution of the meteoroid stream, then the total density of the stream for meteors of all stellar magnitudes will be:

$$\Phi = \int_{-\infty}^{\infty} f(m)\, dm, \tag{2}$$

and if we assume that the law (1) is correct in the whole range of magnitudes, then integral (2) will diverge. Therefore, in order to have a finite value of $\Phi$, we must either limit the interval of integration, or assume a change of the distribution law of $f(m)$. These two solutions do not exclude each other. In reality, there exists some limiting meteoroid mass: if the mass is smaller than this limit, the solar radiation pressure exceeds the solar gravity, and the meteoroid will leave the stream. This is equivalent to the statement that there is some minimal mass, and all particles having a smaller mass are either missing at all, or their contribution is negligible. If $m_{\text{lim}}$ is the magnitude corresponding to this minimal mass, meteoroids with $m > m_{\text{lim}}$ are simply absent. The value of $\kappa$ will decrease gradually, and become equal to unity when $m = m_{\text{lim}}$.

In order to investigate all these effects, it is necessary to conduct observations of the population index in an interval of absolute magnitudes that is as large as possible.

We studied the behavior of $\kappa$ in the range of faint meteors using telescopic meteor observations. The field of view of the telescope restricts the area of observation, and observers find themselves at the same conditions as in usual restricted-field observations, since the subjective eyepiece's field of view is about 45° to 55°, which is similar to the angular diameter of the view field in the circular frame covering 60°. This circumstance permits us to use the method of double count, and the total distribution of meteor numbers for the telescopical range of magnitudes can be found.

We used two 80-mm, 8-time binoculars with 5° field of view. With such instruments, we can see stars to magnitude +11.5. During the observations, two observers faced the same point with their field of view near the star $\alpha$ Lyncis, approximately 10° from the radiant, and retained it for all the observing time. This method permits to find the distribution of meteors in the magnitude range from +4 to +9, and, together with restricted-field visual observations, to spread the entire magnitude range to 10 magnitudes.

But the behavior of the luminosity function in the range of bright meteors remains unknown as before. The problem here is that the density in the stream for such meteors is very small, and it is, therefore, practically impossible to obtain satisfactory statistics. Nevertheless, a way out of this situation is provided by observations near the horizon.

On the one hand, meteors observed there are very far, and consequently they are very bright in absolute magnitude, and, on the other hand, the area of the atmospheric meteor layer in the same field of view is tens of times larger than in the zenith area, so even a small density in the stream allows us to record such meteor numbers that are sufficiently high for statistical processing.

For such observations, we made special frames to choose a given region near the horizon, and the meteors were observed through these frames. Rigid restrictions were put on the dimensions of these frames, however. On the one hand, the observations must be conducted at a zenithal distance as large as possible to obtain the distribution for very bright meteors. On the other hand, the difference in absorption between the lower and upper edges of the frame must not exceed the mean error in the estimation of meteor magnitudes (about one magnitude). That gave a restriction of the maximum difference of zenithal distances between the lower and upper edges of frame. In other words, for a given zenith angle $Z$ of the frame center, there is a maximum value for the difference $Z_1 - Z_2$ that should not be exceeded since, otherwise, the correction to reduce visual magnitudes to zenithal ones will differ between the lower and upper edges of the frame by more than one magnitude, which is unacceptable. As, at large zenith angles, the correction grows very quickly, the frame must be as narrow as possible. As a result, the area of the meteor layer in the atmosphere available for observing decreases, and will not provide us with reliable statistics of bright meteors either. Additionally, observations at very large zenith angles are undesirable also for the strong influence from the lower layer of the atmosphere filled with dust and not having constant characteristics. All these factors have in turn a strong influence on the reduction of the visible magnitude to the zenith, and the correction for such a reduction becomes uncertain.

Therefore, we adopted the following compromise: the lower edge of the frame was installed at a zenithal distance of 85° and the upper one at 70°, whence $Z_1 - Z_2 = 15°$. The extent of the frame along the azimuth was chosen to be the same as in a standard restricted-field observation in the zenith, that is 60°. The observer sits on the chair at a distance of two meters from the frame which is arranged such as to cover a celestial area of 60° in azimuth and 15° in elevation. The center of the frame was directed at a point with an azimuth of 60°. The observations were conducted by a group of three observers and one secretary. Each frame was individual and arranged parallel to the others, the distance between their centers being about two meters.

Obviously, the comparison of the results obtained by all three programs is possible only after the reduction of the apparent stellar magnitudes to zenithal ones. We used the following algorithm: If $m$ is the absolute magnitude, $m_0$ is the apparent magnitude, $r$ is the distance to the meteor (km), and $Z$ is the zenith angle, then the absolute magnitude can be determined from the expression:

$$m = m_0 + 10 - 5\log r - \frac{\chi}{\cos Z} \tag{3}$$

The last term here gives the correction due to atmospheric light absorption. The value of $\chi$ is usually taken equal to 0.2. Therefore, for the calculation of the absolute magnitude, it is necessary to know the zenith angle of the meteor and the distance to it. Taking into account the spherical character of the Earth, the distance to the meteor is determined as follows [2]:

$$r(Z) = \sqrt{R'^2 - R^2 \sin^2 Z} - R\cos Z, \tag{4}$$

where $R$ is the radius of the Earth, $R' = R + h$ ($h$ is the altitude of the meteor above the Earth's surface), and $Z$ is the zenith angle of the meteor. Thus, having the radius of the Earth $R$ and the altitude of the meteor zone $h$, we can find the distance to the meteor $r(Z)$ from the zenith angle and, finally, from formula (3), we can determine the absolute magnitude.

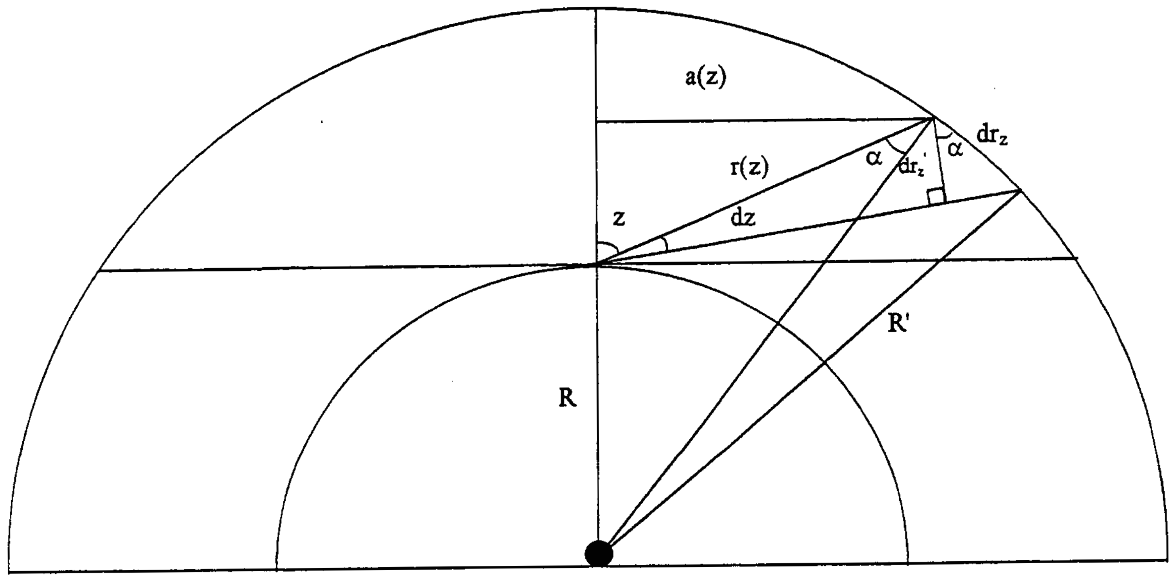


Figure 1 – Looking at an element $dS$ of the area of the meteor zone.

Calculations made with $R = 6370$ km, $h = 120$ km, and $\chi = 0.2$ showed that the mean value of the correction to zenithal magnitudes for the area of the frame is five magnitudes [3]. The range of apparent magnitudes remains the same as in the zenith (from −3 to +4), and it corresponds to a range of zenithal magnitudes from −8 to −1. Thus, the investigation of data obtained with all three programs combined leads to a luminosity function in the range of absolute magnitudes from −8 to +9.

According to the equations of the simplest physical theory of meteors, a Leonid meteor ($V =$ 72 km/s) of magnitude +9 corresponds to a mass of $M = 3 \times 10^{-5}$ g, and a fireball of magnitude −8 corresponds to a mass of $M = 15$ g. Hence, the observations with the three programs provide us with a luminosity function in a range where masses differ by five orders of magnitude (more exactly by $5 \times 10^5$ times).

## 2. The determination of the meteor collection area

The determination of the area of the meteor zone restricted by a frame is very important for the calculation of the meteoroid stream density. In the case of observations near the zenith, where the zenithal distance of the observed region does not exceed 30°, the curvature of the Earth is negligible, and then we can determine the area $S$ of the meteor zone from the geometrical relation:

$$S = \pi H^2 \operatorname{tg}^2 \frac{\alpha}{2}, \tag{5}$$

where $H$ is the altitude of the meteor zone and $\alpha$ is the angular dimension of the field of view. However, if a region far from the zenith is observed, then this approximation becomes unacceptable, and the problem should be solved in a general from.

Let us consider one element of the area of the meteor zone $dS$ (Figure 1) which is located at an arbitrary zenith angle $Z$. The value $dS$ can be determined by the formula

$$dS = dr_Z dr_A, \tag{6}$$

where $dr_Z$ and $dr_A$ are the dimensions of the infinitesimal piece of zenith angle and azimuth, respectively. From Figure 1, it is easy to see that

$$dr_Z = \frac{dr_Z{}'}{\cos\alpha} = \frac{r(Z)dZ}{\cos\alpha}, \tag{7}$$

where $r_Z$ is the distance of the element in the meteor zone, that is at the zenith angle $Z$. The value can be found using the cosine theorem:

$$\cos\alpha = \frac{r^2(Z) + R'^2 - R^2}{2r(Z)R'}. \tag{8}$$

The value of $dr_A$ is determined from the ratio

$$dr_A = a(Z)dA, \tag{9}$$

and, since $a(Z) = r(Z)\sin Z$,

$$dr_A = r(Z)\sin ZdA. \tag{10}$$

Substituting (9) and (7) into (6), and taking (8) into account, we obtain a final expression for $dS$:

$$dS = \frac{2r^3(Z)R'\sin Z}{r^2(Z) + R'^2 - R^2}dZdA. \tag{11}$$

Now the area of a "rectangular" section of the meteor zone which extends from $Z_1$ to $Z_2$ in zenith angle and from $A_1$ to $A_2$ in azimuth will be defined by the expression:

$$S = \int_{A_1}^{A_2}\int_{Z_1}^{Z_2} \frac{2r^3(Z)R'\sin Z}{r^2(Z) + R'^2 - R^2}dZdA. \tag{12}$$

This expression is correct for any zenith angle of the celestial sphere. Integral (12) cannot be evaluated by elementary functions, and we used numerical integration to calculate the area.

## 3. Reduction of the observations

Several methods for the reduction of restricted-field observations exist. Almost all these methods are based on the fact that the group coefficient of perception $p$ is connected with the individual coefficient $p_i$ by the relation:

$$p = 1 - (1 - p_1)(1 - p_2)\ldots(1 - p_k) = 1 - \prod_{i=1}^{k}(1 - p_i), \tag{13}$$

where $k$ is the number of observers in the group. Thus, the total number of meteors is determined by the formula

$$N = \frac{S}{p} = \frac{S}{1 - \prod\limits_{i=1}^{k}(1 - p_i)}, \tag{14}$$

were $S$ is the number of physically different meteors that were seen by the entire group. Then, a method for estimating the perception coefficients is needed. We used the method which Zotkin proposed in 1962 [4]: $p_i = n_i/N$, where $n_i$ is the number of meteors observed by observer $i$. Inserting this value into (14), we obtain

$$S = N\left[1 - \prod_{i=1}^{k}(1 - \frac{n_i}{N})\right] \tag{15}$$

and hence

$$S = N - \frac{1}{N^{k-1}}\prod_{i=1}^{k}(N - n_i)$$

or

$$(N - S)N^{k-1} = (N - n_1)(N - n_2)\dots(N - n_k). \tag{16}$$

This expression is an equation of extent $k - 1$ with respect to $N$. For our case, $k = 3$ and (16) becomes the quadratic equation

$$(n_1 + n_2 + n_3 - S)N^2 - (n_1n_2 + n_1n_3 + n_2n_3)N + n_1n_2n_3 = 0. \tag{17}$$

In order to use this method, it is necessary to obtain the distribution of meteors versus magnitudes for each observer, as well as the total for the group. The logarithm of the meteor number for a given magnitude is often used to develop the luminosity function obtained from observations with different programs, and, as the collection area for each group was—naturally—different, the application of $\log N$ has no meaning. We used the density of the meteoroid stream $\Phi(m)$ to obtain the luminosity function. The value $\Phi(m)$ is determined by the formula [4]

$$\Phi(m) = \frac{N(m)}{ST\cos\alpha}, \tag{18}$$

where $N(m)$ is the total number of meteors for a given magnitude, $S$ is the area in which meteors are registered and $\alpha$ is the angle between the normal to the registration area and the direction of flight of the meteoroid. The correction $\cos\alpha$ is sufficient if the dependence of the absolute magnitude of the meteor on the angle of its entrance into the atmosphere is neglected. In the case of observations with field center in the zenith, the angle $\alpha$ coincides with the zenith distance of the radiant, and the situation corresponds to the approximation of a flat Earth. For the determination of this angle in the general case when observations are conducted in a field with center at a zenith angle $Z$, it is necessary to determine the angle $\beta$ (see Figure 2). Applying the cosine theorem to the triangle with sides $R$, $R'$ and $r(Z)$, we obtain an expression for $\beta$:

$$\cos\beta = \frac{R^2 + R'^2 - r^2(Z)}{2RR'}. \tag{19}$$

Then the angle $\alpha$ is determined by the equation

$$\alpha = Z_\mathrm{R} - \beta, \tag{20}$$

where $Z_\mathrm{R}$ is the zenith angle of the radiant.

