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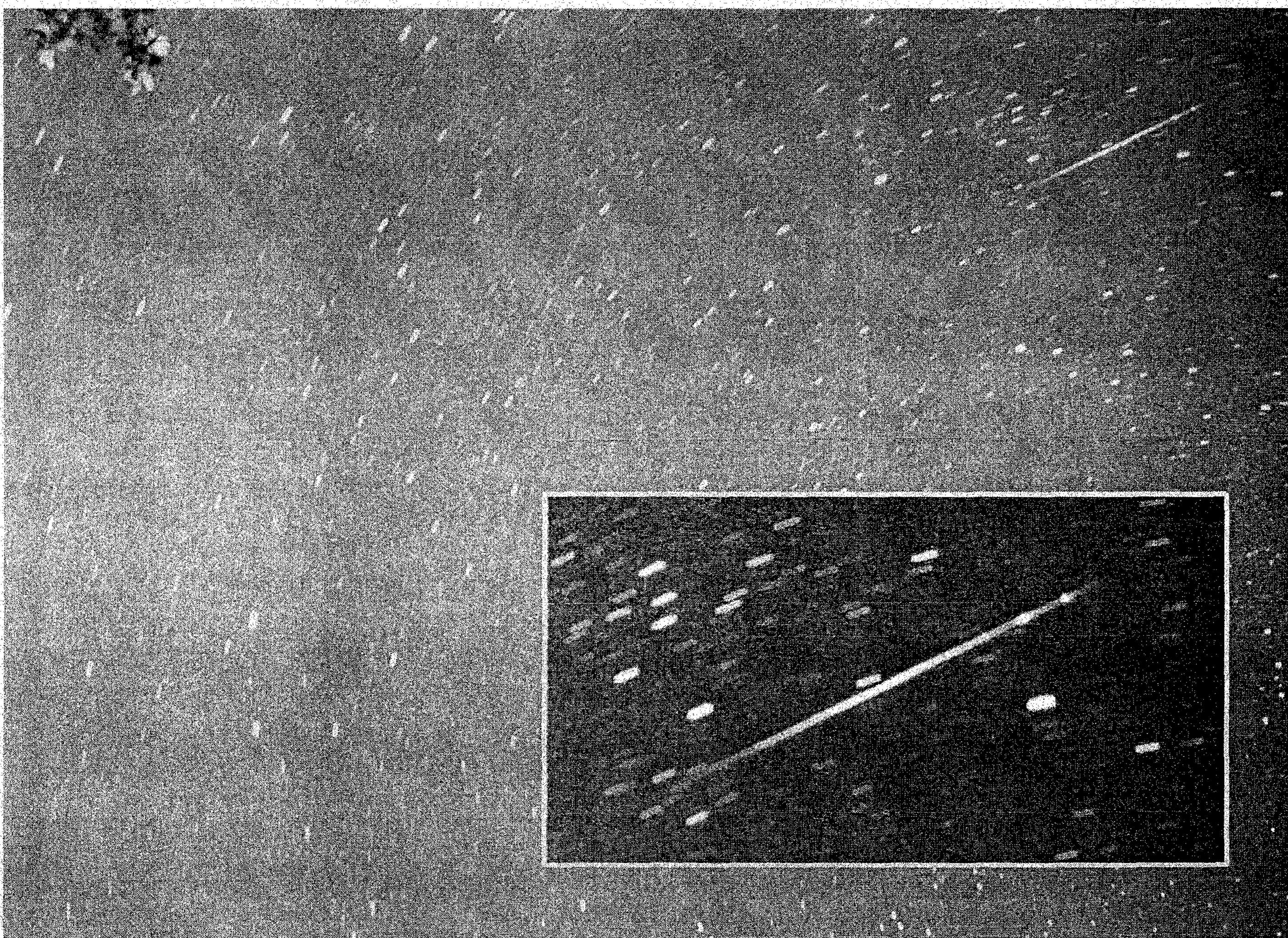

A fine Draconid captured by Peter Bus from Groningen, The Netherlands, on 2002 October 8 at 19h23m UT. The meteor was of magnitude -2, very slow, yellowish in color, showed a very irregular brightness behavior during flight (a so-called short lived spark-train), and ended with a so-called final flare of magnitude -2. A persistent train was visible for about one second. Projecting the visible trail backwards, it passes significantly south of the 1946, 1985 and 1998 radiant positions and also not far from the radiant position of two-multi station photographically recorded Draconids in 1953. (Camera: Canon T-70, 28mm f/3,2 on 400 ASA Sensia II Fujichrome.)

In this issue:
- Electrophonic meteors
- Perseids 2002 analysis
- Initial Leonids 2002 results

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Contents

Useful Information

It had been intended that this issue would be largely dedicated to work on the 2002 Leonids. Many authors are still processing their results, however, and it was felt better to hold these contributions over for the next issue rather than publish hastily-written papers. Only a few, initial Leonids results are presented here.

The February issue *(WGN 31:1)*

This will be edited in January. Those who observed the Leonids in 2002 are encouraged to write up their results and submit them by 2003 January 15. Contributions should be emailed to `wgn@imo.net`; advice to authors can be found on the first two pages of *WGN 30:4*.

Subscriptions and ordering of publications

Volume 31 (2003) of *WGN* is expected to contain two to three hundred pages and costs 20 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription and membership fees. 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.

The International Meteor Conference 2003

communicated by Jürgen Rendtel

IMC 2003 is planned to take place in Bollmannsruh—a hostel situated near the town of Brandenburg in Germany, west of Berlin. The local organizers are the German Arbeitskreis Meteore e.V. As usual, the *IMC* will start on Thursday evening (September 18, 2003) and end on Sunday noon (September 21, 2003). The program includes the General Assembly of the International Meteor Organization (*IMO*).

Several *IMO* members and long-term meteor enthusiasts remember that the *IMO* was founded in 1988 at an *IMC* in Oldenzaal, the Netherlands. *IMC* 2003 marks our 15th anniversary—a good opportunity to look back (with lots of pictures) and to plan for the future.

The hostel in Bollmannsruh provides accommodation for at least 60 participants in bungalows with shower and toilet and a winter garden. For the conference we will use a lecture hall for (nominally) 120 people. Posters can be placed in that room as well as in the lobby outside the lecture room. A cafe and a bar are in the same building. Further facilities include a place for a campfire and barbecue as well as an open air stage.

General and travel information: the location for *IMC* is situated about 15 km northeast of the town of Brandenburg in a rural area by a lake. It can be reached by car from the A2/E30 via Brandenburg (about 30 km) or from the A10/E55 (about 25 km). There is also a bus service from Brandenburg to Päwesin/Bollmannsruh.

From Berlin to Brandenburg there is an hourly railway connection (travel time about 45 min). Participants will be collected from the Brandenburg station. Special arrangements can be made as well. Details such as timetables for trains and buses will be announced in later circulars and the *IMC* web page which is under preparation (see the *IMO* web page for the relevant link). This also holds for the complete information regarding visa regulations etc.

Extended stays before and/or after *IMC* 2003 at the conference site or at other locations in Germany can be arranged. The local organizers are prepared to assist you.

Weather is changeable in September as always in Central Europe. Hence you should be prepared not only for sunny days but also for rain. However, in recent years this period has remained warm and sunny. Temperatures are never below freezing point and snow has never occurred at this time. The average afternoon temperature is about 18°C, the average minimum about 10°C. Swimming in the nearby lake is possible; water temperature depends on the summer and may be 15 or even 20°C as in 2002.

Program of *IMC*: we intend to invite a speaker for a meteor related talk. Of course, we will also try to establish a preliminary program well in advance. This depends on the announcements in the (pre-)registrations. The last years' Leonid returns will certainly be a main topic. But do not forget the many other aspects and also new projects.

Our excursion will go to Berlin where we plan to visit the meteorite collection of the Museum for Natural History. This includes a lecture on meteorites and other rocks which look very similar and a view behind the scene as well. One evening is reserved for a campfire and barbecue (weather permitting).

As in previous years, we offer an early registration fee for the entire conference, including accommodation and full board (Thursday evening to Sunday noon) as well as the Proceedings for 115 EUR. The deadline for early registration is July 31, 2003. Participants registering later should pay a late registration fee of 130 EUR. Reduced rates may be arranged on request.

We look forward to seeing you at *IMC* 2003 in Germany. Please do not hesitate to contact the organizers if you have questions or problems need to be solved.

Members of the local organizing committee: Frank Enzlein, Sven Näther, Ina Rendtel, Jürgen Rendtel, Manuela Rendtel.

International Meteor Conference

Bollmannsruh, Germany, September 18–21, 2003

Registration Form

Each individual participant should fill out a form and return it to *Ina Rendtel, Mehlbeerenweg 5, 14469 Potsdam, Germany*, as soon as possible. Your registration will be guaranteed only after Ina Rendtel has received the minimum pre-payment of 50 EUR. If you wish to participate, but cannot yet decide, simply return this form with the proper option checked to stay on the mailing list for further circulars.

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I intend to travel by __________, together with ______________________________

Additional requests:

- ○ I need travel information from ______________ to Bollmannsruh;
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Lecture: ______________________________

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- 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*!

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communicated by Ina Rendtel, Treasurer

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- **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.

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If you have *not received* a booklet with the *IMO* Membership Directory, you are *not a member* of the *IMO*, although you are a subscriber. If you missed becoming a member, please fill in the form below and return it to the Treasurer; the subscription of *WGN* covers your membership fee.

Membership Application

Yes, I want to join the International Meteor Organization. I agree with the objectives and the constitution of the organization and wish to become an associate member starting January 1, 20____. I understand that my candidacy for voting membership will be submitted to the next meeting of the General Assembly.

First name: ____________ Middle Initial(s): ____________ Last Name ____________

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Occupation: ____________________________________

Place and date of birth (YYYY/MM/DD): ________________________

Activities: ____________________________________

I have special interest in:

- ○ visual observations: ________________________
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- ○ video observations: ________________________

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Letters to WGN

Comments on combined VLF radio and visual observations, 2001 Leonids

Alastair McBeath

I was interested to read in George Drobnock's paper in October's *WGN* (Drobnock 2002) that some correlation between individual VLF radio signatures and visual meteors seemed to be apparent. It would have been useful to have had more data on the nature and numbers of such coincidental events, and I hope George might be persuaded to re-examine his results and present some further findings in this respect. However, I feel the latter stages of the more general qualitative analysis he did give, are open to an alternative interpretation than that visual-radio Leonid rates declined steeply after the first storm peak.

For instance, other North American data shows declining Leonid rates were still at roughly storm level until $\sim 11^h30^m$ UT on November 18, 2001, far above their $\sim 9^h$ UT strength. By contrast, George's main results graph, Figure 3, shows a steep drop in both visual and VLF rates to around or below their $\sim 9^h$ UT level, by the time observing ended at 11^h30^m UT. Certainly, the nonlinear time (x-) axis and irregular labelling makes interpreting Figure 3 difficult, but this is a curious discrepancy. If we assume a site in central Pennsylvania is at about $\phi = 78°, \lambda = 41°$ N, give or take a degree or two, astronomical twilight would begin around 10^h30^m UT on November 18, increasing thereafter until sunrise at about 12^h00^m UT. During this period, observed meteor rates would have dropped sharply, much as seems to have been seen visually. This suggests the drop in Figure 3 was not so much a physical measure of visual Leonid behaviour, but largely resulted instead from deteriorating observing conditions.

It is strange that the VLF radio rate also dropped sharply as dawn approached. VLF reception is much less affected by atmospheric effects than many other types of radio signal, so it is unlikely this had any influence. In any case, the well-known diurnal increases in radio propagation noise and sporadic activity at around $6^h \pm 2$ h local solar time ($= 11^h \pm 2$ h UT for central Pennsylvania), should have caused rates to *increase*, not decrease as was reported. The Leonid radiant's culmination at this site would be at $\sim 11^h30^m$ UT, and it may be this was the real cause of much of the VLF rates drop. For a variety of reasons, radio observers often find that the hours nearest a radiant's culmination see detected meteor echo counts from that source fall significantly, before rising again as the shower radiant passes further into the western sky.

Overall, the post-storm peak results presented graphically show features which are better explained by how and when the observations were made, and give a lesser indication of real features in the 2001 Leonid shower. This does not decrease their utility or interest, merely their interpretation. I hope George and his colleagues will continue their VLF-visual observing and analysis for other meteor showers in future, so we may learn more about VLF-producing meteors.

References

Drobnock G. J., 2002, "VLF Signatures from non-Fireball Meteors – Observations from the 2001 Leonid Shower", *WGN* 30:5, pp. 152–156.

Response to Comments from Alastair McBeath

George John Drobnock

Our intent (Drobnock, 2002) was to identify a relationship between meteors and VLF signatures. The literature about meteors and VLF electromagnetic radiation is strong towards the development of very low frequency electromagnetic waves that produce an electrophonic sound. The general acceptance is one meteor of magnitude -6 or brighter will produce (under proper conditions) an electrophonic noise. Contrary to the fireball induction of VLF energy is the work of Price and Blum (2000) that indicates the detection of electromagnetic impulses in the ELF/VLF spectrum, with visual magnitude not a major factor.

Our premise is – all meteors entering the atmosphere produce electromagnetic energy in the VLF end of the spectrum.

The study of the relationship between meteors and the creation of electromagnetic radiation is a challenge. Foscini (1998) indicated the study of meteors by radar and forward scatter reception by VHF receivers is accomplished by the ionization process and the creation of plasma. The ionization and creation of plasma releases electrons that in the process release energy, some of which may be released in the form of radio frequency electromagnetic energy.

To answer Alastair's comments, the graph in question, Figure 3, was produced to illustrate the general correlation observed during the Leonids of 2002. As visual meteors entered the atmosphere, during storm conditions, there was a corresponding very low frequency electromagnetic increase. The graph from 10:30 UT to 11:30 UT was an interpretation. There was concern as dawn approached as to the influence of the heating of the atmosphere by the sun and increased sferics.

Chernan (1978) indicates a solar enhancement of the atmosphere before sunrise. With our instrumentation, we were noticing an increase in background "noise". From the beginning baseline, as dawn approached, the background level was increasing.

Our observation site (40°22′ N, 78°10′ W) was located in a small valley that allowed a 120 degree view of the sky, and we were within 400 meters from a lake.

Our observations, visual and instrumental, stopped at 5:35 AM Eastern (10:35 UT), the reason was the development of early morning fog, beginning to become visible about 10:31 UT, and the concern with an increase in sferics as mentioned above.

Our observers did comment about the apparent increased activity at 10:16 UT to the west of our observation site. The activity was increasing by 10:39 UT.

We prepared for the 2002 Leonids with expectations to repeat the methodology of 2001. We unfortunately were not able to obtain the same results. Our difficulty in repeating the observations were geographic location and weather. We do plan to re-examine the information collected in 2001.

I want to thank Alastair for his comments.

References

Drobnock G.J., 2002, "VLF Signatures from non-fireball Meteors - Observations from the 2001 Leonid Shower", *WGN* 30:5, pp. 152–156.

Price, Colin & Blum, Moshe, "ELF/VLF Radiation Produced By the 1999 Leonid Meteors", *Earth, Moon, Planets* 82-83, pp. 454–554.

Foschini, L., accepted 1998, "On the interaction of radio waves with meteoric plasma", *Astronomy and Astrophysics 16 December 2001*, Internet PDF file.

Chernan, C.M., 1978, "Handbook of Solar Flare Monitoring and Propagation Forecasting", TAB Books, Blue Ridge Summit, Pa..

November 14–15, 2001 Radio Peak Probably Not Due to Iota-Aurigids

Alastair McBeath

Huan Meng reported a ZHR of $\sim 14 \pm 5$ around 23^{h} UT on November 15, 2001, which he attributed to the possible new minor shower of the ι-Aurigids (Meng 2002). As will be seen elsewhere in this issue (McBeath 2002), I found an unusual radio peak on November 14–15, 2001, chiefly in some of the European and North American results from the *Radio Meteor Observation Bulletins*. I have re-examined the radio data in light of Meng's report, but unfortunately, I can find little to support the proposed ι-Aurigids in 2001. Only one dataset, that of Stan Nelson in New Mexico, USA, showed a strong spike in echo counts at 23^{h}–0^{h} UT on November 15, although the assumed radiant, suggested as within a few degrees of $\alpha = 76°, \delta = +36°$, was well below his horizon then, so this cannot have been the source. Indeed, Stan's data infrequently shows an unexpectedly strong spike in rates at some point between roughly 23^{h}–1^{h} UT, presumably due to some unidentified interference, so this would not be significant anyway, unless other observations supported it. European observers, for whom the supposed radiant area was well above the horizon, recorded nothing out of the ordinary near this time.

Looking at when the other datasets showed their increased counts on November 14–15, there is a better fit to the Leonids than the potential ι-Aurigids, as these generally match the times that strong Leonid rates were detected on subsequent dates. This is not unexpected, as increased radio rates have been found around $\lambda_{\odot} = 233°$ since 1993, as part of the activity leading in to the main Leonid peak around $\lambda_{\odot} = 234°$–$235°$ (in years before the storm maxima began occurring). Given that Japanese results indicated increased bright visual Leonid numbers on November 15, there seems little need to invoke another source to account for the increased radio counts on the same date. As radio observations are apparently capable of detecting minor showers with peak visual ZHRs ~ 3 or lower, a shower with ZHRs ~ 10–15 should have been readily found in most datasets where the radiant was radio-visible. Its absence suggests a very much weaker rate, perhaps even nothing at all, from this proposed shower in 2001.

References

[1] McBeath A., 2002, "SPA Meteor Section Results: November–December 2001", *WGN* 30:6, pp. 258–266.

[2] Meng H., 2002, "Activity of the Iota-Aurigids in 2001 and the Possible Orbit of the Meteoroid Stream", *WGN* 30:5, pp. 175–180.

The Leonids

Bulletin 18 of the International Leonid Watch: Preliminary Analysis of the 2002 Leonid Meteor Shower

Rainer Arlt, Vladimir Krumov, Andreas Buchmann, Javor Kac and Jan Verbert

An analysis of visual observations covering 528 observing hours with 57 045 Leonids logged by 207 observers from 37 countries is presented. The activity peak time of the 7-revolution-old dust trail of Comet 55P/Tempel/Tuttle is found at $4^h10^m \pm 1$ min UT on November 19, 2002. The peak time of the 4-revolution-old dust trail is found at $10^h47^m \pm 1$ min UT on November 19, 2002. Visual activity reached ZHRs of 2510 ± 60 and 2940 ± 210 respectively. The full widths at half maximum are found to be 40 minutes for the 7-revolution trail and 25 minutes for the 4-revolution trail.

1. Introduction

The fifth year of impressive activity of the Leonid meteor shower in a row has again seen a large number of observers reporting their results to the global database of the *IMO*. Two major peaks of activity were predicted by several researchers. We compile the predictions as they were known right before the maxima at the end of this Paper and compare them with the observations. Predicted times varied between November 19, 03^h48^m–04^h04^m UT for the first peak and 10^h23^m–10^h47^m UT for the second peak. The first maximum was derived from the evolution of the dust trail of 1767, ejected by the parent comet 55P/Tempel-Tuttle near its perihelion passage seven revolutions ago. The second maximum originates in the 4-revolution-old dust trail of 1866. While most of the predicted timings are results of numerical integrations of meteoroids, the predicted meteor numbers are chiefly phenomenological.

The present analysis is based on the visual meteor data reported by 207 observers from

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

The input of observing reports into the *Visual Meteor Database* is far from complete. Nevertheless, we would like to present a preliminary analysis of the population index and activity of the 2002 Leonid meteor shower from the current data set.

2. Analysis

We performed a first computation of the population index profile. The usual algorithm with an adaptive bin size is applied. The optimum meteor number for the algorithm was set to 1000 and the minimum step size was set to 15 minutes. We derived the profile shown in Figure 1. Low population indices, i.e. a large fraction of bright meteors, were recorded from Asian geographical longitudes before the first predicted peak. A very steep increase of r was observed until a highest value of $r = 2.53 \pm 0.06$ (7-revolution dust trail).

The population index tends to decrease, although the Atlantic data gap does not provide a conclusive value between $\lambda_\odot = 236\overset{\circ}{.}7$ and $236\overset{\circ}{.}8$. A very high r-value is reached near the predicted American peak with $r = 3.0 \pm 0.1$ (4-revolution trail). The number of observers providing magnitude estimates for the meteors is much smaller than in Europe. The maximum r-values for the same dust trails as observed in 2001 were $r \approx 2.2$ for both peaks (Arlt et al. 2001).

The bad influence of the Moon may have increased the population indices. We checked a similar profile obtained from observations with limiting magnitudes (lm) better than or equal to +5.0. The two peaks in r near the predicted maximum times indeed decreased, but by less than 0.1. We will thus adopt the original r-profile of Figure 1 and postpone a more thorough study of perception effects under moonlight to a later analysis.

The activity of the 2002 Leonids is measured by Zenithal Hourly Rates (ZHR). This is a meteor number extrapolated to one hour duration which a single observer would see under a sky with a limiting magnitude of +6.5 and with the radiant exactly overhead. The scaling to +6.5 involves an enormous extrapolation of observations under the bright Moon, because limiting magnitudes are significantly lower than +6.5 in all observations submitted. A huge fraction of 40% of the observing periods have lm < +5.0. A mere 3% of the intervals have lm > +6.0.

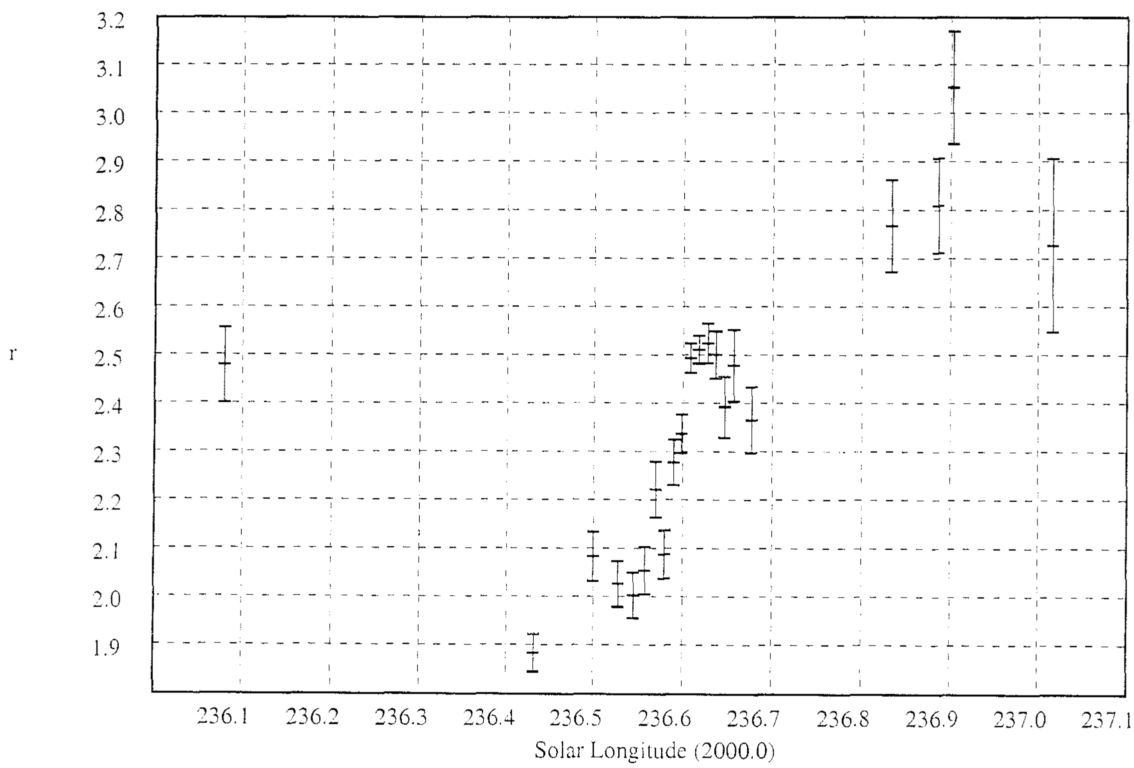

Figure 1 – Population index profile of the 2002 Leonids. Low values denote large fractions of bright meteors; large values represent large fractions of faint meteors.

The low limiting magnitudes make the absolute activity level of the 2002 Leonids in terms of a ZHR virtually inaccessible. A comparison of ZHR profiles from all observations and from those with limiting magnitudes better than or equal to +5.0 is shown in Figures 2 and 3. The graphs are found by an adaptive-bin-size averaging. The adaptiveness is, however, limited to a minimum bin size of 0°0025 or 3.6 minutes. During the two peaks, this minimum is generally reached. Meteor numbers in each average exceed 1000 near the European peak and were above 100 near the American peak. As already mentioned, the European peak (7-revolution trail) is covered by more observations than the American (4-revolution trail), and still the pile of European data waiting for utilization is the largest.

Comparing Figures 2 and 3 immediately reveals the uncertainties caused by the low limiting magnitudes. Since low lm tend to provide higher ZHRs, we may suppose that

(i) the low lm are a result of underestimating the sky quality, or

(ii) the population index is not constant from +4 to +6.

Table 1 – Numerical listing of the 2002 Leonid results. The population indices are interpolated from Figure 1. The ZHRs are taken from Figure 3. Note that *this sample is limited* to observing periods with limiting magnitudes better than +5.0. Solar longitudes refer to equinox J2000.0.