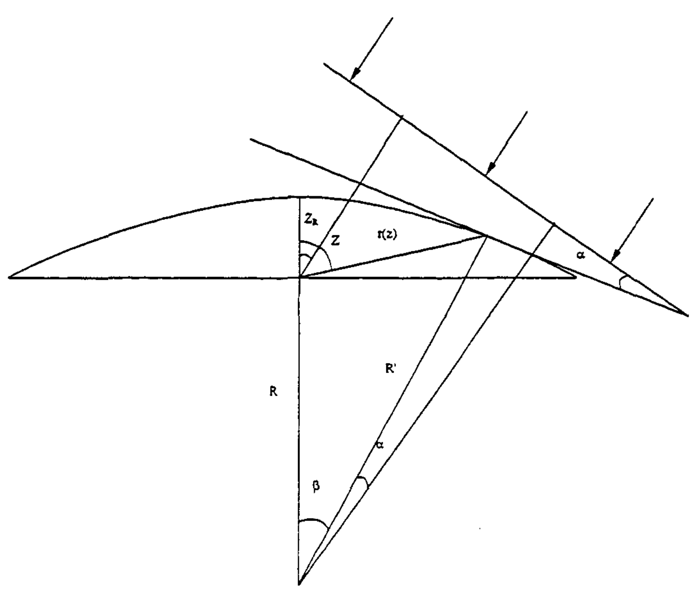


Figure 2 - Determining the angle $\beta$

The density of the meteoroid flux $\Phi(m)$ determined in this way only depends on the absolute magnitude for which it is defined. Instead of the density of the meteoroid flux, one might also use the spatial density $\rho(m)$ of the stream which is connected with $\Phi(m)$ by the linear dependence $\Phi(m) = \rho(m)V$, where $V$ is the geocentric velocity of the meteoroids. This does not reflect on the value of the luminosity function exponent.

If we set the height of meteor appearance to $h = 120$ km for the Leonids, we can calculate the area from which meteors are registered with regard of the Earth's curvature: for frames at low elevation, 261 000 km$^2$, for circles in the zenith, 14 400 km$^2$, and for telescopic meteors, 124 km$^2$.

It is easy to see that the area of registration for the groups with low frames is almost 18 times larger than for the groups with circular frames, which permits to obtain meaningful statistics for bright meteors which have a small density in the stream.

## 4. Observations

Observational material was obtained during one night, November 17-18, 1999. The observations were carried out in the Southern Laboratory of Sternberg State Astronomical Institute (Moscow) in the Crimea.

The clouds have dispersed near midnight UT. The group with circular frames conducted observations from $0^h30^m$ to $3^h30^m$ UT, the group carrying out telescopic observations also from $0^h30^m$ to $3^h30^m$ UT, and the group with rectangular frames from $1^h35^m$ to $3^h15^m$ UT. During this time, they registered 1748, 59, and 1703 meteors, respectively. Already in the beginning of the observations, the activity of the Leonids was so high that observers were forced to record fewer meteor parameters. Hourly rates increased very quickly, and soon we were forced to restrict ourselves to recording the stellar magnitude only. At around $2^h$ UT, the group which conducted simple counts of meteors in an unlimited area of the sky passed on to simple counts per minute. This was done for 15 minutes. The shower reached its peak of activity around $2^h05^m$ UT, and meteor numbers were 120 per minute at that time.

## 5. Analysis of the observational data

The distribution of meteors versus apparent magnitude was derived for each group, and the total number of meteors seen by each observer was found using the method of Zotkin. Then, using formula (18), we determined the density of the meteoroid flux, and, with these values, we developed the general luminosity function shown in Figure 3.

The data of all three groups are presented there. The luminosity function for meteors of magnitudes from $-8$ to $-1$ is obtained from the data of the group which conducted observations through rectangular frames; that for meteors of magnitudes from 0 to $+4$ is obtained from the data of the group which conducted observations with circular frames; and that for meteors of magnitudes from $+5$ to $+9$ on the basis of the data of the "telescopic" group. All three luminosity functions coincide very well at the junctions. It shows that the method of processing is correct and gives a true value for the number of faint meteors.

It is easy to see that $\log \Phi(m)$ does not change linearly with magnitude, as it is usually presumed, but in a more complicated way. The exponent of the luminosity function has a maximum value for bright meteors, and gradually decreases for fainter ones. A linear approximation of the luminosity function is possible only for a small interval of magnitudes, but the whole luminosity function obtained cannot be described as a simple linear dependence.

The mean values of the function exponent $\kappa$ for the three groups is given in Table 1.

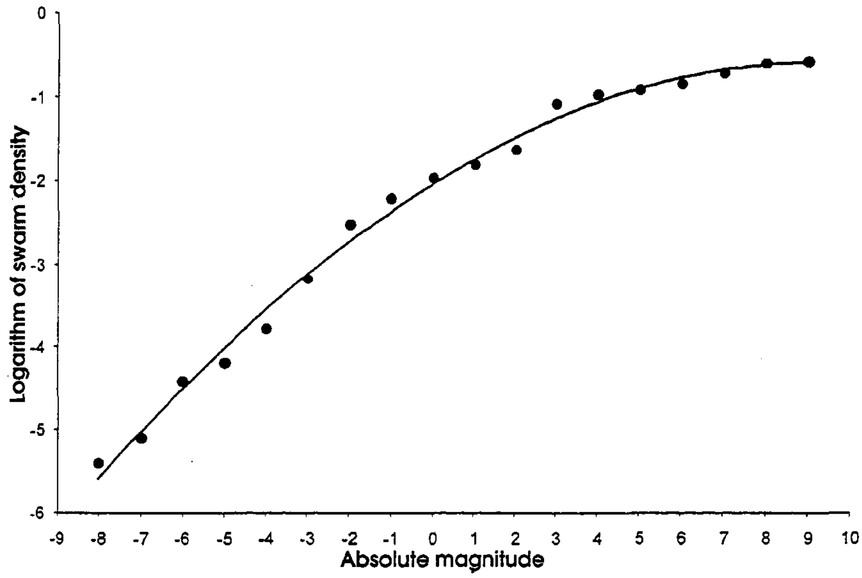


Figure 3 – The luminosity function

Table 1 – Population index for three groups of observing fields.

| Program | Absolute Magnitude | Pre-atmospheric mass | Population index |
|---|---|---|---|
| Frames | −8 to −1 | 14.8 g to 0.02 g | 2.8 |
| Circles | −1 to +4 | 0.02 g to $3 \times 10^{-3}$ g | 1.6 |
| Telemeteors | +4 to +9 | $3 \times 10^{-3}$ g to $3 \times 10^{-5}$ g | 1.3 |

The luminosity function is well approximated by the following polynomial:

$$\log \Phi(m) = -0.051m^2 + 0.3168m - 2.1666, \qquad (21)$$

where $m$ is the absolute magnitude and $\Phi(m)$ is the flux density in the stream expressed in $\mathrm{km^{-2}h^{-1}}$. Using the derivative of (21) and equating it to zero, we find that the luminosity function reaches its maximum near magnitude +10. This fact is especially interesting, because the saturation of the luminosity function at that point suggests that meteors fainter than magnitude +10 (or particles with masses smaller than $10^{-5}$ g) are simply absent in the stream. Probably, those and even smaller particles were thrown out of the stream by solar radiation pressure. Large geocentric velocities of Leonids lead to the fact that even very small particles produce meteors which can be seen visually. This fact allows us to approach the limiting mass closely.

Large statistics provide the possibility to study thin structures in the change of meteor stream density. The whole observing period was divided into ten-minute intervals, and every such span was processed independently. This way, we obtained the profiles for the evolution of the exponent of the luminosity function and the space density of the stream.

The variation in the population index $\kappa$ is shown in Figure 4. From this profile, it is clear that, in the observing time interval near the maximum, no regular change of this exponent is observed. Most likely, it means that the stream includes separated dust clouds that correspond to different ejections from the cometary nucleus. The distribution of particles versus mass in each cloud is different from another, and this is reflected in the profile. It is interesting that the amplitude of the fluctuations of $\kappa$ is substantially larger for bright meteors than for usual ones. And this result cannot be explained by poor statistics for bright meteors, since the observations were conducted near the horizon covering a very large area of collection, and all the points of the graph have good statistical significance, whereas variations of $\kappa$ exceed the error margins.

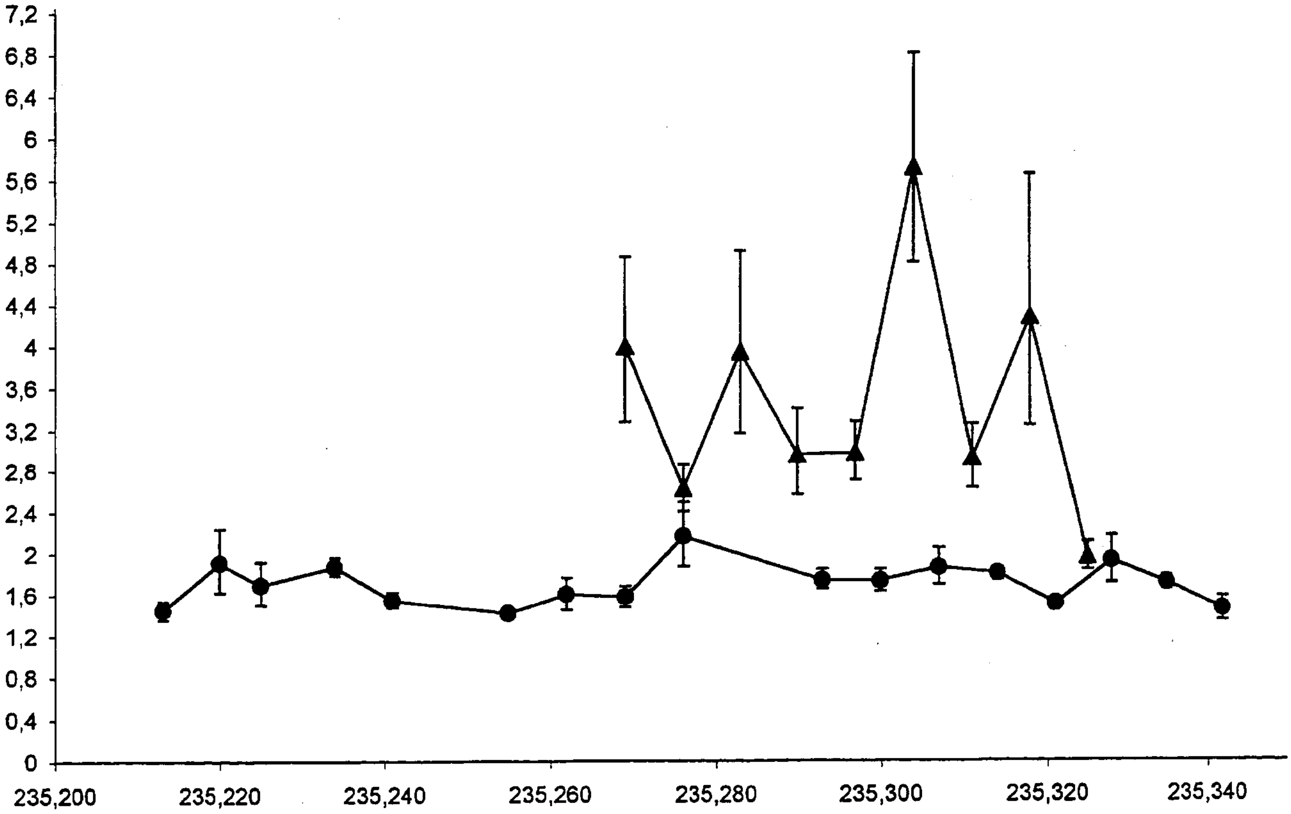


Figure 4 – Variation in the population index $\kappa$.

The profile of the variation of the stream density for bright meteors (i.e., brighter than magnitude −1) is shown in Figure 5.