Solar Long.	Date	r	Intervals	Leonids	ZHR	$\overline{\mathrm{lm}}$
236°5052	Nov 19, 01 : 32	2.07 ± 0.05	29	197	114.6 ± 8.1	+5.48
236°5145	Nov 19, 01 : 45	2.05 ± 0.05	22	194	199.0 ± 14.3	+5.50
236°5239	Nov 19, 01 : 58	2.03 ± 0.05	35	189	110.5 ± 8.0	+5.51
236°5326	Nov 19, 02 : 11	2.02 ± 0.05	26	184	138.1 ± 10.2	+5.44
236°5381	Nov 19, 02 : 19	2.01 ± 0.05	23	196	206.6 ± 14.7	+5.42
236°5430	Nov 19, 02 : 26	2.01 ± 0.05	23	192	225.0 ± 16.2	+5.33
236°5482	Nov 19, 02 : 33	2.02 ± 0.05	23	189	264.8 ± 19.2	+5.36
236°5532	Nov 19, 02 : 40	2.04 ± 0.05	24	181	215.7 ± 16.0	+5.55
236°5571	Nov 19, 02 : 46	2.06 ± 0.05	21	150	320.4 ± 26.1	+5.28
236°5611	Nov 19, 02 : 51	2.12 ± 0.05	22	190	301.7 ± 21.8	+5.33
236°5651	Nov 19, 02 : 57	2.18 ± 0.06	24	189	315.8 ± 22.9	+5.41
236°5693	Nov 19, 03 : 03	2.20 ± 0.06	21	144	285.9 ± 23.7	+5.43
236°5730	Nov 19, 03 : 08	2.16 ± 0.05	22	198	308.0 ± 21.8	+5.39
236°5766	Nov 19, 03 : 14	2.11 ± 0.05	20	180	376.0 ± 27.9	+5.36
236°5801	Nov 19, 03 : 19	2.13 ± 0.05	21	175	342.5 ± 25.8	+5.38
236°5835	Nov 19, 03 : 23	2.18 ± 0.05	22	199	404.3 ± 28.6	+5.38
236°5864	Nov 19, 03 : 28	2.23 ± 0.05	20	163	467.6 ± 36.5	+5.37
236°5891	Nov 19, 03 : 31	2.28 ± 0.05	34	321	543.9 ± 30.3	+5.43
236°5914	Nov 19, 03 : 35	2.30 ± 0.04	33	311	720.9 ± 40.8	+5.40
236°5940	Nov 19, 03 : 38	2.32 ± 0.04	55	547	815.0 ± 34.8	+5.39
236°5969	Nov 19, 03 : 43	2.34 ± 0.04	63	689	798.8 ± 30.4	+5.42
236°5993	Nov 19, 03 : 46	2.37 ± 0.04	50	656	1156.0 ± 45.1	+5.41
236°6019	Nov 19, 03 : 50	2.41 ± 0.04	65	895	1125.7 ± 37.6	+5.49
236°6043	Nov 19, 03 : 53	2.45 ± 0.03	71	1187	1447.6 ± 42.0	+5.44
236°6069	Nov 19, 03 : 57	2.48 ± 0.03	99	1296	1609.0 ± 44.7	+5.46
236°6099	Nov 19, 04 : 01	2.50 ± 0.03	108	1948	2145.3 ± 48.6	+5.46
236°6124	Nov 19, 04 : 05	2.51 ± 0.03	87	1849	2324.3 ± 54.0	+5.48
236°6149	Nov 19, 04 : 08	2.51 ± 0.03	98	1990	2506.0 ± 56.2	+5.45
236°6178	Nov 19, 04 : 12	2.52 ± 0.03	97	1756	2284.6 ± 54.5	+5.46
236°6203	Nov 19, 04 : 16	2.52 ± 0.03	78	1128	1966.8 ± 58.5	+5.46
236°6227	Nov 19, 04 : 19	2.52 ± 0.04	76	1098	1803.8 ± 54.4	+5.43
236°6257	Nov 19, 04 : 24	2.52 ± 0.04	84	1175	1577.5 ± 46.0	+5.43
236°6287	Nov 19, 04 : 28	2.52 ± 0.04	71	843	1332.0 ± 45.8	+5.43
236°6318	Nov 19, 04 : 32	2.51 ± 0.05	61	625	1169.3 ± 46.7	+5.44
236°6343	Nov 19, 04 : 36	2.50 ± 0.05	32	321	987.1 ± 55.0	+5.39
236°6366	Nov 19, 04 : 39	2.49 ± 0.05	43	417	947.1 ± 46.3	+5.43
236°6395	Nov 19, 04 : 43	2.46 ± 0.05	44	430	929.6 ± 44.8	+5.41
236°6425	Nov 19, 04 : 48	2.43 ± 0.06	35	235	585.2 ± 38.1	+5.53
236°6453	Nov 19, 04 : 52	2.40 ± 0.06	32	339	711.1 ± 38.6	+5.64
236°6480	Nov 19, 04 : 56	2.41 ± 0.07	26	197	581.1 ± 41.3	+5.62
236°6506	Nov 19, 04 : 59	2.44 ± 0.07	23	199	588.9 ± 41.6	+5.58
236°6535	Nov 19, 05 : 03	2.46 ± 0.07	29	222	502.3 ± 33.6	+5.63
236°6561	Nov 19, 05 : 07	2.47 ± 0.07	28	190	522.4 ± 37.8	+5.65
236°6591	Nov 19, 05 : 11	2.46 ± 0.07	31	183	407.2 ± 30.0	+5.66
236°6621	Nov 19, 05 : 16	2.44 ± 0.07	31	196	471.8 ± 33.6	+5.57
236°6658	Nov 19, 05 : 21	2.43 ± 0.07	36	190	352.3 ± 25.5	+5.58
236°6708	Nov 19, 05 : 28	2.40 ± 0.07	35	174	316.1 ± 23.9	+5.74
236°6782	Nov 19, 05 : 39	2.38 ± 0.07	32	175	251.9 ± 19.0	+5.94
236°6920	Nov 19, 05 : 58	2.41 ± 0.07	45	174	159.1 ± 12.0	+6.06
236°7139	Nov 19, 06 : 30	2.46 ± 0.07	17	85	141.9 ± 15.3	+5.97
236°7502	Nov 19, 07 : 21	2.56 ± 0.08	2	18	243.0 ± 55.7	+5.10
236°7776	Nov 19, 08 : 01	2.62 ± 0.08	2	12	149.9 ± 41.6	+5.11
236°8125	Nov 19, 08 : 50	2.72 ± 0.09	8	49	283.4 ± 40.1	+5.34
236°8297	Nov 19, 09 : 15	2.76 ± 0.09	18	109	313.2 ± 29.9	+5.35
236°8510	Nov 19, 09 : 45	2.78 ± 0.10	22	143	315.7 ± 26.3	+5.35
236°8675	Nov 19, 10 : 09	2.80 ± 0.10	25	193	615.6 ± 44.2	+5.34
236°8753	Nov 19, 10 : 20	2.80 ± 0.10	30	182	802.2 ± 59.3	+5.36
236°8819	Nov 19, 10 : 29	2.81 ± 0.10	27	188	957.5 ± 69.6	+5.44
236°8864	Nov 19, 10 : 36	2.82 ± 0.10	19	133	1742.1 ± 150.5	+5.46
236°8899	Nov 19, 10 : 41	2.86 ± 0.10	16	175	1615.9 ± 121.8	+5.57
236°8933	Nov 19, 10 : 46	2.92 ± 0.11	18	199	2941.3 ± 208.0	+5.42
236°8963	Nov 19, 10 : 50	2.95 ± 0.11	18	196	2252.2 ± 160.5	+5.49
236°8994	Nov 19, 10 : 54	3.00 ± 0.11	19	159	1740.2 ± 137.6	+5.52
236°9062	Nov 19, 11 : 04	3.04 ± 0.12	28	187	1136.7 ± 82.9	+5.54
236°9188	Nov 19, 11 : 22	3.00 ± 0.12	14	190	507.4 ± 36.7	+5.43
236°9422	Nov 19, 11 : 56	2.94 ± 0.14	9	89	293.9 ± 31.0	+5.59
236°9613	Nov 19, 12 : 23	2.89 ± 0.15	7	62	199.7 ± 25.2	+5.60
236°9841	Nov 19, 12 : 55	2.82 ± 0.16	3	22	150.7 ± 31.4	+5.40

The value of r may have been high for relatively bright magnitudes (say magnitudes 0 to +4) and decrease for magnitudes +4 to +6, as was observed in 1999 (Arlt et al. 1999). We should not forget that the highest limiting magnitudes reported may also be inapplicable, because it is definitely possible that observers, especially inexperienced ones, unconsciously try to reach their usual lm despite the Moon. A good lm does not always mean a more reliable lm!

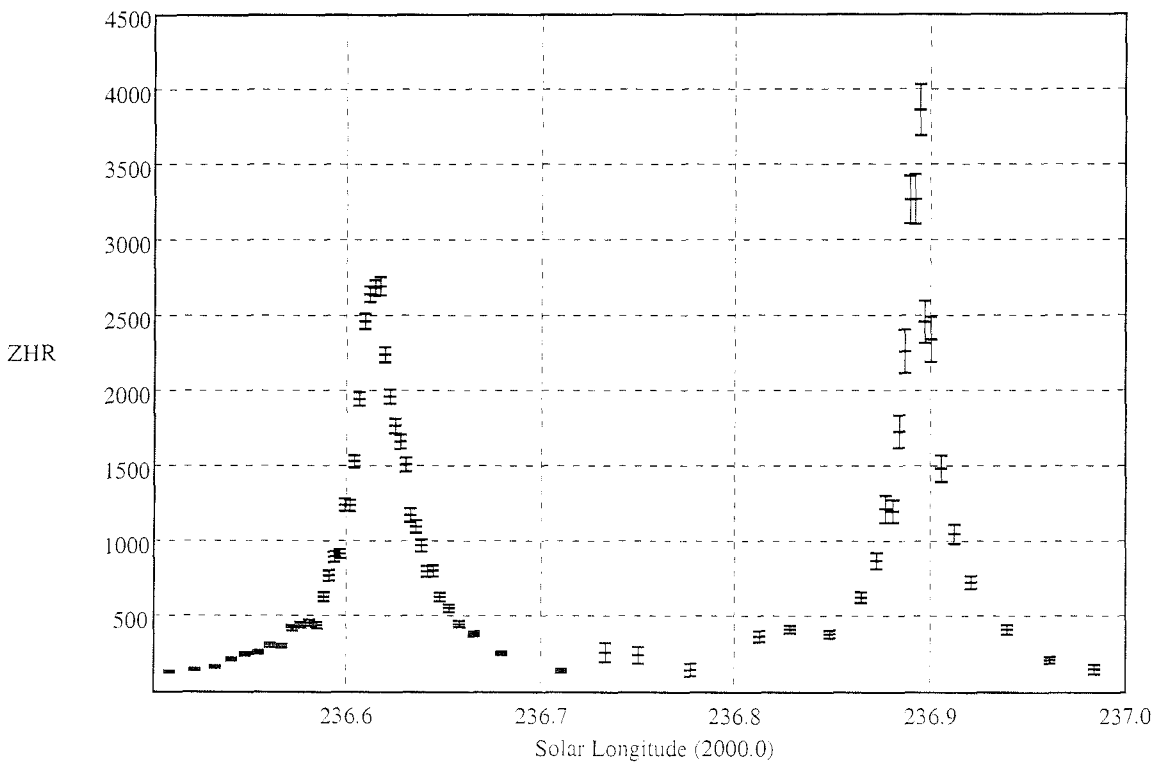

Figure 2 – Activity profile of the 2002 Leonids in terms of the Zenithal Hourly Rate. All observing periods with a maximum correction factor of 10 and a minimum radiant elevation of 20° were used. Implicitly, lm $\geq$ +4.0 because the *Visual Meteor Database* does not store observing periods logged under poorer conditions. The minimum size of averaging windows is 3.6 minutes, but may be larger for periods in which data are less abundant.

The scrutiny of this problem goes beyond the scope of this first analysis; *we suggest assuming the peak values of Figure 3 to be the most reliable ZHR estimates.* These are 2510 ± 60 for the 7-revolution dust trail and 2940 ± 210 for the 4-revolution dust trail. These values are somewhat higher than reported in the first Leonid Circular (Krumov et al. 2002), because smaller averaging bins could be used here.

Because of the size of the Earth, different locations encounter the center of the meteoroid stream at different times. A correction for the topocentric stream encounter must be applied. For the Leonid meteoroid stream, these corrections are of the order of a few minutes—typically shifting the observer's clock time to an earlier topocentric moment. For example, observers in Norway saw the European peak about 5 minutes before colleagues in southern Spain or on Malta. The large fraction of observers in southern France saw the peak 1.6 to 2 minutes earlier, while the group in Algeria encountered the peak 0.7 after topocentric encounter. We applied the correction for topocentric encounter to all individual observing periods according to the equations given by McNaught & Asher (1999).

Although we chose a minimum step size of 3.6 minutes, we permitted periods of up to 6 minutes to be involved in the average. This clearly smears out small-scale structures, but ensures that enough data are used in constructing the profile, thus defining the times of maxima very precisely.

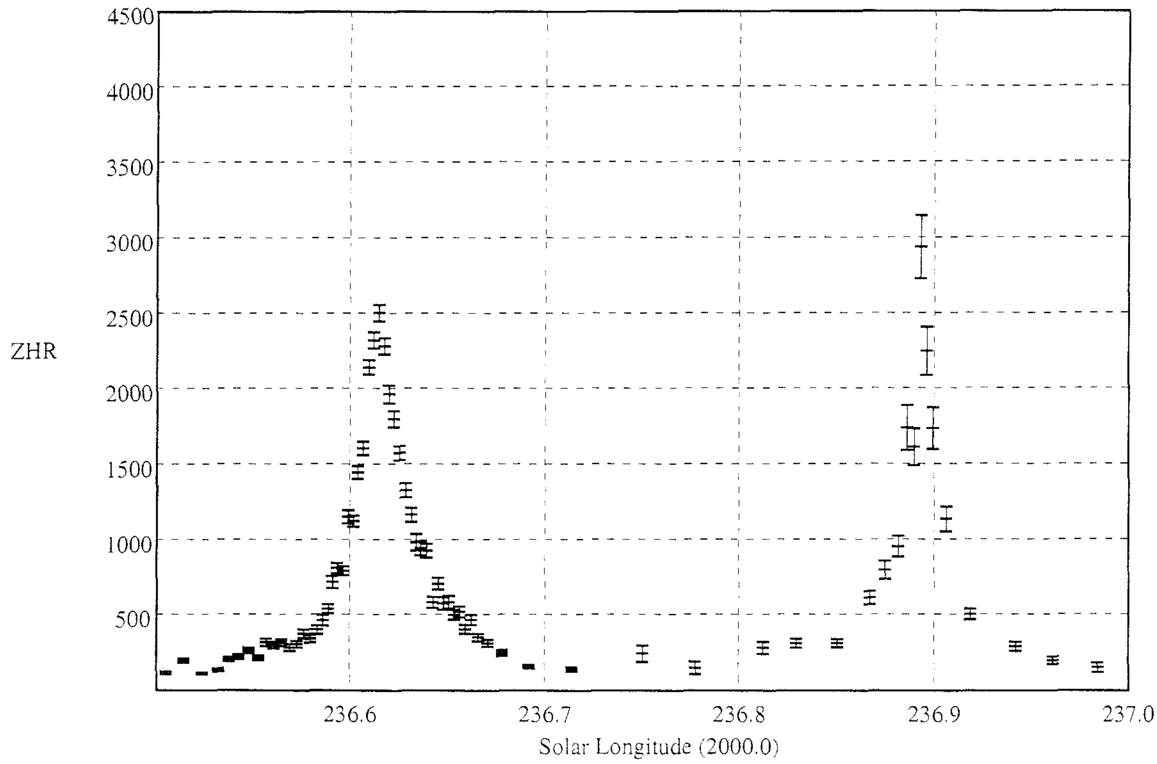

Figure 3 – ZHR profile of the 2002 Leonids as in Figure 2 but based only on observations with a limiting magnitude of +5 or better. We consider this profile more reliable with respect to the determination of the maximum ZHR level of the 2002 Leonids. Numerical data are given in Table 1.

Functions of Lorentz type were applied to the two peaks in order to find their most probable moment of maximum activity and the full width at half maximum (FWHM). The graphs indicate good applicability of Lorentz shapes, although they need not necessarily provide a good fit for a relatively old dust trail like the 7-revolution one.

The first peak in Figure 2 leads to $\lambda_\odot = 236\overset{\circ}{.}6157 \pm 0\overset{\circ}{.}0004$ corresponding to November 19, $04^h10^m \pm 1$ min UT and a FWHM of 39 ± 3 minutes. The fit of the second maximum delivers $\lambda_\odot = 236\overset{\circ}{.}8933 \pm 0\overset{\circ}{.}0004$ corresponding to November 19, $10^h47^m \pm 1$ min UT. The FWHM is significantly shorter with 25 ± 3 minutes. Widths and peak times are the same for fits to the graphs in Figure 2 and 3. The fitting implied a background constant of about $ZHR_{bg} = 100$ (which is also a result of the fits). The FWHMs thus refer to the peak functions above this background level.

A first attempt to look into the fine structure of the two Leonid peaks is shown in Figures 4 and 5. Now all observations are used with the limitations that the total correction factor should not exceed 10 and the radiant elevation should be larger than 20°. The maximum of the 7-revolution dust trail encounter is averaged with a minimum bin size of $0\overset{\circ}{.}001$ corresponding to about 1.4 minutes. Again we permitted larger periods of up to 3 minutes duration to be involved in the averages. Each observing period, however, is used only for one average. The 7-revolution trail in Figure 4 reveals a smooth rise in activity and a ragged decline of activity.

The profile of the 4-revolution trail in Figure 5 is very smooth. The minimum bin size of $0\overset{\circ}{.}001$ is not always reached, because of the smaller number of observing periods available. Reporting no shorter periods than 5-minute bins is a particular drawback in North American observations.

Fits of Lorentz profiles again delivered the same peak centers and FWHMs for both maxima. The results are apparently independent of the data sampling applied. This fact is particularly satisfying as we have attempted to achieve sub-bin accuracy for the peak times by applying reasonable fit functions. Choosing the highest ZHR value for the peak time from Figure 4 or 5 would certainly not be wise. Table 2 finally summarizes the predictions of Leonid maxima in 2002 and the observed peak times and ZHRs obtained in this preliminary analysis.

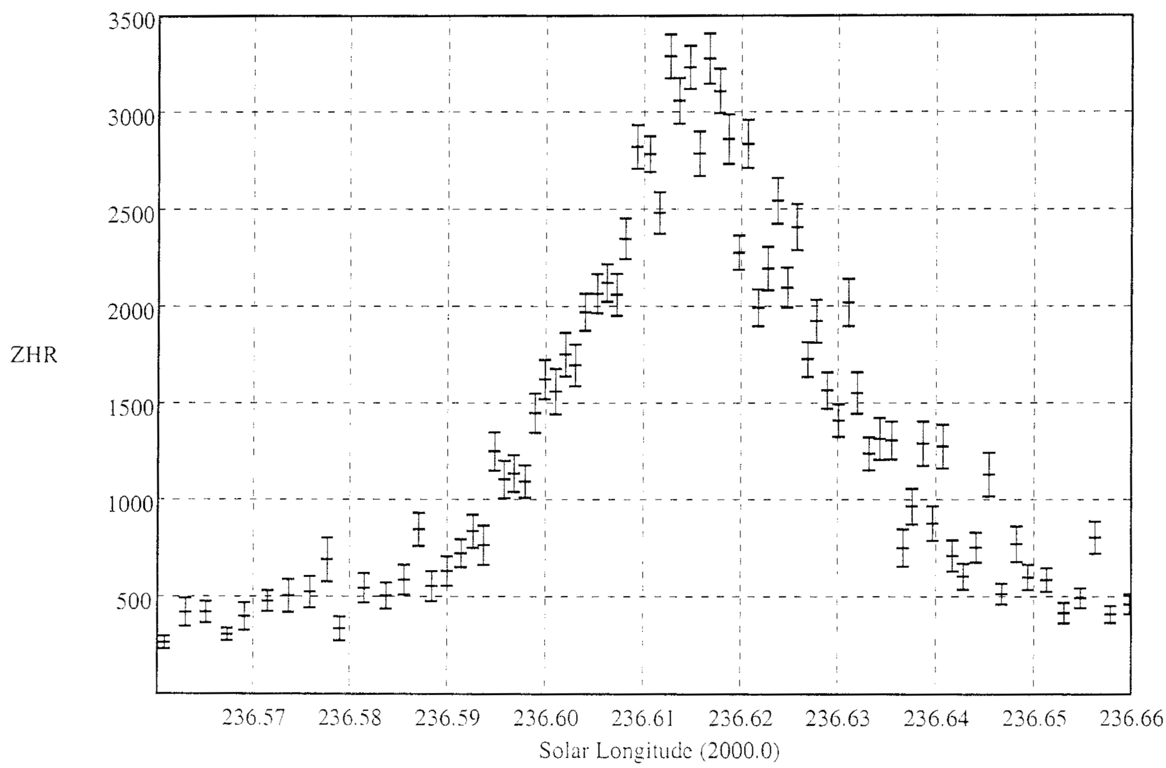

Figure 4 – ZHR profile of the 2002 Leonids near the time of encounter of the 7-revolution dust trail. The bins for averaging are about 1.4 minutes wide near the peak and are about 3 minutes wide in the wings of the graph. The ZHRs may be overestimated due to the low limiting magnitudes involved in the graph (lm $\geq +4.0$). The maximum total correction permitted is 10, the minimum radiant elevation is 20°.

Table 2 – Comparison of predicted Leonid maxima with the preliminary, observed peak times and activity levels in 2002. The observed times are the topocentric stream encounters.

Source	7-revolution dust trail		4-revolution dust trail	
	Time	ZHR	Time	ZHR
Numerical integrations				
Lyytinen & van Flandern (2000)	04 : 02	4500	10 : 44	7400
Lyytinen et al. (2002)	04 : 03	3500	10 : 40	2600
McNaught & Asher (2002)	03 : 56 ± 5	1000 (810–2000)	10 : 34 ± 5	6000 (2900–6000)
Vaubaillon (2002)	04 : 04	3600	10 : 47	3200
Phenomenological models				
Jenniskens (2002)	03 : 48	5900	10 : 23	5400
Langbroek (2002)	–	2000+ (2000–5700)	–	2400+ (2400–5200)
Observed	04 : 10 ± 1	2510 ± 60	10 : 47 ± 1	2940 ± 210

Acknowledgments

The present analysis is based on a part of the observations submitted to the *IMO*. A name list of observers would be confusing, since reports not yet included are not worse than others. We would therefore like to emphasize our gratitude here to all the observers contributing to the global picture of the 2002 Leonid storms. We would also like to thank Jürgen Rendtel and Orlando Benitez Sanchez for their help in data input.

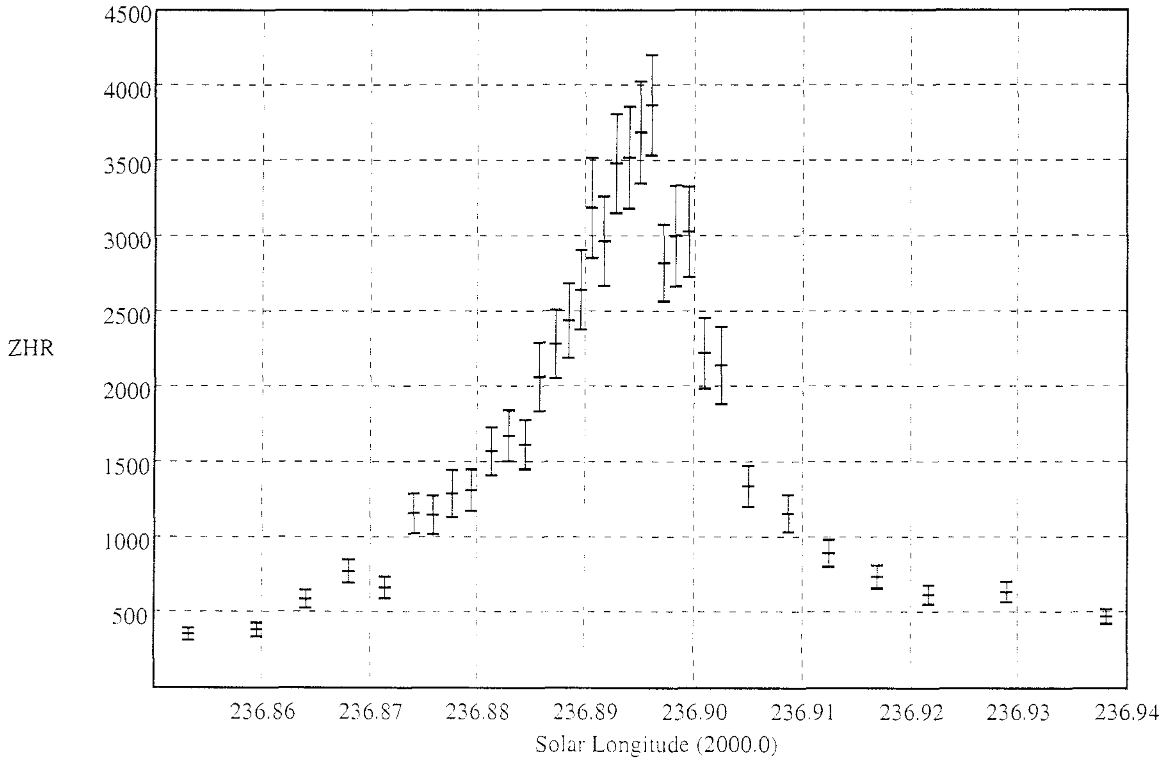

Figure 5 – ZHR profile of the 2002 Leonids near the time of encounter of the 4-revolution dust trail. The length of the averaging bins reduces to about 2 minutes near the peak. As in Figure 4, the ZHRs may be overestimated due to the low limiting magnitudes; the same constraints hold here, too.

References

Arlt R., Bellot Rubio L.R., Brown P., Gyssens M., 1999, "Bulletin 15 of the International Leonid Watch: First Global Analysis of the 1999 Leonid Storm", *WGN* 27:6, pp. 286–295.

Arlt R., Kac J., Krumov V., Buchmann A., Verbert J., 2001, "Bulletin 17 of the International Leonid Watch First Global Analysis of the 2001 Leonid Storms", *WGN* 29:6, pp. 187–194.

Jenniskens P., 2002, "Predictions of Leonid activity, peak time, and viewing conditions", `http://aio.arc.nasa.gov/~leonid/1998.html`, November 2002.

Krumov V., Gyssens M., Arlt R., 2002, "IMO Shower Circular: Leonids 2002", `http://www.imo.net/news/news.html`, November 22, 2002.

Langbroek M., 2002, "Observational evidence for 'punctuated equilibria' in the evolution of Leonid dust trail widths and implications for meteor rate predictions", *Mon. Not. R. Astron. Soc.* 334, pp. L16–L20.

Lyytinen E., van Flandern T., 2000, "Predicting the strength of Leonid outbursts", *Earth, Moon and Planets* 82–83, pp. 149–166.

Lyytinen E., van Flandern T., Nissinen M., 2000, "Leonid predictions for the year 2002", `http://www.ursa.fi/ursa/jaostot/meteorit/leoeng02.html`, November 2002.

McNaught R.H., Asher D.J., 1999, "Variation of Leonid maximum times with location of observer", *Meteorit. Planet. Sci.* 34, pp. 975–978.

McNaught R.H., Asher D.J., 2002, "Leonid Dust Trail Structure and Predictions for 2002", *WGN* 30:5, pp. 132–143.

Vaubaillon J., 2002, "Activity Level Prediction for the 2002 Leonids", *WGN* 30, pp. 144–148.

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The 2002 Leonids Using 28 MHz Ham-band Radio Observations (HRO) over Japan

Takashi Usui, Hiroshi Ogawa, Takema Hashimoto, Kouji Ohnishi, Noriyuki Yaguchi, Kimio Maegawa

The 2002 Leonids were expected to present a spectacular appearance over Europe and America. No spectacular appearance was expected in Japan. On the evening of November 17 (UT), however, the 1965 dust trail was predicted to approach the Earth closely. Therefore, Japanese observers tried to detect this trail using 28 MHz radio. This is because 28 MHz observations can detect fainter meteor echoes than 53 MHz observations which are prevalent in Japan. This study shows the observing method and results of 28 MHz observations of the 2002 Leonids. We found that the Leonids were detectable for longer at 28 MHz than at 53.75 MHz. This indicates that the distribution of fainter (smaller) meteors is wider than that of larger ones.