Figure 6 presents the variation of the stream density for particles producing meteors near magnitude +4.

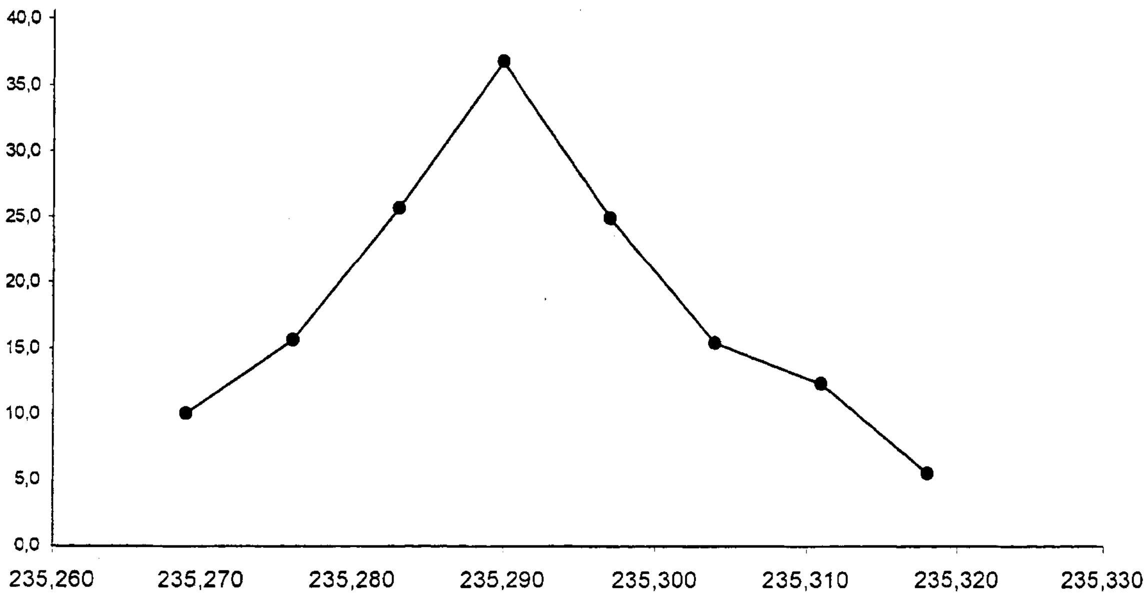


Figure 5 – Profile of the variation of the stream density for meteors brighter than magnitude −1.

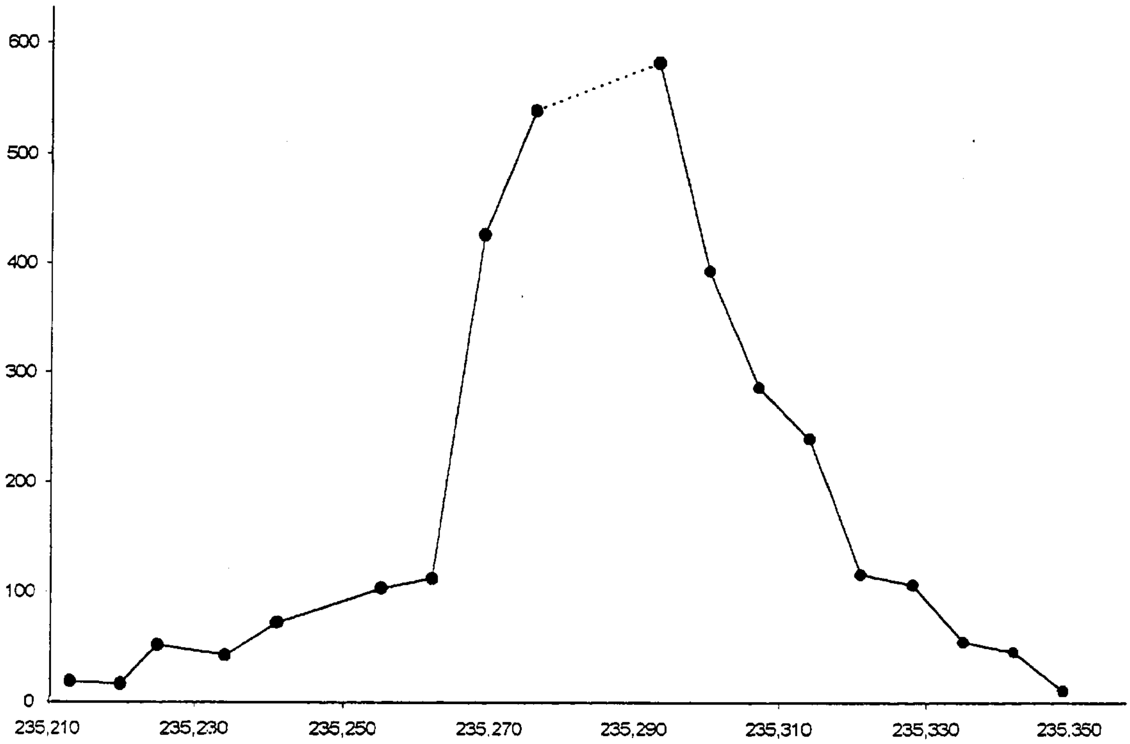


Figure 6 – Profile of the variation of the stream density for meteors near magnitude +4.

One can see that the maximum is sharp enough, and the change of activity before and after the maximum is the same and almost linear. It is necessary to note the fast increase of the spatial density: during half an hour only, it increased by more than six times for faint meteors, and by three times for bright ones. During this time, the Earth traveled the distance $S = VT$ along its orbit and approached the cometary orbit to a distance of $R = VT \sin\varepsilon \approx 17\,000$ km, where $\varepsilon$ is the elongation of the radiant from the apex. Thus, the boundary of the dense portion of the stream turns out to be very sharp, and it underwent little dispersion in ejection velocities from the cometary nucleus. The fact that the peak of activity at different returns was not always so long in time [5], although the Earth passed at different distances from the cometary orbit, favors the assumption that the stream has a flat shape, with a considerable extent within the orbital plane, and a thickness of some tens of thousands of kilometers only.

## 6. Conclusions

1. Observations of the 1999 Leonids showed that maximum activity was considerably (about 30 times) inferior to the shower of 1966, and the ZHR climbed up to about 4500. In this respect, the shower of 1999 resembles the return of the Leonids in 1866 (7200 meteors per hour).
2. The luminosity function of the Leonids over the large interval of magnitudes studied here cannot be approximated by a straight line but can be well approximated by a parabola.
3. The values of $\kappa$ for rectangular frames, circular frames, and telescopic meteors were found to be 2.8, 1.6, and 1.3, respectively.
4. The profile of $\Phi(m)$ reaches its maximum value around magnitude +10, corresponding to a mass of $10^{-5}$ g. This means that particles with masses smaller than $10^{-5}$ g are absent in the stream. This results probably from solar radiation pressure which has a considerable effect on such particles.
5. The mean distance between particles producing meteors of magnitude +9 (corresponding to a mass of $3 \times 10^{-5}$ g) was found to be about 170 km; for meteors of magnitude 0, it was found to be 273 km; and for meteors of magnitude −8, it was found to be about 4150 km.

### Acknowledgments

The authors express their thanks to the Director of the Southern Laboratory of the P.K. Sternberg State Astronomical Institute, Dr. E.A. Kolotilov, for offering the opportunity to conduct the observations. We also thank the members of the observing group of the Simferopol Amateur Astronomers Society who took part in the observations. We are most grateful to V.M. Mozhzherin for the very useful discussions and valuable comments.

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## 2000 Ursids

# Possible Ursid Outburst on December 22, 2000

*Peter Jenniskens, SETI Inst./NASA Ames Res. Ctr, and Esko Lyytinen*

The Ursid shower has broad Filament-type outbursts around the perihelion passage of parent 8P/Tuttle, but also isolated narrow outbursts at aphelion. We calculated Tuttle's dust trail encounters in the same way as for the Leonid showers. We discovered that it takes 6 centuries to change the orbit enough to bring the meteoroids to Earth's orbit. During that time, the meteoroids and comet separate in mean anomaly by about 6 years, explaining the unusual aphelion occurrences. Our study predicts enhanced activity on December 22, 2000, at around $7^h29^m$ UT.

### 1. Introduction

During a cold winter night in December of 1986, Norwegian observers Kai Gaarder and Lars Trygve-Heen saw a spectacular outpour of Ursid meteors over a period of 3 hours [1]. A similar outburst had been reported by visual observers at Skalnaté Pleso Observatory in 1945 [2,3]. These Ursid outbursts are very unusual, because they occur when the parent comet 8P/Tuttle is near aphelion. The comet's orbital period is around 13.6 years. At the time of this writing, in early December 2000, it is only a few months before the comet will reach aphelion again.

### 2. Ursid Filament

Let us first examine other recent Ursid showers to show the unusual aspects of these aphelion outbursts. The annual shower component has a maximum ZHR of 8. On top of that, there are frequent outbursts when the comet is near perihelion (Figure 1). In 1994, the comet passed 0.061 AU outside of the Earth's orbit. In December 1993, Bob Lunsford observed the ascending branch of an outburst from Mt. Laguna, California, to a maximum ZHR of 100 ($r = 2.5$). Japanese observer H. Shioi observed the peak in 1994 [4], from which we derive a maximum ZHR of 50 ($r = 2.6$). In 1996, rates were still elevated with maximum ZHRs of the order of 25 [5], and, in 1997, ZHRs were of the order of 16.

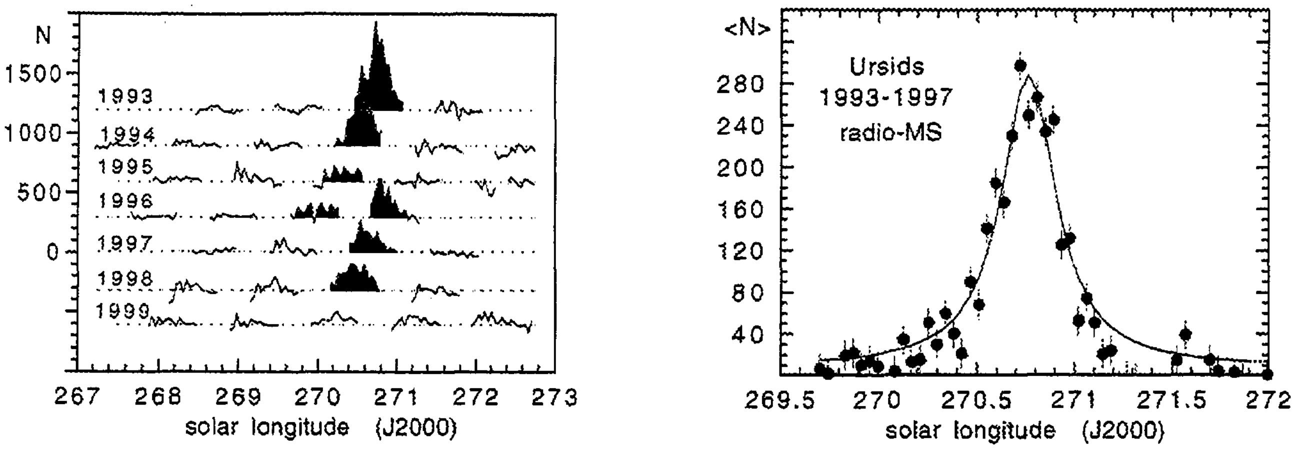


Figure 1 – *Left*: Ursid Filament as observed around perihelion passage of Comet 8P/Tuttle (1994) by forward meteor scatter. Counts ($N$) are raw reflections after subtraction of daily background. Data are from I. Yrjölä/*Global-MS-Net*. *Right*: Mean activity profile after correction for observability.

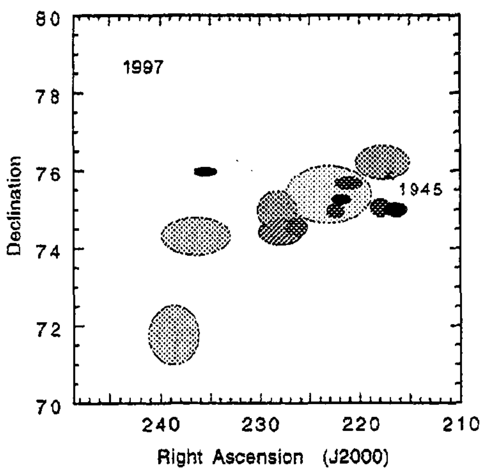


Figure 2 – 1997 Ursid radiants.

Similar outbursts were observed during the previous return of the comet, by Japanese observers in 1981 [6] and by Jos Nijland and Hans Breukers of the *Dutch Meteor Society* in 1982, who observed the descending branch starting at a ZHR of about 35. These perihelion outbursts occurred at a significantly different point in the orbit than the 1986 outburst, about 6 hours earlier, and were significantly wider. We have $B = 2.5 \pm 0.5$ [1] or a Lorentz curve width of $W = 0.^{\circ}35 \pm 0.^{\circ}05$. In 1997, we obtained 13 outburst Ursid orbits from two-station video observations in California (Table 1). These show significant scatter of radiants with a wide range in right ascension, more than in declination, even without 3 possible outliers (Figure 2, Table 1).

Table 1 – Ursid orbits (J2000) from the 1945 outburst [3—recalculated] and as observed from California during the 1997 Ursid outburst (P. Jenniskens and M. Koop; calculations M. de Lignie).

| Year | 1945<br>3 single station<br>(aphelion outburst) | 1997<br>median of 10 orbits<br>(perihelion outburst) |
|---|---|---|
| Date | Dec 22.773 ± 0.051 | Dec 22.434 ± 0.057 |
| $\alpha_{geo}$ | $217.^{\circ}06 \pm 0.^{\circ}07$ | $222.^{\circ}1 \pm 4.^{\circ}2$ |
| $\delta_{geo}$ | $+75.^{\circ}63 \pm 0.^{\circ}05$ | $+75.^{\circ}0 \pm 0.^{\circ}5$ |
| $V_{geo}$ | 33.47 km/s (assumed) | 32.25 km/s ± 0.87 km/s |
| $a$ | 5.716 AU (assumed) | 4.62 AU ± 0.93 AU |
| $e$ | 0.8363 ± 0.0015 | 0.795 ± 0.040 |
| $q$ | 0.9357 AU ± 0.0002 AU | 0.944 AU ± 0.006 AU |
| $i$ | $53.^{\circ}10 \pm 0.^{\circ}03$ | $51.^{\circ}5 \pm 1.^{\circ}1$ |
| $\omega$ | $206.^{\circ}73 \pm 0.^{\circ}04$ | $204.^{\circ}9 \pm 2.^{\circ}0$ |
| $\Omega$ | $271.^{\circ}35 \pm 0.^{\circ}05$ | $270.^{\circ}64 \pm 0.^{\circ}06$ |

## 3. Outbursts at aphelion

Even though the Ursid shower was among many other minor showers observed earlier visually by William F. Denning and Cuno Hoffmeister, and Denning even correctly associated the shower with Comet 8P/Tuttle, it was the unusual outburst of 1945, observed by four observers at Skalnaté Pleso Observatory and reported by Antonin Becvár [2], that put the shower on the map. A young Zdenek Ceplecha calculated the orbit from the pinpoint radiant derived from three single-station photographed Ursids and an assumed orbital period of the comet [3]. Ceplecha (*personal correspondence*) recalls: *"It was a horrible amount of computations at that time. It was done by means of a mechanical computer with a handle, called 'Odner.' Nine decimal digits were kept in the calculations!"* This result established the comet association. On request, Ceplecha checked the calculations with his then current 486 PC (Table 1) and found the results still completely valid.

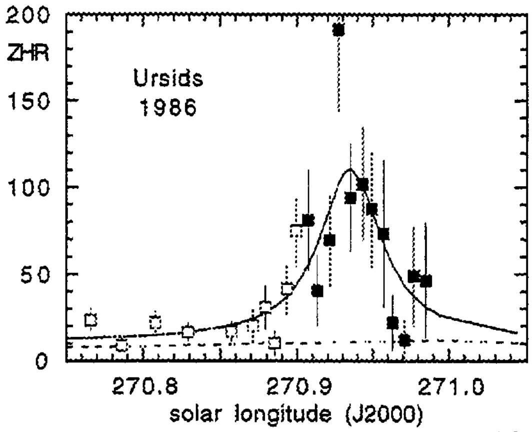

Figure 3 – 1986 Ursid outburst ZHR curve [1].

One remarkable feature of this outburst, as well as of the more recent 1986 observations by Gaarder and Trygve-Heen (shown in Figure 3), is that the shower stood alone. There was no outburst in 1946 [3] and no sign of an outburst in radio-MS data in 1987 [7]. Moreover, the stream is a factor of 6 narrower, with $B = 17 \pm 3$ rather than $B = 2.5$ or a Lorentz width of $W = 0\overset{\circ}{.}05 \pm 0\overset{\circ}{.}01$.

Note the difference in scale in Figures 1, *right*, and Figure 3. Also, the magnitude distribution index may have been slightly steeper. From Kai Gaarder's magnitude estimates, we have $r = 2.8$ [1,7].

## 4. Model calculations for aphelion outburst

We submit that the broad 1981–1982 and 1993–1997 perihelion outbursts are probably due to the accumulation of dust from multiple debris trails, with dust in orbital resonances, forming a structure much like the Leonid and Perseid Filaments of other Halley-type comets. This accumulation may have occurred over a relatively long period of time.

Given the much more narrow width of the aphelion outbursts, on the other hand, it is not unreasonable to argue that the material responsible for the 1986 outburst is not very old, and can probably be traced back to a single dust trailet. Similarly, the 1945 outburst might well be identified with a single dust trailet. That has the exciting prospect of predicting possible Ursid outbursts in December of 2000 and beyond, analog to recent predictions of Leonid returns [8,9].

Comet 8P/Tuttle has an orbit outside of Earth's orbit. For a meteoroid to hit Earth, the particle's perihelion distance ($q$) has to move inward to the Sun. As before, we calculated the orbital evolution of dust trails ejected over the past 800 years ending up in orbital resonances close to that of the comet. The comet currently librates around the "high" 13:15 mean motion resonance with Jupiter. A big number of the particles will get into slightly longer orbital periods and end up trapped in the mean motion resonance 12:14 (or 6:7). Because it takes the particles longer to travel around the Sun, they will gradually move away from the comet. If, at these resonances, the librations are small, meaning that the particles will keep near the center of the "window," then there will be a systematic decrease of $q$ more rapidly than for the comet itself. Near the leading edge of the resonance, the particles may have close encounters with Jupiter that will increase the perihelion distance instead.

We find that it takes about 6 centuries for dust to move close to Earth's orbit. During that time, the separation of the particles and comet in mean anomaly, as a result of the difference in orbital period, increases to $13/15 \times 14/12 \times 600$ years $= 606.67$ years.

This is a natural explanation of why the 1986 and 1945 outbursts occurred about 6 years after the comet's closest encounter with Earth's orbit, or near aphelion. We also find that the resonances effectively confine the dust to a single-year return, thus explaining the lone nature of the outbursts (Figure 4).

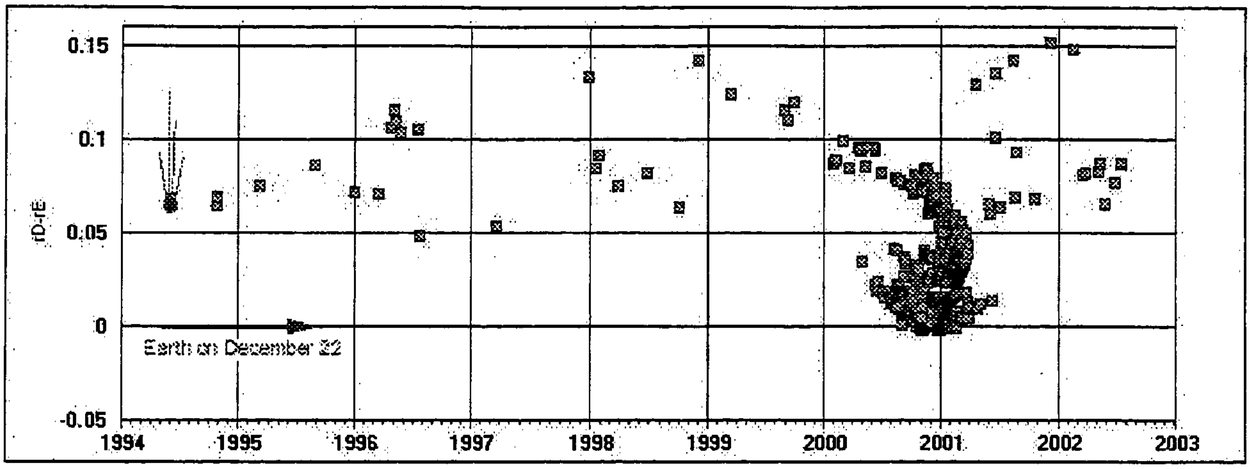


Figure 4 – Relative positions of particles from the 1365, 1378, 1392, and 1405 returns of Comet 8P/Tuttle at the time of ecliptic plane crossing. Resonances effectively confine the dust to a narrow stream seen only in December 2000, 6 years after the comet's ecliptic plane crossing.

Inspecting the historic variations of the perihelion distance $q$ of the parent comet, we find maybe a dozen returns that could have resulted in a dust trail close to Earth's orbit at the present time. We examined a number of those trails to identify the ones likely to cause an outburst. Of course, many trails from encounters further back in time may contribute as well, but those should be less significant.

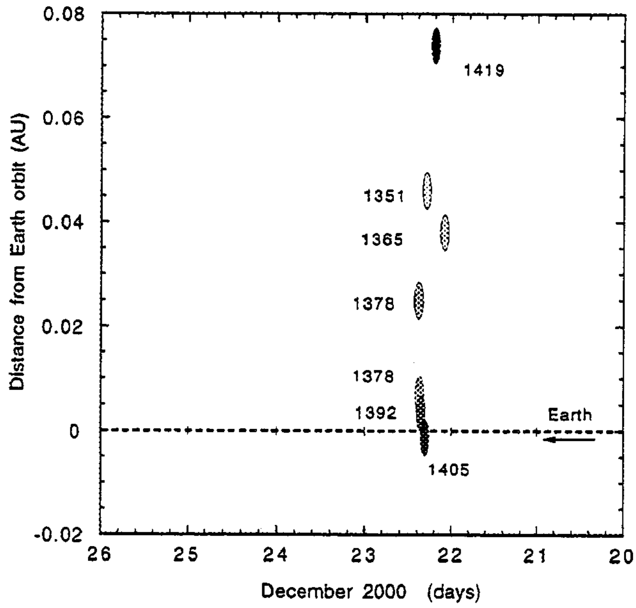


Figure 5 – Detail of Figure 4. Position of trails relative to the Earth's path (dashed line) in December 2000. The size of the ellipses is twice the full-width-at-half maximum as measured in Section 3.

We find that a trail from dust ejected 44 revolutions back in the year 1378 is the likely source of the 1986 outburst. The trail comes close to the Earth's orbit and the timing is to within 0°01 from the observed value. The same trail is near Earth's orbit as well in December of 2000, when the encounter occurs at solar longitude (B1950) $\lambda_\odot = 270°12$, but at a distance of +0.0069 (and at 0.025) AU.

The dust from 1392 can account for the 1945 outburst, when the miss distance was less than 0.001 AU. This trail can perhaps produce a meteor outburst in December 2000 at solar longitude (B1950) $\lambda_\odot = 270\overset{\circ}{.}105$. However, the miss distance ($r_D - r_E$) is again relatively large, at +0.0035 AU (Figure 5).

Rather, it is the next 45-revolutions trail (to this year) of 1405 that is a prime candidate for an outburst in December 2000. It has a small $r_D - r_E = -0.0013$ AU at solar longitude (B1950) $\lambda_\odot = 270\overset{\circ}{.}056$. This miss distance was confirmed in a more densely populated model.

Finally, we notice that the particles from many returns accumulate in the same 6:7 resonance "window." This process is perhaps responsible for the Ursid Filament.

## 5. Discussion: prospects for the 2000 encounter

The solar longitude of the 1405 trailet passage in December 2000 corresponds to $7^h29^m$ UT. From recent Leonid observations, we measured a trail that is wider by a factor of 4 in the plane of the comet orbit [10]. That puts the Earth smack in the trail (Figure 5). The particles of this trail are expected to be smaller than during past outbursts in 1945 and 1986, perhaps rather near the visual detection limit under good observing conditions. If the width is just a bit wider, the trailet of 1392 may show up at $8^h38^m$ UT. If so, these events probably make a continuous profile 4–5 hours wide, but can perhaps be recognized separately. Both events favor northern hemisphere observers in the Americas. The Moon is out of the way providing for generally good observing conditions.

The expected intensity of the shower is hard to predict. Both the historic 1945 and 1986 encounters had miss distances smaller than 0.001 AU, but the dust densities in the trail according to the mean anomaly factor seem to be smaller than in this year. In other words, the time difference between the 1994 comet passage and this year's Ursid shower is closer to the ideal 6.67 years. Interestingly, the 1405 trailet piece actually seems to "start" only one day after the Earth encounter in 2000, where there is a turning point. At that point, the mean anomaly factor is locally quite high. We expect the A2 effect to smoothen this, so that dust is probably present during the December 22 encounter, but that, of course, will also lessen the density somewhat.

The 1378 dust (at $8^h59^m$ UT) should not be ignored. There is some uncertainty in the 1378 trailet position, because the A2 effect has not been studied. This trail shows a relatively rapid increase of $r_D$ towards the end of this year. There seems to be quite a lot of these resonant particles present. Since there are particles around the $r_E$ only about a month or two earlier, it may even be that the A2 effect will help bring those near the Earth at the correct radii, if not otherwise.