1. Introduction

In the 2002 Leonids, a spectacular appearance was expected over Europe and America [1–3]. On the other hand, no appearance like this was expected in Japan. However, one challenging prediction was made, namely that the Earth would approach the 1965 (1-revolution) dust trail on November 17 20h UT. The calculated distance between the 1965 trail and the Earth was about 0.0018 AU [4]. Since this distance is in the outer region of the dust trail, the density of meteors would be weak. Further, at the time, it was four years and eight months after the parent comet had passed. Thus, if the storm due to the 1965 (1-revolution) dust trail happened as in the 1969 storm observed by radar, the velocity of the dust particles encountered in 2002 would be very fast, as ejected from the parent comet 55P/Tempel-Tuttle in 1965. This would imply small particles with faint magnitudes.

Japanese Radio Observation were started in 1971 by Kazuhiro Suzuki *et al.*. In 1996 new radio observations, Ham-band Radio Observation (HRO) using 53.750 MHz, started. The transmitting station is the Fukui National College of Technology (Fukui, Japan). These observations have become the prevalent method in Japan [5].

In the observation of the Leonid meteor shower, since the velocity of dust particles is very fast (71 km/s), most of the meteor echoes observed at 53 MHz are overdense. This causes the height ceiling effect [6]. In this study, since the main purpose was the detection of the 1965 dust trail, we had to use a lower frequency that can detect fainter meteors than 53 MHz. The next lower Ham-band than 50 MHz is the 28 MHz band. On this occasion, therefore, some Japanese observers tried to detect the 1965 dust trail activity by using 28 MHz Ham-band Radio Observation.

2. Transmitting Station

We used the 28 MHz-band in this Leonid observation. The transmitting station was located in Toyoshina, Nagano, Japan (137.90°E, 36.28°N). The frequency was 28.208 MHz with a 50-W continuous carrier beacon (callsign JR0YAN). This transmitting station is managed by Noriyuki Yaguchi. The antenna is a loop antenna that is shown Figure 1 and the antenna pattern is shown in Figure 2. The antenna plane is horizontal so that the signal is transmitted to the zenith.

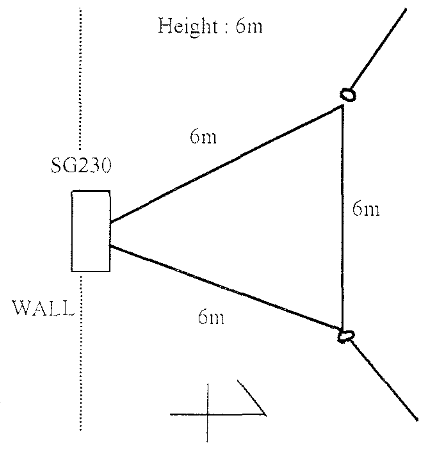

Figure 1 – The transmitting antenna for 28 MHz observations at Toyoshina, Nagano, in Japan.

3. Observing methods and stations

The observing method was the same as for 53 MHz observations [5]. An SSB receiver was used, which translated (converted) the echoes at radio frequencies into the audio spectrum. Various kinds of receiving antenna were used, e.g. a two-element Yagi and a dipole.

At the receiving station, the observing software HROFFT was run under the Windows operating system. This software was developed by Kazuhiko Ohkawa. It analyzed the audio input signals by Fast Fourier Transform. On this occasion, since the forward scatter method was being used for the first time at 28 MHz, most of the stations observed at both 28 MHz and 53 MHz for comparison. For such observations, we used 2-channel HROFFT that can observe two channels (stereo-input) synchronously. This is the best tool for monitoring two radio signals. The observed image file is shown in Figure 4.

This 28 MHz observation was the first such trial. At first, therefore, we confirmed the effectiveness of this technique. As a result, we succeeded in obtaining many meteor echoes. In daytime a continuous carrier was received, however, so we could not observe in daytime. But we could see the daily variation at all observing sites. The detailed results are shown in the next section.

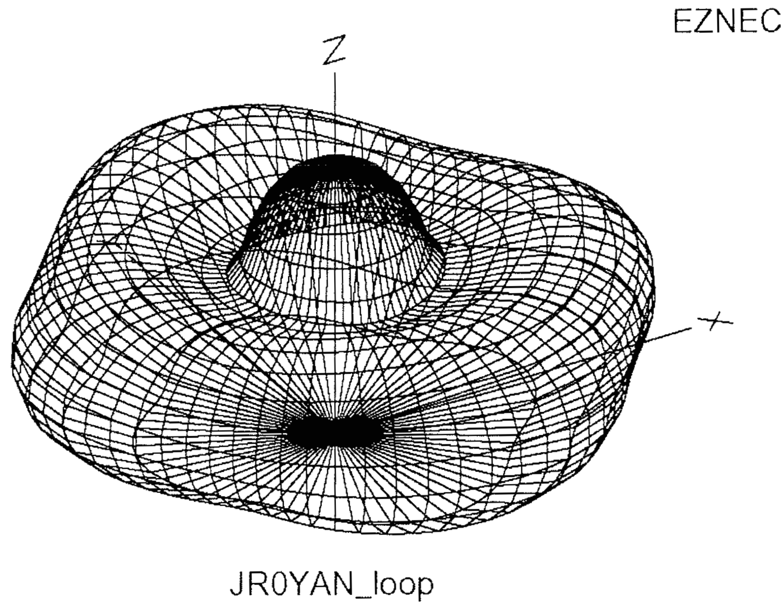

Figure 2 – The radiation pattern of the transmitting antenna. (Simulated by Kimio Maegawa using *EZ-NEC* software, x-axis: west.)

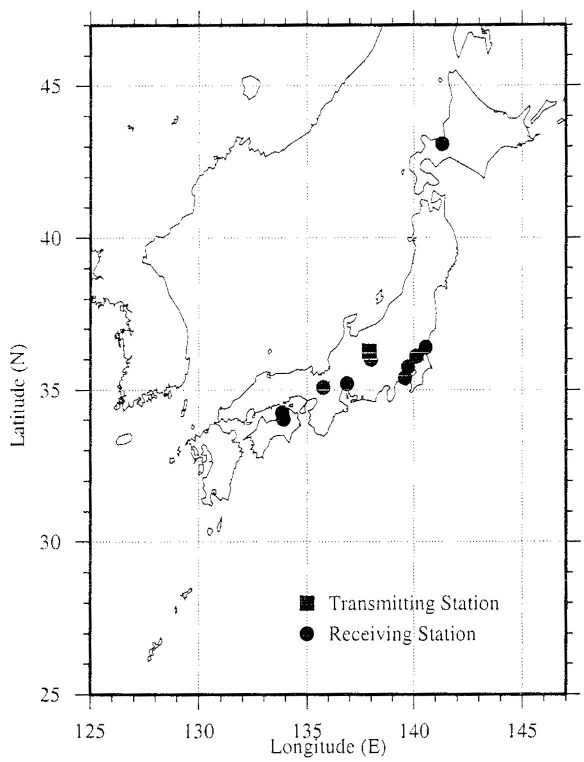

Figure 3 – Map of the 28 MHz observing stations.

The observing stations are mapped in Figure 3. There were eleven observing sites. The observers were the following:

Toshihiko Masaoka, Hiroshi Ogawa, Takashi Usui, Hirotoshi Hara, Masaaki Ogawa, Taku Nakajima, Ikeda and Awa High School (Masafumi Onodera), Sigeo Sambe, Ibraki National College of Technology (Radio Club), Yasushi Yoshikawa, Nagano National College of Technology (Kouji Ohnishi).

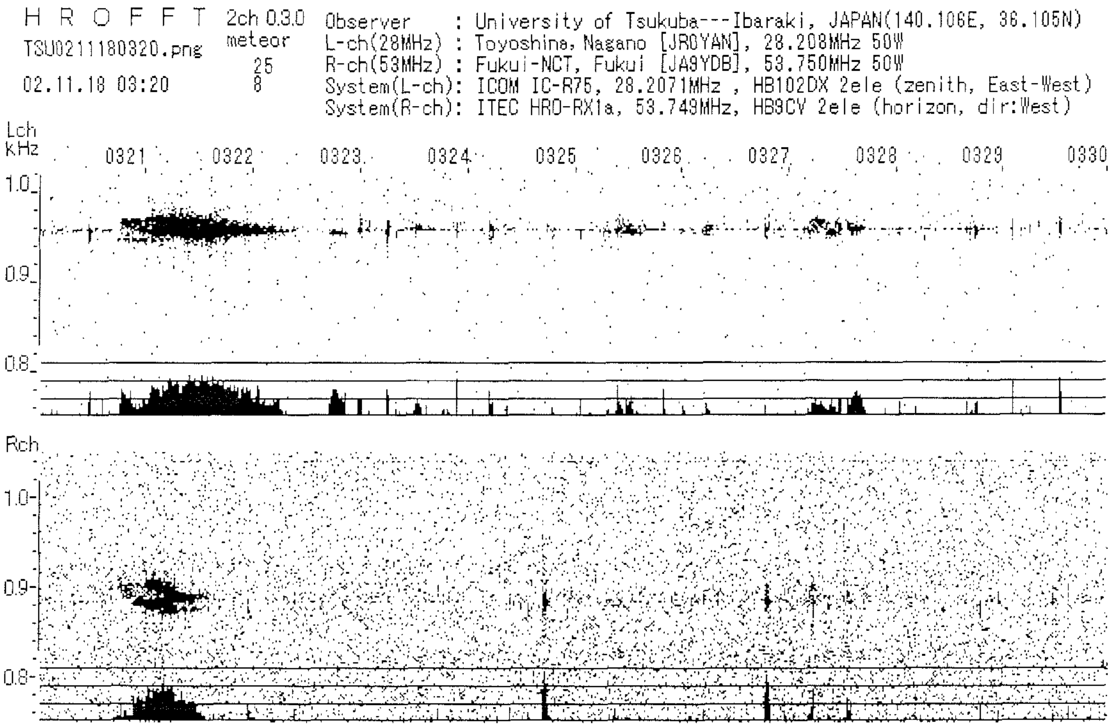

Figure 4 – Image file produced by the 2-channel HROFFT. L-ch is 28.208 MHz and R-ch is 53.750 MHz at University of Tsukuba station (Hiroshi Ogawa).

4. Results

Figure 4 shows the image file produced by the 2-channel HROFFT software at the Tsukuba observing station. The observer obtained one image file every 10 minutes. Therefore, the total image numbers were 144 per day. The vertical axis is frequency and horizontal axis is time. The 28 MHz observations obtained many more echoes than 53 MHz. Moreover, the continuous echoes lasted longer. If a very long echo appeared, some short ones were hidden. Therefore, we have to consider this effect. For the moment, however, we ignore it.

Figure 5 shows the graph of echo counts at 28.208 MHz at the Tokushima observing station. Figure 6 shows the echo counts at 53.750 MHz at the Osaka observing station. The horizontal axis is the time scale in Universal Time (UT). The vertical axis is the hourly count. The distance between the transmitting and receiving stations was about 400 km at the Tokushima station (Toyoshina-Tokushima) and about 160 km at the Osaka station (Fukui-Osaka).

The results using 28 MHz caught the beginning of the Leonid activity around November 14. On the other hand, the 53 MHz observations did not catch this activity. Around November 16, the 53 MHz observations caught the increase in Leonid activity. Therefore the 28 MHz observations caught the Leonid activity earlier than the 53 MHz observations.

This frequency-dependant difference is caused by the height ceiling effect. The ceiling height of 28 MHz observations is higher than that of 53 MHz observations. Thus the limiting magnitude of meteors at 53 MHz is about $m = 3$ and that at 28 MHz observation is about $m = 6$. Therefore, 28 MHz observations can detect more and fainter meteor echoes. Thus, the earlier detection of Leonid activity at 28 MHz than at 53 MHz means that dust particles of smaller size were distributed more widely than larger ones. Therefore there is some potential to detect the size distribution by comparing the 28 MHz and 53 MHz HRO data.

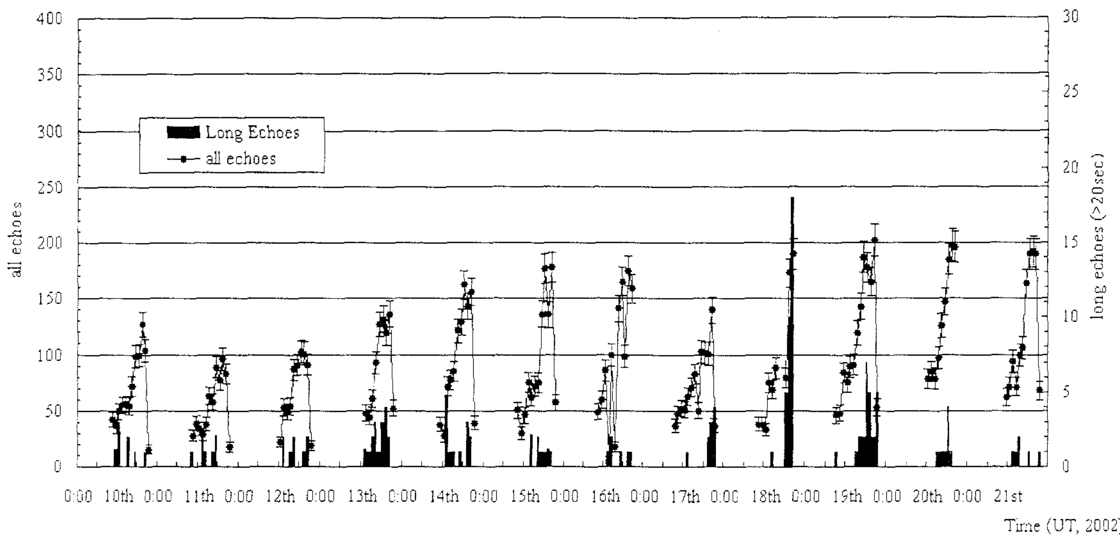

Figure 5 – The hourly rate at 28.208 MHz at the Tokushima observing station (Ikeda and Awa High School).