## Acknowledgments

We thank Ilkka Yrjölä for contributing his radio-MS observations to this work. We thank Mike Koop and other observers of the *California Meteor Society* for support of the 1994 and 1997 Ursid campaigns. We thank Marc de Lignie of the *Dutch Meteor Society* for calculating the Ursid orbits from multi-station video records, using software developed by Zdenek Ceplecha. Part of this work was supported by NASA's Planetary Atmospheres program.

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*At the time of this editing, it is still too early to make definitive statements about the 2000 Ursid activity. Some observations seem to confirm the predictions above, while some others do not. Poor weather in many places may have contributed to this somewhat confusing picture. We hope to be able to report a clearer picture in the February issue.* (Ed.)

# Ongoing Meteor Work

# 1996–1998 Polish Telescopic Meteor Database

*Arkadiusz Olech and Michał Jurek, Warsaw University Observatory*

A summary of 1996–1998 telescopic observations collected by the *Comets and Meteors Workshop* is presented. In total, 1074 meteors were seen during 171.91 effective observing hours by 15 observers. The date, time of appearance, magnitude, angular velocity, and equatorial coordinates for each observed event is given. The full 1996–1998 *Polish Telescopic Meteor Database* (*PTMDB*) is accessible via internet.

## 1. Introduction

Since its foundation in 1988, the *International Meteor Organization* (*IMO*) unites meteor enthusiasts world-wide, both amateurs and professionals, and collects observational material obtained by all kind of techniques, such as visual, photographic, telescopic, radio, and video observing. Each year, the *IMO* publishes a volume of the *WGN Observational Report Series* containing the visual data (e.g., [1–3]). Up to now, the full *Visual Meteor Database* (*VMDB*) of the *IMO* contains 79 230 hours of effective observing time with 1 544 414 meteors observed in the period 1984–1998. (*The 1999 data, just published in volume 12 of the* Observational Report Series, *increase especially this last number significantly, as a consequence of the 1999 Leonid storm.— Ed.*) Unfortunately, the *VMDB* contains only data for hourly rates and magnitude distributions of meteors from the *IMO Working List of Visual Meteor Showers*. The information about the equatorial coordinates and angular velocities of the particular events is not presented. This causes serious problems in at least two aspects. First, wrong classification of a meteor made by an observer is input into the *VMDB* without the possibility of correction. Second, the current format of the *VMDB* makes the detection of new weak showers impossible.

The growing interest in meteor observations in Poland caused a large flow of observational data obtained mainly by visual and telescopic techniques. Polish visual observations are a significant contribution into the annual *VMDB* of the *IMO* (in the period 1997–1999, we were collecting about 2000 hours of observations per year, which is about 20% of all visual data collected world-wide).

Unfortunately, our telescopic data are not available for other investigators, because the *IMO* does not publish telescopic data in the *WGN Observational Report Series*. Thus, we decided to make available our telescopic data to the whole astronomical community. Our database, contrary to the *VMDB* of the *IMO*, contains the information about the time of appearance, magnitude, angular velocity, and equatorial coordinates of all events. The complete 1996–1998 *Polish Telescopic Meteor Database* (*PTMDB*) is available electronically and can be downloaded from the following URL: `http://www.astrouw.edu.pl/~olech/TEL/`. The usefulness of our data was demonstrated in the detection of several weak showers, like the $\alpha$-Cygnids [4,5], Delphinids [6], and $\alpha$-Lyrids [7].

## 2. Observational data

Telescopic observations present a very useful tool for meteor investigators. Meteors are very often plotted with larger accuracy than in the case of visual observations. It gives the possibility to study the structure and drift of the radiant. We also obtain information about the magnitude distribution for fainter events. The main problem with telescopic observations is that this kind of watching meteors requires good equipment (preferably binoculars with a large field of view mounted on a tripod), experienced observers, and a lot of patience because this kind of watching meteors is less comfortable than visual observations.

Each July since 1995, the Polish *Comets and Meteors Workshop* (*CMW*) organizes an Astronomical Camp, which takes place at the Observational Station of the Warsaw University Observatory in Ostrowik. The number of participants is always at least 15, so we organize two 4-person groups observing visually, one or two persons working with several cameras pointing in different directions, and 4–6 persons observing different fields telescopically.

Our telescopic observers mostly use $10 \times 50$, $20 \times 60$, and $7 \times 35$ binoculars and 50-mm Russian refractors AT-1, which are very good for telescopic observations due to their field of view, which is as large as 10°. Thus it is not surprising that the majority of our telescopic data is collected in July, but there are also several reports from other months.

Table 1 summarizes our telescopic work in the period 1996–1998. In total, 1074 meteors were seen during 171.91 effective observing hours by 15 observers.

Table 2 shows the list of the *CMW* observers with their effective observing time and number of meteors seen in each of the years 1996–1998.

Table 1 – *Polish Telescopic Meteor Database* (*PTMDB*) grand totals for 1996–1998.

| Year | Observers | $T_{\rm eff}$ | Meteors |
|---|---|---|---|
| 1996 | 8 | $20^{\rm h}\!.54$ | 95 |
| 1997 | 10 | $38^{\rm h}\!.43$ | 230 |
| 1998 | 8 | $112^{\rm h}\!.94$ | 749 |
| Total | 15 | $171^{\rm h}\!.91$ | 1074 |

Table 2 – Effective observing time ($T_{\rm eff}$) and number of meteors seen ($N$) per observer in 1996–1998.

| Observer | Code | 1996 | | 1997 | | 1998 | | Total | |
|---|---|---|---|---|---|---|---|---|---|
| | | $T_{\rm eff}$ | $N$ | $T_{\rm eff}$ | $N$ | $T_{\rm eff}$ | $N$ | $T_{\rm eff}$ | $N$ |
| | | | | | | | | | $\leq mit$ |
| Konrad Szaruga | SZAKO | $1^h.35$ | 8 | $5^h.64$ | 48 | $52^h.54$ | 269 | 59.53 | 325 |
| Michał Jurek | JURMC | $2^h.27$ | 4 | $3^h.36$ | 14 | $18^h.83$ | 159 | 24.46 | 177 |
| Mariusz Wiśniewski | WISMA | | | | | $16^h.56$ | 174 | $16^h.56$ | 174 |
| Tomasz Dziubiński | DZITO | $9^h.23$ | 4 | $5^h.93$ | 47 | | | $15^h.16$ | 93 |
| Tomasz Fajfer | FAJTO | $3^h.00$ | 18 | $10^h.50$ | 57 | | | $13^h.50$ | 75 |
| Marcin Konopka | KONMA | | | $3^h.25$ | 14 | $10^h.00$ | 48 | $13^h.25$ | 62 |
| Marcin Gajos | GAJMR | $1^h.81$ | 11 | $2^h.70$ | 21 | $4^h.53$ | 30 | $9^h.04$ | 62 |
| Jarosław Dygos | DYGJA | | | $4^h.15$ | 11 | $4^h.86$ | 50 | $9^h.01$ | 61 |
| Paweł Brewczak | BREPA | | | | | $3^h.67$ | 6 | $3^h.67$ | 6 |
| Andrzej Skoczewski | SKOAN | | | $0^h.74$ | 4 | $1^h.95$ | 13 | $2^h.69$ | 17 |
| Łukasz Pospieszny | POSLU | | | $1^h.18$ | 4 | | | $1^h.18$ | 4 |
| Rafał Kopacki | KOPRA | $1^h.00$ | 3 | | | | | $1^h.00$ | 4 |
| Krzysztof Wtorek | WTOKR | $1^h.00$ | 3 | | | | | $1^h.00$ | 4 |
| Maciej Reszelski | RESMA | $0^h.98$ | 10 | | | | | $0^h.98$ | 10 |
| Michał Kopczak | KOPMI | $0^h.88$ | 2 | | | | | $0^h.88$ | 2 |
| Total | | $20^h.54$ | 95 | $38^h.43$ | 230 | $112^h.94$ | 749 | $171^h.91$ | 1074 |

## 3. Coordinate files

The files coor96.txt, coor97.txt, and coor98.txt contain data for each observed meteor such as the date of appearance, the serial number of the meteor, its magnitude, its angular velocity (in scale from $A$ to $F$ with $A$ corresponding to the angular velocity 2°/s and $F$ to over 25°/s), the time of appearance, the equatorial coordinates of beginning and end, the *IMO* code of the observer and the three-letter code. In Table 3, we give a byte-by-byte description of these files; below, we show a small sample of such a file:

```
1998 07 17/18  1  6.5 C 20:47 331.78  60.17 331.33  58.61 JURMC AFD
1998 07 17/18  2  4.0 B 20:51 338.26  56.11 332.60  55.17 JURMC AFD
1998 07 17/18  3  6.0 C 20:54 329.77  60.06 325.14  60.67 JURMC AFD
1998 07 17/18  4  7.0 C 21:07 332.61  58.67 331.89  59.56 JURMC AFD
1998 07 17/18  5  7.0 C 21:30 327.08  56.58 327.80  55.67 JURMC AFD
1998 07 17/18  6  8.0 C 21:33 339.50  57.18 328.50  55.14 JURMC AFD
1998 07 17/18  7  8.0 C 21:43 336.22  58.86 334.17  59.69 JURMC AFD
1998 07 17/18  8  3.5 C 21:45 332.89  57.11 331.90  57.50 JURMC AFD
1998 07 17/18  9  6.5 D 22:13 270.28  52.19 272.57  52.91 JURMC AFI
1998 07 17/18 10  7.0 F 22:16 272.10  53.06 273.32  53.29 JURMC AFI
```

Table 3 – Byte-by-byte description of the coor9?.txt files.

| Bytes | Format | Units | Description |
|---|---|---|---|
| 1– 4 | I4 | | Year |
| 6– 7 | I2 | | Month |
| 9–13 | A5 | | Day/Day |
| 15–16 | I2 | | Serial number of meteor in report |
| 18–21 | F4.1 | | Magnitude of meteor |
| 23 | I1 | | Angular velocity in scale form $A$ to $F$ |
| 25–29 | A5 | | Time (UT) |
| 31–36 | F6.2 | ° | RA of beginning of meteor (J2000) |
| 38–43 | F6.2 | ° | Decl. of beginning of meteor (J2000) |
| 45–50 | F6.2 | ° | RA of end of meteor (J2000) |
| 52–57 | F6.2 | ° | Decl. of end of meteor (J2000) |
| 59–63 | A5 | | *IMO* code of observer |
| 65–67 | A3 | | Three letter-code |

## 4. Date files

The files `date96.txt`, `date97.txt`, and `date98.txt` contain information about each observing run, such as three-letter code allowing to connect each observation with data on meteors presented in the coordinate files, *IMO* code of observer, longitude and latitude of place of observation, date, UT time of begin and end of observation, solar longitude (J2000) of middle time of each run, equatorial coordinates of observed field, effective time of observation, stellar limiting magnitude estimated by the naked eye (if not estimated then 0.00 is input), stellar limiting magnitude in field of view (if not estimated then 00.00 is input), lens diameter of equipment used, its magnification and size of field of view. Below, we show a small sample of such a file:

```
AEZ KONMA 21.4 E 52.1 N 15 07 98 2252 2345 114.232 244 19 0.83 5.64 00.00 60 20 03.7
AFA JURMC 21.4 E 52.1 N 15 07 98 2256 2340 114.231 330 57 0.67 5.80 00.00 50 05 10.0
AFB WISMA 21.4 E 52.1 N 15 07 98 2257 0008 114.241 346 30 1.12 0.00 09.40 50 10 05.0
AFC SZAKO 21.4 E 52.1 N 16 07 98 2126 2140 115.116 289 23 0.22 0.00 09.50 35 07 07.0
AFD JURMC 21.4 E 52.1 N 17 07 98 2035 2145 116.055 332 57 1.00 5.98 00.00 50 05 10.0
AFE SZAKO 21.4 E 52.1 N 17 07 98 2019 2224 116.063 289 22 2.00 0.00 09.25 35 07 07.0
AFF WISMA 21.4 E 52.1 N 17 07 98 2032 2200 116.059 317 12 1.33 0.00 10.00 50 10 05.0
AFG KONMA 21.4 E 52.1 N 17 07 98 2030 2206 116.060 245 46 1.50 0.00 10.30 60 20 03.7
AFH BREPA 21.4 E 52.1 N 17 07 98 2140 2245 116.096 318 30 1.00 0.00 09.00 70 20 04.5
AFI JURMC 21.4 E 52.1 N 17 07 98 2155 2305 116.108 270 54 1.00 6.53 00.00 50 05 10.0
AFJ WISMA 21.4 E 52.1 N 17 07 98 2230 2308 116.120 333 44 0.55 0.00 10.30 50 10 05.0
```

InTable 5, we give a byte-by-byte description of these files.

Table 4 – Byte-by-byte description of `date9?.txt` files.

| Bytes | Format | Units | Description |
|---|---|---|---|
| 1– 3 | A3 | | Three-letter code |
| 5– 9 | A5 | | *IMO* code of observer |
| 11–15 | F5.1 | ° | Longitude of place of observation |
| -17 | A1 | | Hemisphere designation |
| 19–22 | F4.1 | ° | Latitude of place of observation |
| -24 | A1 | | Hemisphere designation |
| 26–27 | I2 | | Day |
| 29–30 | I2 | | Month |
| 32–33 | I2 | | Year |
| 35–38 | I4 | | Time of beginning of observation (UT) |
| 40–43 | I4 | | Time of end of observation (UT) |
| 45–51 | F7.3 | ° | Solar longitude of middle time of observation (J2000) |
| 53–55 | I3 | ° | RA of center of field of view (J2000) |
| 57–59 | I3 | ° | Decl. of center of field of view (J2000) |
| 61–64 | F4.2 | h | Effective time of observation |
| 66–69 | F4.2 | | Limiting magnitude estimated using naked eye |
| 71–75 | F5.2 | | Limiting magnitude estimated in field of view |
| 77–79 | I3 | mm | Lens diameter of equipment used |
| 81–83 | I3 | | Magnification |
| 85–88 | F4.1 | ° | True field of view |

The 1999–2000 data are still under reduction, but they will be available to the astronomical community as soon as possible.

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# The Observation of Lunar Impacts. Part II

*Costantino Sigismondi and Giovanni Imponente*

The frequency and the characteristics of lunar impacting meteorites are reconsidered under the general assumption of belonging to the sporadic meteoroids. We develop the model for evaluating the luminous energy detected in the visual band during the impact. The values obtained are consistent with the luminosity of an Earth's meteor as seen at the Moon's distance, although we recover significantly smaller magnitudes for the lunar impacts with respect to other authors.

## 1. The detection of lunar impacts

Although lunar transient phenomena (LTP) have been observed since several tens of years, it is only recently that they reached the dignity of a scientific problem. Thanks to the effort of some groups of scientists orchestrated by D. Dunham, it was possible to detect unambiguously five flashes onto the night side of the Moon [1] during the 1999 Leonids. The opportunity to detect other impacts out of known active showers has been taken into account in our first paper [2]. Our goal there was to evaluate the possibility to have really observed one of them during the total eclipse of the Moon of January 21, 2000. A similar approach has been followed by Ortiz et al. [3] in order to explain another possible lunar impact observed on July 16, 1999.

The technological possibility to monitor the Moon quite continuously by CCD video cameras down to magnitudes fainter than the visible limit, as well as their detection's quantum efficiency being larger than the classical photo plates, have allowed to attain a rather big number of detected events during the last 12 months. The publishing output at the same period was comparable to the whole activity till then [8]. In this way, one can say that the Moon becomes the best laboratory for studying the meteor showers thanks to its large collecting area with respect to that coverable by a single observer or even by a network of observers and of instruments devoted to that purpose.

Moreover, during a meteor shower, the Moon may be visible from different places with different radiant positions. Thus, the large meteoroid population can be studied without considering the problems of the effect of the radiant position in the sky nor the collecting volume effect due to the brightness of the fireballs that are visible at great distances and at low elevations. The latter case occurred in the fireballs' peak of the 1998 Leonids when it was frequently said that it was easier to look toward the horizon to see more fireballs [4].

Finally, the Moon is sampling a region about 400 000 km apart from the Earth and can intercept the stream in denser regions as happened with the 1999 Leonids. Hence, better knowledge of the structure be achieved by also looking at the dark side of the Moon. In addition, one can study the temporary sodium atmosphere of the Moon during meteor showers [5].

## 2. The relation between kinetic energy and magnitude of a lunar impact

Developing the approach of our first paper [1] we consider the formula giving the amount of radiation, assuming the kinetic energy transforms entirely into radiant energy (luminous efficiency $\eta \approx 1$):

$$W_M = \frac{\sigma T^4 \times A_M}{4\pi\, d^2_{\rm moon}},$$

where $A_M \approx (M/\rho)^{2/3}$ is the area of the incoming meteoroid and $d_{\rm moon} \approx 3.84 \times 10^8$ m is the Earth-Moon average distance.

In our previous work, we assumed an impacting velocity of $v = 41$ km/s, obtained averaging the geocentric velocities of all known meteors showers. Here, we extend to the whole spectrum of velocities, and we recover the behavior of the equation for different values of the mass. Moreover, we take into account that the typical velocity for sporadic meteoroids is 20–30 km/s [3,6,7].

To calculate the visual magnitude, we must take into account that the eye is sensitive in a range of wavelengths between 400 nm–700 nm, with a mean of 550 nm. It implies that its maximum detection efficiency is reached for a temperature of about 5300 K.

The kinetic energy in calories (neglecting the melting heats and assuming the calorimetric equation for liquid water in the whole range of impacting energies) corresponds to an increment of temperature for each gram of matter equal to $\Delta T = v^2 \times 10^6/2 \times 4184$ m s$^{-2}$ K$^{-1}$. Therefore, the temperature depends only on the velocity, here measured in km/s.

Calculating the value of $W_M$ as a function of velocity $v$ and mass $M$, we obtain typical values of

$$W_M \approx 3 \times 10^{-8}\ \mathrm{W/m^2},$$

for a 10 g icy meteoroid impacting at 41 km/s and producing a $\Delta T \approx 2 \times 10^5$ K. The eye can detect only about 1/2 000 000 of such a flux, due to the ratio $(5300/2 \times 10^5)^4$, therefore the energy flux in the visual range is $W_M \approx 1.5 \times 10^{-14}$ W/m$^2$, i.e., a magnitude

$$m = -2.5 \log \frac{1.5 \times 10^{-14}}{3.7 \times 10^{-9}} = +13.5,$$

where $3.7 \times 10^{-9}$ W/m$^2$ is the visual energy flux corresponding to a magnitude 0 event. That value is consistent with the calculation of the magnitude $m_{\rm E}$ of a similar object impacting in the Earth's atmosphere using the Verniani formula [12], as seen at the distance $d_{\rm moon}$ of the Moon:

$$m_{\rm E} = 40 - 2.5 \log \left[2.732 \times 10^{10} M^{0.92} V_{\rm G}^{3.91} \times (d_{\rm atm}/d_{\rm moon})^2\right],$$

where $M$ is the meteoroid mass in grams, $V_{\rm G}$ its geocentric velocity in km/s, and $d_{\rm atm} \approx 100$ km is the typical height for a meteor in the Earth's atmosphere. With the previous parameters, the magnitude of the lunar flash should be $m_{\rm E} \approx +13.8$. In this case, we consider only the general concordance between the calculated magnitudes, even if the efficiency $\eta$ of transformation of kinetic energy into radiation is not the same in the atmosphere [13] and without atmosphere.

As a conclusion, we consider that the impact of a 10 g meteoroid onto the surface of the Moon can be seen only with rather large amateur telescopes (about 40 cm diameter), as claimed during the Leonid meteor shower by R. Venable [9].

In our simple model of luminous energy release during an impact, once we fix the impacting mass, we find luminosities significantly smaller than other authors listed in [10]. It is difficult to explain that difference of more than five magnitudes by a luminous efficiency for the lunar impacts that is 100 times larger than for terrestrial impacts. Verniani [12] already noted that fragmentation processes in the atmosphere increase the brightness of the meteors of magnitude $\approx +1$, and then their luminous efficiency $\eta$. For lunar impacts only considering the release of all the kinetic energy available per electron $E_{e^-}$ by atomic decay after the disintegration (that for ice at 71 km/s is $E_{e^-} \approx$ 43 eV) all in visible radiation ($\eta = 1$), particles as small as 10 grams could be detected. Therefore, we generally agree with Bellot Rubio et al. [14], who obtain masses of some kilograms for the Leonids' lunar impactors of 1999.

In a following paper, we will discuss the observation of the "Padua Impact" during the total eclipse of the Moon of January 21, 1999, already quoted in [2], and its possible confirmation by a CCD image taken by Gary Emerson [11].

**Acknowledgments**

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# Observational Results

# SPA Meteor Section Results: January–February 2000

*Alastair McBeath*

A summary of information provided to the *SPA Meteor Section* from January and February, 2000, is given. The Quadrantid maximum was quite well viewed visually and by radio, and perhaps produced two peaks on January 4, a chiefly visual one around $3^h$–$5^h$ UT (ZHRs of $125 \pm 20$; $\lambda_\odot 283\overset{\circ}{.}06$–$283\overset{\circ}{.}14$, eq. J2000.0), and a mainly radio one around $9^h$–$12^h$ UT (ZHRs around $70 \pm 10$; $\lambda_\odot = 283\overset{\circ}{.}31$–$283\overset{\circ}{.}44$). January 9, $1^h56^m$ UT, brought a brilliant fireball over northern England which was widely-seen. A possible shower association is suggested for the minor radio peak first detected on January 24–25, 1998 ($\lambda_\odot = 304°$–$305°$), which recurred weakly in both 1999 and 2000. February was notable for more bright fireball sightings from the UK, with two on February 10-11, one on February 13-14, and another widely-seen event over southern Scotland on February 14-15.

## 1. Introduction

Coverage of the moonless 2000 Quadrantid return was only hampered by typically poor winter weather in the UK, but useful results were obtained even so. The main points of interest in both months turned out to be sporadic fireballs however. Our observing tallies are in Table 1.

The photographic results were provided by Jürgen Rendtel and Jörg Strunk of the German *Arbeitskreis Meteore* (*AKM*) group. Along with the other *AKM* results used here, these were extracted from their monthly journal *Meteoros* numbers 3:2, 3:3, and 3:4 (all 2000), kindly provided by Ina Rendtel. No trails have yet been reported from their all-sky negatives.

Table 1 – Visual, photographic, radio, and video hours' totals, plus visual meteor numbers and video trails recorded in each month. In January, 661 visual Quadrantids were reported from the meteor tally.

| Month | Visual | Meteors | Photo | Radio | Video | Trails |
|---|---|---|---|---|---|---|
| January | $80^{h}.2$ | 1124 | $144^{h}.1$ | $5415^{h}$ | $192^{h}.3$ | 675 |
| February | $57^{h}.4$ | 290 | $110^{h}.1$ | $3237^{h}$ | $137^{h}.1$ | 391 |

Most of the radio data came from *Radio Meteor Observation Bulletins* (*RMOB*s) 78–81 (February to May, 2000, inclusive), thoughtfully submitted by Chris Steyaert. The radio observers included the following persons:

Jean-Louis Aillaud (Réunion Island, Indian Ocean; *RMOB*), Enric Fraile Algeciras (Spain; *RMOB*), Mike Boschat (Canada; *RMOB*), Maurice de Meyere (Belgium; *RMOB*), Del Dobberpuhl, John and Jack Meyer (Arizona, USA; *RMOB*), Ghent University (Belgium; *RMOB*), Werfried Kuneth (Austria; *RMOB*), R.B. Minton (New Mexico, USA; data also in *RMOB*s 79 and 80), Sadao Okamoto (Japan; *RMOB*), Ton Schoenmaker (the Netherlands; *RMOB*), Pierre Terrier (France; *RMOB*), Garfield Tsao (Taiwan; *RMOB*), Ilkka Yrjölä (Finland; *RMOB*).

Analyses of the raw data were carried out as usual, with Figure 1 given here as representative of what the majority of observers reported during January and February.

Video reports came from the *AKM* team (Michael Gerding, Sirko Molau, Mirko Nitschke, Jürgen Rendtel, and Ulrich Sperberg) in Germany, and Steve Evans in England.

Our visual-watch observers were as follows:

*AKM* members Franziska Böttcher, Frank Enzlein, Christoph Gerber, Mathias Growe, Isabel Händel, Ralf Kuschnik, Sven Näther, Jürgen Rendtel, Roland Winkler, Nikolai Wünsche (all in Germany); Jay Brausch (North Dakota, USA), Mary Cook (England), Roberto Gorelli (Italy), Lucy Hague (Scotland), Michael Maunder (England), Alastair McBeath (England), Trevor Pendleton (England), George Spalding (England).

This list does not include most of the casual fireball witnesses.

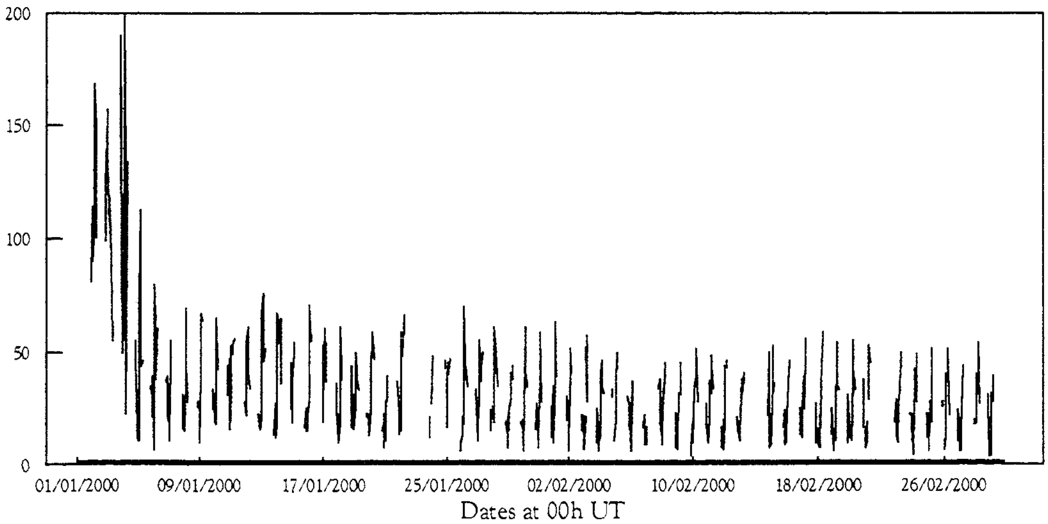


Figure 1 – All-echo raw hourly radio meteor counts from January and February, 2000, in data collected by Maurice de Meyere. Maurice generally operated his radio set-up for 11 hours daily, between $21^{h}$ and $8^{h}$ UT. Other gaps indicate times when interference prevented accurate data recording or when the system was non-operational (e.g., on January 22-23, February 13-14, and February 21-22). The peak Quadrantid count extends off the top of the graph so as not to lose most of the fine detail later in January and throughout February. The missing count value of 300 occurred in the single hour $3^{h}$–$4^{h}$ UT on January 4.