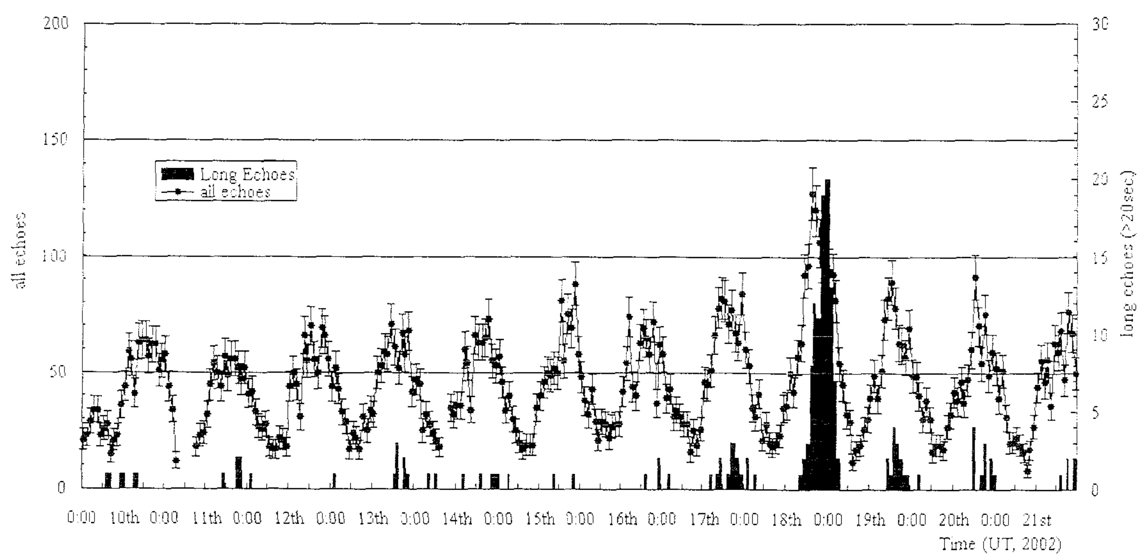

Figure 6 – The hourly rate at 53.750 MHz at the Osaka observing station (Masayoshi Ueda).

5. The detection of the 1965 dust trail

As shown in the previous section, 28 MHz observation is very useful for obtaining a meteor shower profile and analyzing its characteristics. Using this result, we tried to detect the activity provided by the 1965 dust trail activity. Here we used 10 minute count rates because the FWHM of 1965 dust trail would be short, as was the 1969 radio storm. However, we could not find a clear peak from this result at the present. For the moment, however, we cannot determine that there was no 1965 dust trail activity. This is because three possibilities exist, as follows. (1) Although 1965 dust trail activity existed, the meteor magnitude was fainter than $m = 6$, and 28 MHz observations can only detect meteor echoes brighter than sixth magnitude. (2) So far we have only analyzed results from some observing stations. Although observing stations were located at 11 points, we have not yet received data from all observing sites. Therefore, it may be possible to detect some activity if we unify all observed data. (3) There was no 1965 dust trail activity at all.

6. Conclusion and future work

The potential and effectiveness of 28 MHz observations were shown in this study. Since these observations can detect fainter meteor echoes, it becomes possible to obtain a meteor size distribution profile by comparison with 53 MHz observations. During the daytime, however, it is difficult to use 28 MHz observation because of a continuous carrier received. Therefore, we cannot detect meteor activity during the daytime. But observation during the night was achieved.

This study succeeded in obtaining a Leonid activity profile of dust particles. In the center of the Leonid stream there are many bright meteors (large particles); faint meteors (small particles) are distributed around the Leonid dust tube.

No clear 1965 dust trail activity was detected in this study. There are not enough data, however, and various interpretations are possible. Therefore, we are researching further these possibilities for the detection of the 1965 dust trail activity.

Acknowledgments

We thank all observers who participated in 28 MHz observation and all participants of *The International Project for Radio Meteor Observation.*

References

[1] R. H. McNaught and D. J. Asher, "Leonid Dust Trail Structure and Predictions for 2002", *WGN* 30 (2002), pp. 132–143.

[2] E. Lyytinen, T.Van Flandern and M. Nissinen, "Leonid Predictions for year 2002", `http://www.ursa.fi/ursa/jaostot/meteorit/leoeng02.html`, 2002.

[3] Jeremie Vaubaillon, "Activity Level Predictions for the 2002 Leonids", *WGN* 30 (2002), pp. 144–148.

[4] R. H. McNaught and D. J. Asher, "Leonid Dust Trails and Meteor Storms", *WGN* 27 (1999), pp. 85–102.

[5] K. Maegawa, "HRO: A New Forward-Scatter Observation Method Using a Ham-Band Beacon", *WGN* 27 (1999), pp. 64–72.

[6] D. W. R. McKinly, "Meteor Science and Engineering", McGraw-Hill Book Company (1961).

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The 2002 Leonid MAC Airborne Mission: First Results

Peter Jenniskens, SETI Institute

The *NASA*- and *USAF*-sponsored *2002 Leonid Multi-Instrument Campaign* consisted of two instrumented aircraft that flew from Madrid, Spain, to Omaha, Nebraska, with 38 researchers on board to cover the two Leonid storm peaks. Both aircraft were above clouds and under perfect observing conditions, with a radiant climbing from 35 to 67 degree elevation and the full Moon relatively low in the sky. All instruments worked as expected and aurora, moon, and meteors made the view scenic and truly spectacular at times. This report is a brief impression of the mission and a first look at some of the results in the weeks following the campaign.

1. Introduction

In the *2002 Leonid Multi-Instrument Aircraft campaign*, we had the privilege of using the *NASA* DC-8 Airborne Laboratory for meteor storm research, in a stereoscopic viewing with the *USAF/ FISTA* aircraft used in earlier missions [1–8]. This was our fourth and final mission as part of the *Leonid MAC program* and offered a team of 38 researchers from 7 different countries a chance to see the 2002 Leonid storms under ideal observing conditions. By following a westward trajectory from Madrid (Spain) to Omaha (Nebraska), we were able to have a 10-hour night in which the Leonid radiant rose from 35 degrees at the onset to 67 degrees just before landing. Moreover, the near-full Moon was relatively low in the sky near the nose of the planes.

Figure 1 – The DC-8 "Airborne Laboratory" aircraft crew and scientists (photo Eric James).

2. Experiments

At Torrejon de Ardoz, near Madrid, we were hosted by the *Centro de Astrobiologia* (*CAB*) of director Juan Perez-Mercader. Three *CAB* participants operated one of many instruments on the DC-8 aircraft. Those instruments included the *German University of Bremen* sub-mm spectrometer "ASUR" that measured NO, O_3, HCl, HCN and H_2CO repeatedly during flight, in search of variations in the abundance of upper atmosphere molecules from the increased influx of meteoroids or their effect on the atmosphere. In the same direction, a fiber-optic coupled slit-spectrograph of the *University of East Anglia* (UK) measured OH, Na, and O_2 airglow at optical wavelengths, while a near-IR InGaAs camera from *Utah State University* imaged the OH airglow. The USU team also filmed meteors through narrow-band filters. Three high-resolution spectrographs targeted the near-UV (using high-definition TV detection—ISAS, Japan), the visible region (*SETI Institute*) and the near-IR (*CAB*), this last using unintensified cooled CCD cameras. A prototype automatic rapid pointing "AIMIT" meteor tracker was operated by George Varros, as a technology demonstration in a project with Peter Gural and the author.

Figure 2 – The NCK-135 *FISTA* aircraft crew and scientists (photo courtesy Eric James).

In addition, a team of eight amateur astronomers counted the meteors detected by window-mounted intensified cameras using a video headset display. An automatic tool developed by Chris Crawford and Mike Koop took a tally of the counts, which were analyzed, displayed, and transmitted in the form of brief one-line e-mails via globalstar satellite uplink by interactive software developed and operated by Morris Jones. This provided near-real time counts to satellite operators. The flux measurement team consisted of meteor observers Chris Crawford, Peter Gural, David Holman, Morris Jones, Jane Houston-Jones, Bob Lunsford, David Nugent, and Ruediger Jehn. Ruediger represented *ESA*, who helped distribute the counts.

For the first time, *FISTA* was equipped with "sticky tape", a dust collector from the *University of New Mexico at Albuquerque* in an attempt to gather meteoric debris from the first storm peak in the hours after the storm. The *FISTA* aircraft also deployed a 3–5.5 micron mid-IR spectrograph "MIRIS", capable of taking images and spectra of meteors and of persistent trains in search of the 3.4-micron band of complex organic molecules in meteoroids. In addition, *FISTA* deployed low-resolution slit-less spectroscopic techniques at ultraviolet (Rick Rairden, Lockheed Palo Alto) and optical wavelengths (Jiři Borovička, Ondrejov Observatory, Czech Republic). Kristina Smith operated two Digital Array-Scanned Interferometer (DASY) spectrographs as a technology demonstration. A third spectrograph (*SETI Institute*) recorded low resolution spectra of intrinsically faint meteors on high-definition TV (*NASA Ames*) for measurements of meteoroid composition. Finally, Ian Murray of the *Canadian University of Regina* performed a study of meteor light curves and meteoroid morphology, completing an airborne dataset covering 1998–2002, complemented by the photometric studies of Hans Stenbaek-Nielsen on the DC-8.

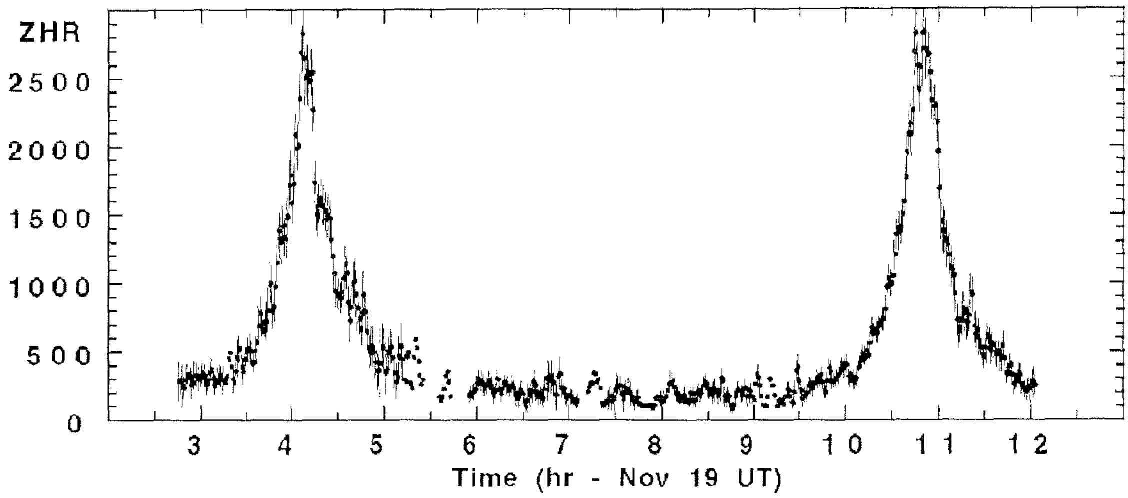

Figure 3 – Summary of 1-minute meteor counts (courtesy Leonid MAC flux measurement team).

3. Results

Near-real time flux measurements[1]

The Leonid meteor storms occurred much as predicted. European observers saw the peak at 04^h06^m UT (ZHR $\approx 2,300$/hr—scaled to early *IMO* results [9]), while observers in the Americas witnessed a storm peaking at 10^h47^m UT (ZHR $\approx 2,600$/hr). Times are corrected for topography [10]. Both peaks were narrow, with a full-width-at-half-maximum of only 0.52 and 0.50 hours respectively. Both peaks were rich in faint meteors. Preliminary results from 1-minute counts (with a 3-point average and given in 2-minute intervals) are presented in Table 1 and Figure 3. They show a very precise slightly asymmetric Lorentz-shaped flux profile with no obvious filamentary structure or sub-peaks. A high background of activity persisted between the two storm peaks. That background may reflect the 1833 dust trail encounter (Lyytinen's prediction put the encounter time at 06^h36^m UT [11]). However, the high rates before the first storm peak and gradual decline during the observing period suggest that this is a manifestation of the Leonid Filament [12], peaking before 03^h UT. Indeed, the magnitude distribution index was measured to be smaller between the storms: $r = 1.7 \pm 0.3$, versus a storm value of $r = 2.1 \pm 0.3$. These values will be improved upon further analysis. Also the absolute scale of the flux measurements is still uncertain. The near-real time data had peak rates of 1,000/hr and 1,400/hr, respectively. Similar data from visual observations by Jim Richardson and a team of observers at *Mount Lemmon Observatory* puts the peak ZHR of the 2nd storm as low as 800/hr, with pre-storm $r = 2.5$ versus a storm value of $r = 3.5$. A further improvement of results is expected when the sky limiting magnitude and r have been studied in more detail, and when also the *FISTA* intensified video camera tapes (operated by Mike Koop) have been examined.