## 2. January

As expected, a significant proportion of all the observations were concentrated in the first week of January to cover the Quadrantids, though the German team endured some useless weather for observing, and saw barely a Quadrantid between them this year. Shower ZHRs other than around their maximum on January 3-4 were low, still below 5 after midnight UT on January 2 in our reports, for instance, making an interesting contrast with the radio data on the same night, which showed distinctly enhanced, if still relatively low, counts. The near-maximum spell was quite well observed visually on the European night of January 3-4, albeit several watchers had to struggle with unhelpful sky conditions around or during their observations. ZHRs on January 3-4 (all the Quadrantid ZHRs given here were calculated using an assumed $r$-value of 2.1, after [1]) rose sharply from the earliest reliable values of $50 \pm 15$ between $22^h30^m$ and $2^h$ UT to $125 \pm 20$ by $3^h$–$5^h$ UT ($\lambda_\odot = 283.^\circ06$–$283.^\circ14$, eq. J2000.0), dropping back to $75 \pm 15$ before $7^h$ UT, and falling further to $55 \pm 15$ during the next three hours. Predictions from past returns certainly suggested $5^h$–$6^h$ UT on January 4 ($\lambda_\odot = 283.^\circ16$) would be likely to see the Quadrantid maximum in 2000 [1]. However, Jay Brausch's data from the USA hinted at a possible resurgence in $\lambda_\odot$ Quadrantid ZHRs to $70 \pm 10$ around $11^h$ UT ($\lambda_\odot = 283.^\circ40$), but only his visual data are available to us from then.

The radio reports are unclear about giving a single Quadrantid maximum time. From five European and North American reports which covered both the expected $5^h$ UT peak and around $11^h$ UT on January 4, as well as comparison data for a day or two to either side at the same time of day, a mean peak time of $8^h42^m$ UT can be derived, but the scatter on this value is large, with different radio reports showing a single sharper peak at some time between $3^h$ and $12^h$ UT. Four of the five radio reports give a stronger suggestion of a peak between $9^h$ and $12^h$ UT ($\lambda_\odot = 283.^\circ31$–$283.^\circ44$), yielding a mean peak time of $10^h08^m$ UT ($\lambda_\odot = 283.^\circ36$). Some caution needs to be used in interpreting the radio data, however, as the equivalent local (i.e., solar) time mean value was $7^h08^m$, about an hour or two before the shower radiant's culmination (scatter: $2^h$–$12^h$ local time). All the five detected maxima (plus a sixth from Japan where interference prevented coverage of the $5^h$ UT period) were found during the best-visibility rising branch of the radiant's elevation curve, too. Even so, the possibility of a dual peak for the Quadrantids in 2000 cannot be discounted.

Visual magnitude distributions for the Quadrantids and January sporadics are given in Table 2. Too few train reports were received for a full analysis of them, but 16% of Quadrantids (17/104 meteors) and 4% of sporadics (2/52 meteors) left persistent trains.

Table 2 – Global magnitude distributions for the Quadrantids and January sporadics seen in good sky conditions (limiting magnitude of +5.5 or better, average cloud cover less than 20%), including mean limiting magnitude and corrected mean magnitudes.

| Shower | $-3^-$ | $-2$ | $-1$ | 0 | +1 | +2 | +3 | +4 | $+5^+$ | Tot | Lm | $\overline{m}_{6.5}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrantids | 5 | 7 | 26 | 43 | 86 | 140 | 173 | 96 | 28 | 604 | 6.09 | 2.66 |
| Sporadics | | 2 | 4 | 14 | 13 | 43 | 50.5 | 52 | 22 | 200.5 | 5.93 | 3.37 |

Around $1^h56^m$ UT on January 9, a probably sporadic fireball reaching magnitude −15 to −20 occurred over northern England, as reported by 19 eye-witnesses from northern Scotland southwards to south-east Ireland, south Wales, and the northern English Midlands. Acoustic sounds heard some minutes after the event were also reported from several sites, along with two reports of such sounds made by people indoors in northern England who were woken from sleep by the severity of the detonation. The majority of reports indicated a probable surface track for the bolide starting not far from Appleby in Cumbria ($\varphi = 54°35'$ N, $\lambda = 2°30'$ W) and ending more than 10 km offshore of Seaton Sluice in Northumberland ($\varphi = 55°05'$ N, $\lambda = 1°15'$ W).

The atmospheric trajectory was probably angled at $33° \pm 3°$ from the horizontal (based on an assumed start height of about 90 km, and a calculated end height based on observations of about 30 km), yielding an atmospheric path length of about 110 km. Best estimates for the object's duration were $\sim 5$ s, giving an atmospheric trajectory not allowing for deceleration (which was noted as quite marked in some reports made almost perpendicular to the meteor's trail) of about 22 km/s.

The acoustic sounds from this fireball were typical of their type, described generally as sonic booms or explosions, and most reports mentioning acoustic sounds were made within a few tens of kilometers off the surface track at most, with the exception of an observer in Banff, Scotland, some 280 km from the meteor's proposed end-point, whose report of such sounds regrettably did not include an estimate of the delay before they were heard. The time involved should have been 13–15 minutes, but rather than dismissing this report, we must note that the track for any acoustic waves would have been mostly over water on a night noted by several observers as being very calm.

Some reports mentioned late-stage fragmentation of the fireball, with orange-red pieces falling from the green-yellow main mass, and several witnesses saw three larger fragments falling away near the end of the object's flight. Any meteorites would have splashed down into the North Sea at least 40–60 km from land.

Only a single report of possible simultaneous sounds was received for this bolide, made by an observer on Eston Nab ($\varphi = 54°33\!'\!.5$ N, $\lambda = 1°07'$ W), a hill around 60 km south-east of the surface track's closest approach, described as "whoosh, then rustling." Fuller reports on this fireball were issued on the *IMO News* e-mailing list on February 13, 2000, (available in the *IMO*'s Web-archive at `http://www.imo.net`) and on the *Meteor Section* pages of the *SPA* Website at `http://www.popastro.com`.

Other visual meteor watches carried out in Moon-free skies during the rest of January revealed the usual declining sporadic rates, along with traces of minor shower activity. The Coma Berenicids apparently faded away after mid-month, as none were reported to us after January 16. However, see the discussion of the $\lambda_\odot = 304°$–$305°$ radio peak below.

Comparing the radio activity with that recorded previously [2], the near-Quadrantid "bulge" petered out by $\lambda_\odot \approx 285°$ (January 6) this year, a little earlier than is sometimes seen (the "bulge" is not necessarily due only to Quadrantids, it must be noted). The minor $\lambda_\odot = 289°$ and $\lambda_\odot = 290°$–$294°$ peaks (January 10 and January 11–15, respectively) were noted only weakly in the available reports, with a more consistent peak in all at $\lambda_\odot \approx 288°$. The $\lambda_\odot = 298°$ peak did not recur, but most observers recorded a minor spike at $\lambda_\odot \approx 299°$ (January 20) instead.

The remaining minor radio maxima were recovered much as in past years.

The weak $\lambda_\odot = 304°$–$305°$ (January 25–26) enhancement first observed in 1998 [3] as possibly coincident with a number of fireball reports, was noted very weakly in only half the available datasets this year, more especially in Japanese and European long-duration echo counts. A possible source for this activity has now been defined by Roberto Gorelli [4], with a radiant at $\alpha = 188°$ and $\delta = +22°$, in Coma Berenices, perhaps due to material shed by Comet Lowe 1913 I. Roberto indicated the shower meteors to be swift ($V_\infty = 59$ km/s), with maximum activity during $\lambda_\odot = 304\overset{\circ}{.}2$–$305\overset{\circ}{.}0$ (January 24.9–25.7, 2000).

It is unclear if this shower is related to the Coma Berenicids which we expect to end by January 23 or so [1]. Reference [4] suggests that the $\lambda_\odot = 304°$–$305°$ peak may be due to a separate, previously unknown shower, coincidentally radiating from Coma. All observers are urged to cover this period in future years to check for possible activity. The year 2001 is an ideal opportunity with New Moon on January 24 to find out about this (see the call for observations elsewhere in this issue).

### 3. February

February's visual and radio activity often receives little coverage, since it is expected to be generally uninteresting for northern hemisphere watchers, with no major showers active. Certainly, the radio results produced no real surprises this year, with the few minor peaks recovered as expected (including that around $\lambda_\odot = 331°$ (February 20) first noted in 1998 [3], which had been only weakly detected in 1999). The exception was that of the $\lambda_\odot = 325°$ peak (February 14), again first spotted in 1998. From data in 1999, when a weak signature was found in about half the available results around $\lambda_\odot = 326°$, and this year, when all the data sets recorded at least a minor increase around this same date, it seems more likely this slight peak recurs a day later than the 1998 results implied.

Visual observations scattered throughout the month showed low sporadic rates and some signs of early Virginid activity, although with very few plots being added to the *Section*'s on-going project on these minor streams. A loose "cluster" of casual fireball sightings from the UK fell around the February 12–13 weekend however, which was of greater interest. Four fireballs in total seem to have occurred between February 10-11 and 14-15, the first three noted by observers at single sites only. Details on each event follow.

On February 10-11 at $2^h40^m$ UT two witnesses sea-fishing with long carbon-fiber rods on the Dorset coast observed a magnitude −6 to −8 orange-yellow fireball passing slowly east to west almost parallel to the sea horizon, at an elevation of about 30°, thus probably well out to sea over the Channel or northern France. Both reported hearing hissing or fizzing sounds simultaneous with their sighting.

Four hours later, around $6^h45^m$ UT on February 11, a single witness spotted a fireball of perhaps Full Moon brilliance while driving in the English north Midlands. The object was low in the north-western sky, heading roughly east to west approximately parallel to the horizon, and appears to have been moving quite slowly.

At about $18^h21^m$ UT on February 13-14, another driver and a colleague in the same car, about 10 km north of the Firth of Forth in southern Scotland, spotted a near-vertical bright fireball passing just east of Sirius. It was moving relatively slowly.

The final event in this short series occurred between $17^h45^m$ and $17^h50^m$ UT on February 14-15. Reports from at least ten witnesses were forwarded to us by Mike Dale of the Royal Observatory in Edinburgh, but most were too sketchy to give any useful details. The sightings were clustered in central and eastern Scotland, and one witness indicated the fireball could have been moving roughly south-east to north-west over this general region. The object was clearly bright to have been spotted over such a wide area, and one report suggested it was green in color, but nothing further could be determined about it.

### Acknowledgments

Many thanks go to all our observers and correspondents. Please keep sending in your reports, and clear skies to one and all!

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# SPA Meteor Section Results: March–April 2000

*Alastair McBeath*

Reports sent to the *SPA Meteor Section* from March and April, 2000, are discussed. Waning gibbous moonlight was unhelpful for visually covering the Lyrid maximum, but a poorly-defined peak between roughly $16^h$ and $11^h$ UT on April 21–22 ($\lambda_\odot = 31\overset{\circ}{.}8 - 32\overset{\circ}{.}6$, eq. J2000.0) was suggested by the radio observers. Three bright fireballs were reported from multiple sites in the UK over the March 4-5 weekend, with further such events on March 18-19 and April 5-6.

## 1. Introduction

Surprisingly few watches were reported to us during March this year, though April was better, despite the Moon being a problem for the Lyrids. Table 1 features the observing totals.

Table 1 – Visual, photographic, radio, and video hours' totals, with visual and video meteor numbers recorded in each month, including a partial breakdown of visual meteor types.

| Month | Visual | VIR | LYR | SAG | Meteors | Photo | Radio | Video | Trails |
|---|---|---|---|---|---|---|---|---|---|
| March | $14\overset{h}{.}5$ | 8 | | | 87 | $35\overset{h}{.}7$ | $3604^h$ | $52\overset{h}{.}4$ | 105 |
| April | $89^h$ | 31 | 22 | 29 | 553 | $129\overset{h}{.}2$ | $5068^h$ | $165\overset{h}{.}6$ | 361 |

All the photographic reports were produced by *Arbeitskreis Meteore* (*AKM*) members Jürgen Rendtel and Jörg Strunk in Germany. Ina Rendtel provided all the *AKM* details used in this article, in the form of their monthly journal *Meteoros* 3:4, 3:5, and 3:6 (2000). The all-sky cameras were operating as part of the *European Fireball Network*, and no trails have yet been found. The majority of the radio data came via Chris Steyaert in his regular *Radio Meteor Observation Bulletins* (*RMOB*s), numbers 80–82, inclusive, April to June 2000. Contributing radio observers comprised the following:

> Enric Fraile Algeciras (Spain; *RMOB*), Mike Boschat (Canada; *RMOB*), Maurice de Meyere (Belgium; *RMOB*), Didier Favre (France; *RMOB*), Ghent University (Belgium; *RMOB*), Rafael Haag (Brazil; *RMOB*), Werfried Kuneth (Austria; *RMOB*), R.B. Minton (New Mexico, USA; data also in *RMOB*s 81 and 82), Sadao Okamoto (Japan; *RMOB*), Ton Schoenmaker (the Netherlands; *RMOB*), Pierre Terrier (France; *RMOB*), Garfield Tsao (Taiwan; *RMOB*), Ilkka Yrjölä (Finland; *RMOB*).

The raw data were analyzed as normal, with the graph in Figure 1 chosen as representative of the more complete datasets from March and April.

Video data came exclusively from *AKM* observers Detlef Koschny (the Netherlands), Sirko Molau (Germany), Mirko Nitscke (Germany), and Jürgen Rendtel (Germany).

Our visual observers included the following:

> *AKM* members Rainer Arlt, Frank Enzlein, Christoph Gerber, Isabel Händel, Ralf Kuschnik, Sven Näther (Germany and Morocco), Jürgen Rendtel, Roland Winkler, Nikolai Wünsche, Oliver Wusk (all in Germany unless stated); Mary Cook (England), Roberto Gorelli (Italy), and Tim Cooper (South Africa).

Seventy-one meteors were plotted during the March-April part of our Virginid project this year.

## 2. March

March turned out to be a struggle for our visual watchers particularly, and very few Virginids were spotted. As in the recent past, Tim Cooper proved our most steadfast plotter of Virginids, but, sadly, his weather-limited observations this year did not reveal any probable candidate radiants in either the first half of March or April, even when combined with data from other watchers.

Indeed, greater visual interest was generated by the appearance of at least three bright fireballs over the UK during the opening weekend of the month. The first was around $22^h00^m$–$22^h05^m$ UT on March 4-5, and was a magnitude −6/−9 slow, green fireball as reported from three sites in south Wales and south-west England. All the observers commented on its late fragmentation, but unfortunately none were able to give accurate details on the meteor's track through the sky.

On March 5-6, two fireball events took place, the first at around $18^h10^m$ UT, a fairly swift meteor of perhaps magnitude −5/−8, white and fragmenting into two at its end. It was seen from two locations in south-west Scotland. The second fell between $20^h20^m$ and $20^h30^m$ UT, and was possibly of around magnitude −6/−10 as reported by two witnesses in central-southern Scotland. From the approximate tracks through the stars given for the latter event, this meteor may have passed over north-eastern Scotland, though no additional reports were secured from there, regrettably.

A further fireball, of magnitude −5/−10, or so, then occurred around $19^h40^m$ UT on March 18-19 as seen by four witnesses at two separate sites, one in central-eastern Scotland, the other in north Wales. The meteor was very slow moving and bright green in color, but showed no sign of fragmentation. From the rough sky locations, this meteor probably passed over northern England or just offshore over the North Sea from there.

All the minor March radio echo count peaks recorded previously [1] were recovered again, and there were no particular surprises reported, except for what seem to be typical slight variations seen from year to year.

## 3. April

The fireball theme begun back in January continued into April with a bright green meteor reported as widely seen from south-west Scotland to south Wales on April 5-6 in several media sources forwarded to the Section. The object may have passed over the northeastern Irish Sea, but, despite the obvious media interest, for once no eye witness observations reached us, and not even an accurate timing could be established for it, other than during the evening hours.

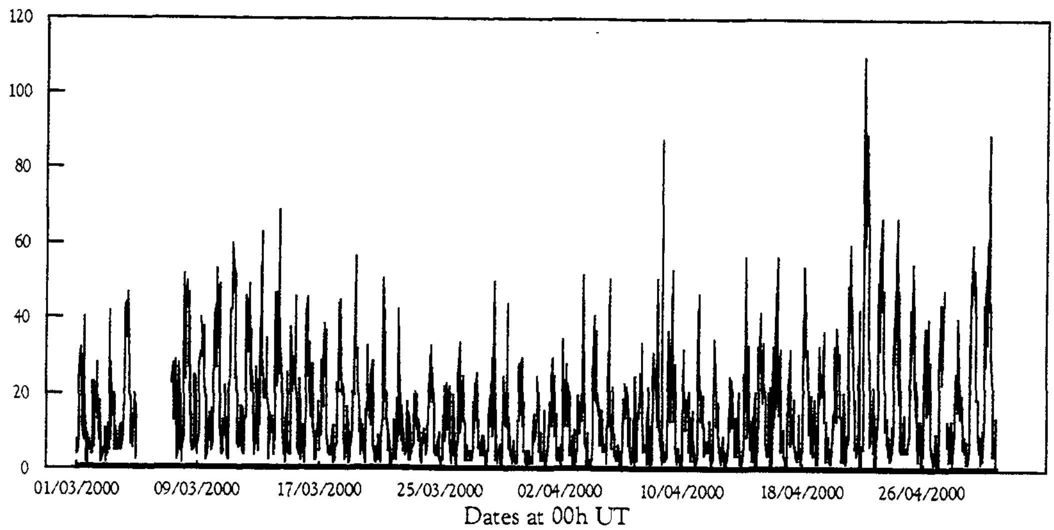


Figure 1 – Raw hourly radio meteor percentage reflection time echo counts (×10) from March and April, 2000, in data collected by Ghent University. The set-up was operated continuously, except from midnight UT on March 5 to $9^h$ UT on March 7, due to a computer fault, and a few single-hour breaks in April due to Sporadic-E or other interference. Interestingly, the huge auroral storm seen worldwide on April 6-7 did not create any problems for the Ghent observations.

Radio reports indicated the echo count peak around $\lambda_\odot = 18°$ (April 8; part of the $\lambda_\odot = 17°$–$18°$ peak, which sometimes stretches between $\lambda_\odot = 14°$ and $\lambda_\odot = 19°$—see [1]) was recovered quite strongly in several data sets, as Figure 1 demonstrates with the Ghent University results. Other lesser peaks around $\lambda_\odot = 13°$, $\lambda_\odot = 14°$, and $\lambda_\odot = 16°$ in this interval were also found in most reports. The $\lambda_\odot = 20°$ and $\lambda_\odot = 22°$–$24°$ peaks (April 10 and 12–14) were only very weakly traced, though a better-seen peak at $\lambda_\odot \approx 21°$ was probably the former's return this year, while the latter was barely seen at all and then only around $\lambda_\odot = 24°$. Both minor peaks have proved problematical at times in recent years, so may be particularly time-sensitive, or perhaps not present each year.

The rest of the identified April radio peaks were found much as usual after this, with the Lyrid maximum typically the strongest for the month in most reports around $\lambda_\odot = 32°$ (April 22). Late month increasing counts were seen especially from $\lambda_\odot \approx 39°$ (April 29) onwards too, probably due to the $\eta$-Aquarids, as is normally noted at this time.

Relatively few Lyrids were spotted in 2000, making a visual analysis of them difficult, as even the *IMO* preliminary report [2] indicated. The *IMO* data suggested a prolonged maximum for the shower, with ZHRs of $20 \pm 10$ persisting throughout the UT evening hours of April 21 until about midday UT on April 22. A maximum between April 21-22, $22^h$–$5^h30^m$ UT ($\lambda_\odot = 32\overset{\circ}{.}1$–$32\overset{\circ}{.}5$) was expected from recent returns.

The radio data also favored a generally less sharp peak for the Lyrids on April 21-22, but without any strong correlation between data sets. A mean UT peak time around $8^h40^m$ on April 22 can be derived, but the spread is large, at between April 21, $16^h$ UT to April 22, $11^h$ UT ($\lambda_\odot = 31\overset{\circ}{.}8$–$32\overset{\circ}{.}6$). The equivalent local (i.e., solar) time values for the mean and the scatter were April 22, $5^h35^m$ and April 21, $23^h$ to April 22, $13^h$, respectively, with the Lyrid radiant well on view for all our northern hemisphere radio reporters between $20^h$–$22^h$ and $11^h$–$13^h$ local time daily, culminating around $4^h$. The fact that the mean peak radio time fell after the shower radiant's culmination is interesting, and somewhat unusual (shower peaks are often picked up preferentially during the rising part of a radiant's diurnal elevation curve in many of our regular radio reports), but, because of the large spread in time values, it cannot be seen as particularly significant. The correlation between the scant visual and radio peak UT times is probably the most important part of this discussion, suggesting what the visual observers saw was a genuine aspect of the 2000 Lyrids, not merely an artifact due to poor conditions and few watchers.

Too few Lyrids were seen for any kind of magnitude or train analysis on them, with a single, red probable Lyrid fireball, perhaps of magnitude $-3/-5$, reported to us from one location in northern England, circa $21^h05^m$–$21^h10^m$ UT on April 21-22.

Before the Lyrids, weak visual rates from the Virginids were spotted, but, as mentioned above, no analysis of any possible radiants was practical from our plotting project this year. After the Lyrids, visual observers noted only a few Sagittarids and a single $\eta$-Aquarid before the month's end, along with the typical relatively low sporadic rates.

## Acknowledgments

My thanks as ever are sent to all the contributing observers and correspondents essential to any report of this kind. Clear skies!

## References

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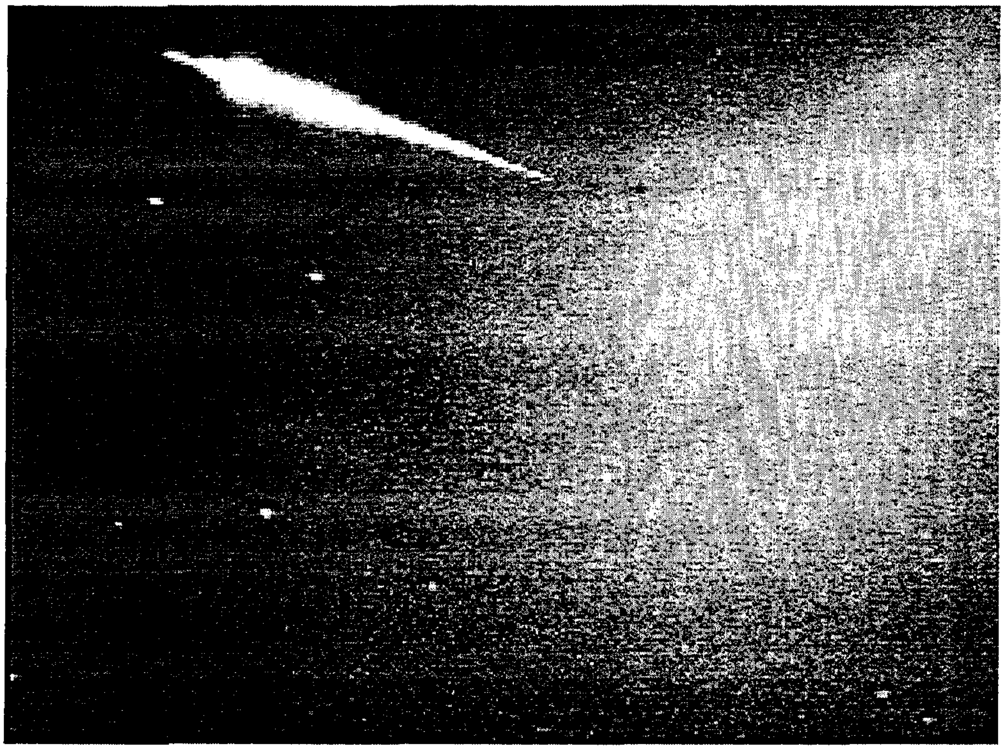

The bright moonlight had less effect on intensified video meteor cameras during the Leonid 2000 activity period. This Leonid fireball occurred near the zenith in Ursa Major on November 17, 2000, at $5^h03^m49^s$ UT. It was recorded by Jürgen Rendtel's CARMEN. The meteor appeared before the Earth reached the first of the three Leonid trails (see the analysis elsewhere in this issue).

The Ursids produced enhanced activity in the morning (UT) of December 22, 2000. European observers and cameras were able to record an increase of rates until dawn. However, this bright Ursid already appeared earlier this night at $0^h25^m23^s$ UT. The field of the CARMEN meteor camera was in Gemini at this time. The bright Leonid meteor and this Ursid were observed from Marquardt, Germany (12°57′50″ E, 52°27′34″ N).

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