These observations provide important new data for dust trail models. The narrow flux profiles agree within error with the predicted durations of approximately 0.64 and 0.60 hours [14], respectively, and demonstrate that the dust trails do not widen over time, as in the models by Lyytinen et al. (radiation pressure), Asher & McNaught, and Vaubaillon and Colas (a.o., from dynamic forces on dynamically different orbits). The strong showing of the 1767 dust trail relative to that of 1866 in Asher's model illustrates again that the trail positions are slightly further inward to the sun than calculated. The most important result may have been the high abundance of faint meteors. This is actually predicted in theoretical models, because the smaller grains are supposed to have the highest surface-to-mass ratio and therefore the strongest push from water vapor drag during ejection and solar radiation pressure while in orbit. However, last year's shower did not show that effect. Hence the distribution of meteoroid sizes in the trails is still poorly understood.

[1] It needs to be emphasized that the term "flux" is misleading. The author refers to visual meteor activity, while flux measures particles per unit time and unit area and is only accessible after thorough analysis—Ed.

Table 1 – Preliminary results from 1-minute counts on November 19, 2002.

Time (hr)	$\lambda_\odot$ (J2000)	ZHR (/hr)	Time (hr)	$\lambda_\odot$ (J2000)	ZHR (/hr))	Time (hr)	$\lambda_\odot$ (J2000)	ZHR (/hr)	Time (hr)	$\lambda_\odot$ (J2000)	ZHR (/hr)
2.767	236.5580	284± 99	4.950	236.6497	365± 83	7.467	236.7554	136± 41	09.567	236.8437	175± 32
2.800	236.5594	253±108	4.983	236.6511	546±110	7.500	236.7569	221± 47	09.600	236.8451	250± 36
2.833	236.5607	292± 56	5.017	236.6525	355± 76	7.533	236.7583	248± 40	09.633	236.8465	238± 40
2.867	236.5621	336± 52	5.050	236.6539	496± 73	7.567	236.7597	188± 43	09.667	236.8479	261± 33
2.900	236.5636	257± 69	5.083	236.6553	533± 76	7.600	236.7611	195± 45	09.700	236.8493	282± 36
2.933	236.5650	332± 67	5.117	236.6567	345± 74	7.633	236.7625	216± 58	09.733	236.8507	328± 39
2.967	236.5664	304± 58	5.150	236.6581	309± 93	7.667	236.7639	185± 56	09.767	236.8521	203± 31
3.000	236.5677	316± 49	5.183	236.6595	539±108	7.700	236.7653	140± 38	09.800	236.8535	285± 39
3.033	236.5692	324± 52	5.217	236.6609	293± 72	7.733	236.7667	156± 39	09.833	236.8549	354± 52
3.067	236.5706	257± 47	5.250	236.6623	462±163	7.767	236.7681	117± 29	09.867	236.8563	275± 33
3.100	236.5720	345± 48	5.283	236.6637	261± 92	7.800	236.7695	95± 24	09.900	236.8577	297± 39
3.133	236.5733	302± 43	5.317	236.6651	456±161	7.833	236.7709	100± 25	09.933	236.8591	335± 41
3.167	236.5748	275± 36	5.350	236.6665	520±184	7.867	236.7723	111± 28	09.967	236.8605	397± 38
3.200	236.5762	332± 45	5.383	236.6679	324±115	7.900	236.7737	89± 22	10.000	236.8619	395± 39
3.233	236.5776	293± 49	5.417	236.6693	291±103	7.933	236.7751	155± 39	10.033	236.8633	314± 38
3.350	236.5825	295± 63	5.600	236.6770	169± 42	7.967	236.7765	155± 39	10.067	236.8647	322± 31
3.383	236.5839	359± 82	5.633	236.6784	168± 42	8.000	236.7779	144± 39	10.100	236.8661	271± 34
3.417	236.5853	514± 66	5.667	236.6798	318± 79	8.033	236.7793	158± 36	10.133	236.8675	376± 34
3.450	236.5867	385± 56	5.700	236.6812	280± 70	8.067	236.7807	214± 34	10.167	236.8689	438± 42
3.483	236.5881	444± 56	5.917	236.6903	175± 33	8.100	236.7821	278± 48	10.200	236.8703	434± 41
3.517	236.5895	511± 58	5.950	236.6917	200± 33	8.133	236.7835	245± 38	10.233	236.8717	507± 41
3.550	236.5909	501± 51	5.983	236.6931	217± 38	8.167	236.7849	196± 36	10.267	236.8731	559± 53
3.583	236.5923	419± 51	6.017	236.6945	297± 38	8.200	236.7863	147± 24	10.300	236.8745	625± 52
3.617	236.5937	566± 61	6.050	236.6959	273± 36	8.233	236.7877	178± 41	10.333	236.8759	652± 53
3.650	236.5951	779± 82	6.083	236.6973	231± 37	8.267	236.7891	154± 28	10.367	236.8773	680± 47
3.683	236.5965	655± 68	6.117	236.6987	294± 40	8.300	236.7905	142± 30	10.400	236.8787	732± 53
3.717	236.5979	718± 90	6.150	236.7001	251± 40	8.333	236.7919	196± 30	10.433	236.8801	805± 59
3.750	236.5993	1000±101	6.183	236.7015	175± 40	8.367	236.7933	136± 21	10.467	236.8815	1022± 68
3.783	236.6007	797± 91	6.217	236.7029	302± 43	8.400	236.7947	212± 33	10.500	236.8829	993± 61
3.817	236.6021	970± 74	6.250	236.7043	227± 31	8.433	236.7961	199± 35	10.533	236.8843	1195± 69
3.850	236.6035	1379± 94	6.283	236.7057	224± 33	8.467	236.7975	283± 40	10.567	236.8857	1393± 74
3.883	236.6049	1302±107	6.317	236.7071	265± 39	8.500	236.7989	227± 43	10.600	236.8871	1398± 83
3.917	236.6063	1331± 95	6.350	236.7085	219± 38	8.533	236.8003	188± 31	10.633	236.8885	1588± 77
3.950	236.6077	1481±102	6.383	236.7099	260± 39	8.567	236.8017	226± 41	10.667	236.8899	1945±103
3.983	236.6091	1790±121	6.417	236.7113	184± 37	8.600	236.8031	194± 52	10.700	236.8913	2154± 99
4.017	236.6105	1727±103	6.450	236.7127	161± 49	8.633	236.8045	212± 48	10.733	236.8927	2255±114
4.050	236.6119	1985±111	6.483	236.7141	217± 44	8.667	236.8059	286± 41	10.767	236.8941	2817±124
4.083	236.6133	2350±118	6.517	236.7155	145± 29	8.700	236.8073	147± 31	10.800	236.8955	2410±110
4.117	236.6147	2819±121	6.550	236.7169	139± 59	8.733	236.8087	171± 34	10.833	236.8969	2820±111
4.150	236.6161	2499±134	6.583	236.7183	180± 55	8.767	236.8101	86± 23	10.867	236.8983	2702±151
4.183	236.6175	2520±148	6.617	236.7197	280± 51	8.800	236.8115	180± 33	10.900	236.8997	2667±106
4.217	236.6189	2539±120	6.650	236.7211	204± 41	8.833	236.8129	219± 44	10.933	236.9011	2329± 95
4.250	236.6203	1728±109	6.683	236.7225	164± 35	8.867	236.8143	187± 43	10.967	236.9025	2298± 97
4.283	236.6217	1486±104	6.717	236.7239	155± 42	8.900	236.8157	234± 43	11.000	236.9039	1954± 93
4.317	236.6231	1613± 97	6.750	236.7253	307± 62	8.933	236.8171	167± 45	11.033	236.9053	1447±101
4.350	236.6245	1562± 99	6.783	236.7267	299± 68	8.967	236.8185	206± 38	11.067	236.9067	1360±105
4.383	236.6259	1467± 97	6.817	236.7281	281± 85	9.000	236.8199	146± 37	11.100	236.9081	1270±112
4.417	236.6273	1471± 91	6.850	236.7295	175± 75	9.033	236.8213	335± 44	11.133	236.9095	1111± 99
4.450	236.6287	1193± 83	6.883	236.7309	315± 72	9.067	236.8227	248± 36	11.167	236.9109	1051± 91
4.483	236.6301	941± 81	6.917	236.7323	224± 43	9.100	236.8241	104± 26	11.200	236.9123	726± 79
4.517	236.6315	899± 73	6.950	236.7337	219± 34	9.133	236.8255	96± 24	11.233	236.9137	667± 70
4.550	236.6329	933± 72	6.983	236.7351	157± 29	9.167	236.8269	297± 74	11.267	236.9151	803± 83
4.583	236.6343	1139± 88	7.017	236.7365	162± 37	9.200	236.8283	250± 62	11.300	236.9165	705± 85
4.617	236.6357	859± 73	7.050	236.7379	147± 24	9.233	236.8297	176± 44	11.333	236.9179	763± 86
4.650	236.6371	818± 95	7.083	236.7393	123± 28	9.267	236.8311	103± 26	11.367	236.9193	908± 87
4.683	236.6385	1009±111	7.200	236.7442	206± 52	9.300	236.8325	145± 36	11.400	236.9207	625± 69
4.717	236.6399	821±111	7.233	236.7457	261± 65	9.333	236.8339	116± 29	11.433	236.9221	595± 90
4.750	236.6413	663± 80	7.267	236.7471	344± 86	9.367	236.8353	217± 38	11.467	236.9235	531± 56
4.783	236.6427	909±123	7.300	236.7484	278± 70	9.400	236.8367	172± 27	11.500	236.9249	462± 62
4.817	236.6441	645± 74	7.333	236.7498	231± 58	9.433	236.8381	121± 23	11.533	236.9263	612± 60
4.850	236.6455	495± 80	7.367	236.7513	94± 24	9.467	236.8395	352± 49	11.567	236.9277	510± 71
4.883	236.6469	535±102	7.400	236.7527	131± 33	9.500	236.8409	284± 54	11.600	236.9292	543± 64
4.917	236.6483	417± 80	7.433	236.7541	159± 48	9.533	236.8423	156± 42	11.633	236.9305	470± 62

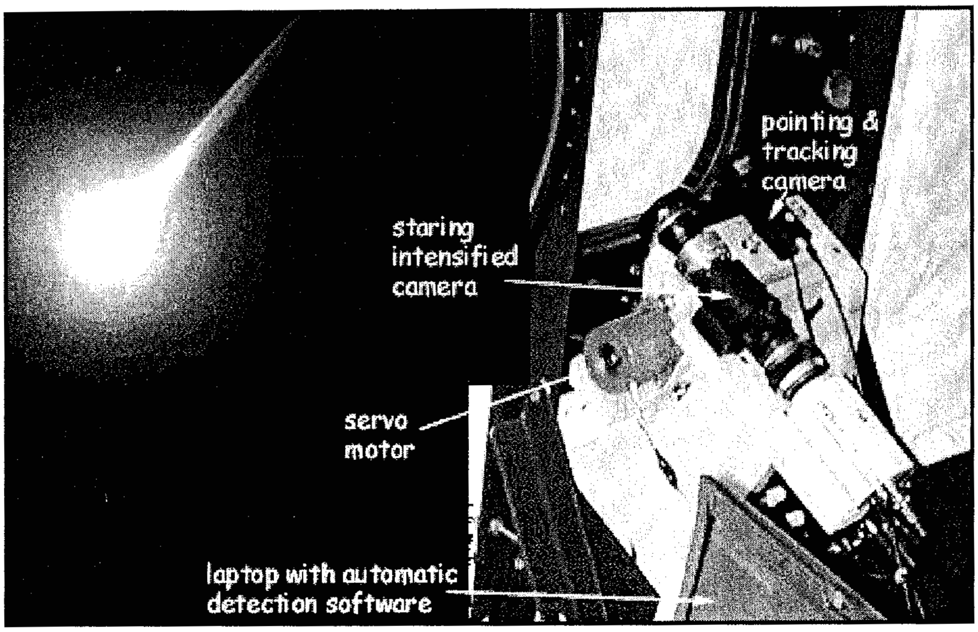

Figure 4 – Bright −8 magnitude 06:49:55 UT fireball tracked after automatic pointing (courtesy George Varros).

Spectroscopy and Imaging of meteors

Some other highlights include a tracked −8 magnitude Leonid fireball at $06^h49^m55^s$ UT November 17 (Figure 4). This and the tracking of many fainter meteors demonstrated for the first time that automatic rapid pointing to meteors is possible from aircraft. After a brilliant flash, the meteor re-appeared before burning out. A persistent train was visible for at least 4 minutes.

University of Alaska at Fairbanks researcher Hans Stenbaek-Nielsen operated a high-speed camera on board the DC8 and recorded 59 meteors at 1000 frames/s. None was captured brighter than last year's "shocking Leonid" [8], but several fainter ones confirm the formation of a shock front, opening up not quite as wide (Figure 5). In addition, the peculiar diffuse high altitude beginning of two bright fireballs was captured (see inset Figure 5, lower left), a phenomenon discovered by Pavel Spurný and Hans Betlem during the 1998 campaign [13].

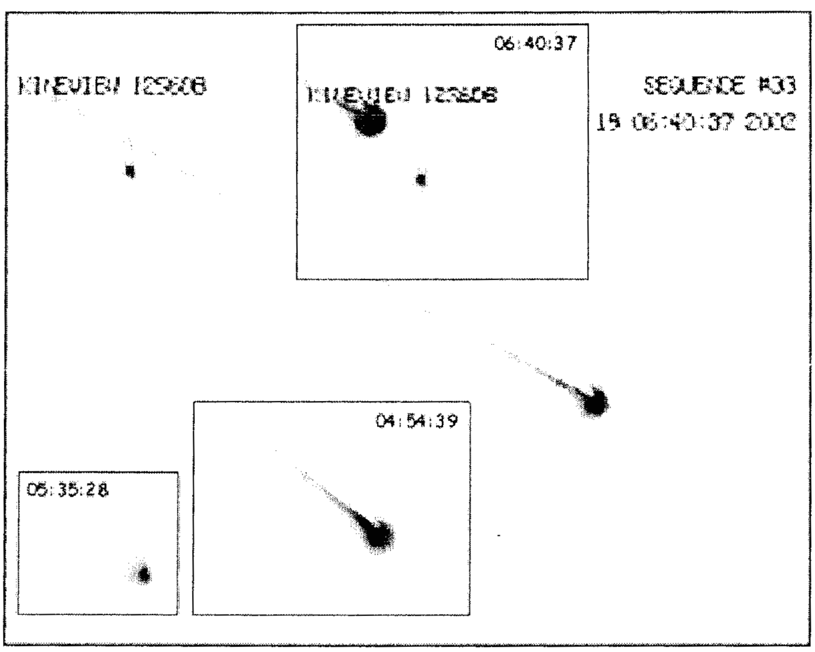

Figure 5 – Composite of high frame-rate images (courtesy Hans Stenbaek-Nielsen).

The *SETI Institute* cooled CCD spectrograph recorded some 40 optical spectra, twice the harvest from 2001. The instrument was operated by Emily Schaller of *Caltech*, who captured the particularly nice result shown in Figure 6. This meteor has a (not yet identified) molecular band with mission Q-branch in an early part of its trajectory, where the metal atom lines are still weak.

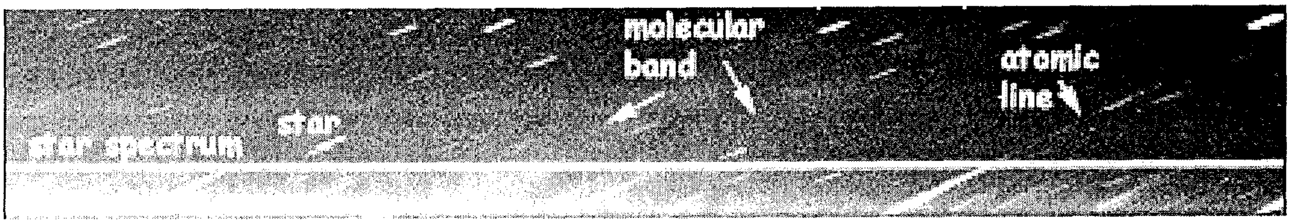

Figure 6 – Cooled CCD spectrum of a meteor in the blue with a newly identified molecular band emission (courtesy Peter Jenniskens and Emily Schaller).

Finally, Jiři Borovička reports that the Ondrejov video spectrometer detected at least 130 low resolution meteor spectra of various qualities during the first 90 minutes of observation, which included the $4^{\rm h}$ UT peak. This completes homogeneous material of Leonid video spectra taken with the same camera in 5 different years (1998–2002). Shinsuke Abe of *ISAS* recorded about 30 HDTV spectra at ultraviolet wavelengths down to 300 nm, several of high quality. Other results include the first near-IR spectrum of a meteor by Mike Taylor and Kim Nielsen of *Utah State University* (DC-8), the second detection of persistent train emission at mid-IR wavelengths from *FISTA* (George Rossano, *Aerospace Corporation*), continuous coverage of airglow and upper atmosphere molecules by the *University of East Anglia* (John Plane and Alfonso Saiz) and the *University of Bremen* teams (Armin Kleinboehl and Holger Bremer). The *University of East Anglia* cooled slit-spectrograph was pointed at three persistent trains, one of which moved astonishingly rapidly in upper atmosphere winds.

Dust collection

Until now, only two silica spheres of questionable origin had been captured during the Leonid storms by a weather balloon in 1999. This year three collectors mounted outside *FISTA* and coated with silicone oil by Mike Zolensky and Jack Warren at the *NASA Johnson Space Center Cosmic Dust Facility* collected about 1100 particles. After scrutiny of the collectors, Frans Rietmeijer and Melissa Pfeffer report having identified about 150 particles on the storm-night collector that are the best candidates to include Leonid meteoroids. This will not be known until the morphology and composition of each particle has been analyzed. However, at least one extraterrestrial, but non-Leonid, fluffy aggregate particle, and one spherule, were collected on the way from Omaha to Spain.

Acknowledgments

We thank the aircraft operators at *NASA Dryden Flight Research Center*, notably mission managers Bob Curry and Chris Jennison, and at the *USAF Edwards Air Force Base*, especially mission managers Don Bustillos and Jon Haser for their heroic efforts to make the *2002 Leonid MAC* mission possible. Some 300 people took responsibility for bringing various aspects of the campaign together. Our host at Torrejon de Ardoz in Spain was Juan Perez-Mercader, the director of the *Centro de Astrobiologia*. Capt. Rafael Gomez-Blanco made the logistic arrangements. The mission was sponsored by *NASA's Astrobiology Program* (Mike Meyer), *NASA's Planetary Astronomy program* (John Hillman), and by *NASA Ames Research Center* (Greg Schmidt). Support was also received from *CAB* and the *European Space Agency*. The participation of individual research teams was made possible by local institutes and organizations. The mission was executed as part of the *Aerospace MOIE program* (Ray Russell). I also thank Hal Roey, Brenda Simmons, Debbie Kolyer, Sue Lehr, Edna deVore, and Chris Chyba of the *SETI Institute* for their efforts on behalf of this final *Leonid MAC mission*. Finally, I thank Charlie Hasselbach for moral support and many good ideas.

References

[1] P. Jenniskens and S. Butow, "Successful Leonid Airborne Mission Validation Flight during August 1997 Perseids", *WGN* 25, 1997, pp. 215–217.

[2] P. Jenniskens and S. Butow, "Successful Leonid Airborne Mission", *WGN* 26, 1998, pp. 249–252.

[3] P. Jenniskens and S. Butow, "The 1998 Leonid multi-instrument aircraft campaign—an early review", *Meteoritics & Plan. Science* 34, 1999, pp. 933–943.

[4] P. Jenniskens and S. Butow, "The 1999 Leonid Multi-Instrument Aircraft Campaign: The Storm from Altitude", *WGN* 27, 1999, pp. 305–307.

[5] P. Jenniskens, S.J. Butow, M. Fonda, "The 1999 Leonid Multi-Instrument Aircraft Campaign—an early review", *Earth, Moon and Planets* 82–83, 2000, pp. 1–26.

[6] P. Jenniskens and B.A.S. Gustafson, "The Rare 1932 Dust Trail Encounter of November 17, 2000, As Observed from Aircraft", *WGN* 28, 2000, pp. 209–211.

[7] P. Jenniskens, "The 2001 Storm from 11 Kilometers Altitude: First Results", *WGN* 29, 2001, pp. 195–199.

[8] P. Jenniskens and R.W. Russell, "The 2001 Leonid Multi-Instrument Aircraft Campaign—an early review", *Tokyo 2002 Leonid MAC Workshop proceedings*, in press.

[9] V. Krumov, M. Gyssens, R. Arlt, "IMO Shower Circular, LEONIDS 2002", *electronic circular*, 22 November 2002.

[10] McNaught R.H. and Asher D.J., "Variation of Leonid maximum times with location of observer", *Meteoritics & Planetary Science* 34, 1999, pp. 975–978.

[11] E. Lyytinen, T. Van Flandern, "Improved 2001 Leonid Storm Predictions from a Refined Model", *WGN* 29, 2001, pp. 110–118.

[12] P. Jenniskens and H. Betlem, "Massive Remnant of Evolved Cometary Dust Trail Detected in the Orbit of Halley-Type Comet 55P/Tempel-Tuttle", *Astrophysical Journal* 531, 2000, pp. 1161–1167.

[13] P. Spurný, H. Betlem, K. Jobse, P. Koten, J. van't Leven, "New type of radiation of bright Leonid meteors above 130 km", *Meteoritics & Plan. Science* 35, 2000, pp. 1109–1115.

[14] P. Jenniskens, "Model of a One-Revolution Comet Dust Trail from Leonid Outburst Observations", *WGN* 28, 2000, pp. 221–226.

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The 2002 Leonids as monitored by the International Project for Radio Meteor Observations

Hiroshi Ogawa, Shinji Toyomasu, Kouji Ohnishi, Shinobu Amikura, Kimio Maegawa, Peter Jenniskens

A spectacular appearance of the 2002 Leonids was anticipated in Europe, Africa and America. Radio Meteor Observation by forward scatter is one of best methods for monitoring meteor activity in real time without weather problems. By combining worldwide data, it is possible to monitor the Leonid activity at all times. The International Project for Radio Meteor Observations was planned for that purpose. As many as 115 observing stations in 23 countries participated. The observing period started on November 01 and ended on the 25th. The data of selected stations were presented on a Flash live website starting November 14. This paper reports a first analysis of the 2002 Leonid Radio Meteor data. We achieved 24-hour coverage and clearly detected two peaks around 04^h10^m UT and 10^h50^m UT on November 19. In addition, some background activity was detected.

1. Introduction

Radio Meteor Observation (RMO) by forward meteor scatter is one of the best methods for monitoring meteor shower activity. This is because RMO is possible even in bad weather conditions or in daytime. At any given site, however, we cannot cover the whole activity of the Leonids because the radiant is not always above the horizon. To solve this problem, we worked to combine data from stations around the world. An international project for radio observations was started during the 2001 Leonids. In the 2001 project, 91 observing stations in 15 countries were represented [1]. We do not recommend or demand a particular observing method. Rather, each observer uses his own preferred observing method, choice of frequency, receiver, etc.. Only when these data are combined do we define common indices for shower activity, scaled from such quantities as "Activity Level" and "Reflection Time".

The 2002 Leonids were expected to have two main peaks visible in Europe, Africa and America [2–6]. The first peak would peak at November 19 04^h00^m UT, over Europe and North Africa, caused by the 1766 (7-revolution) dust trail, while the second peak caused by the 1866 (4-revolution) dust trail was predicted to peak around 10^h30^m UT that day over North America. Asia and Australia might have observed the beginning of the first peak and the ending of the second, although Jenniskens predicted rather narrow storm profiles [6]. There might also be a return of the Leonid Filament or other broad (and older) shower components [7].

It was very important to monitor the Leonid activity at all times to obtain the detailed signature of these multiple dust trails, the intensity, broadness, and peak time of which are related to the formation and evolution of the dust trails. Goals of the 2002 International Project for RMO were not only to obtain the whole Leonid activity profile, but also to provide near-real-time flux information via dedicated Leonid "Live" and "Flash" websites and mailing lists. We succeeded in achieving those goals. This paper reports the first analysis of the data, based on results from 115 observing stations in 23 countries.

2. Observers and observing stations

The location of the participating stations is shown in Figure 1. Most stations were located in Japan (shown in Figure 2) and in Europe, but multiple sites were also in the United States, India and Australia, providing a global coverage.

The following observers participated in the project:

American observers

Gilberto Klar Renner (Brazil), Rafael Haag (Brazil), Brian Chapel (Canada), Michael Boschat (Canada), Glenn Bock (USA), Jeffrey L. Brower (USA), Stan Nelson (USA), Antonio Martinez (Venezuela);

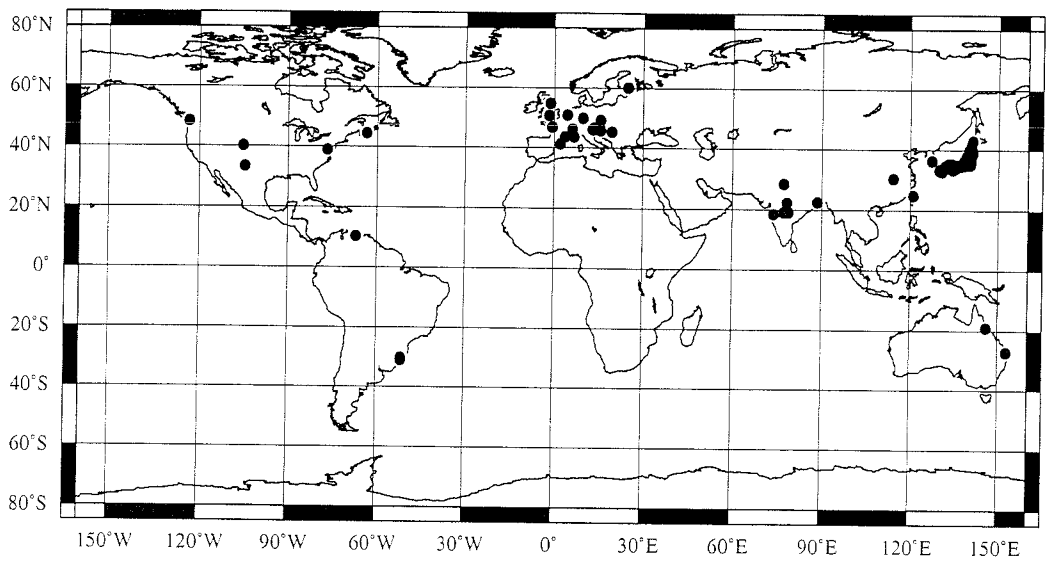

Figure 1 – Observing stations in the world.

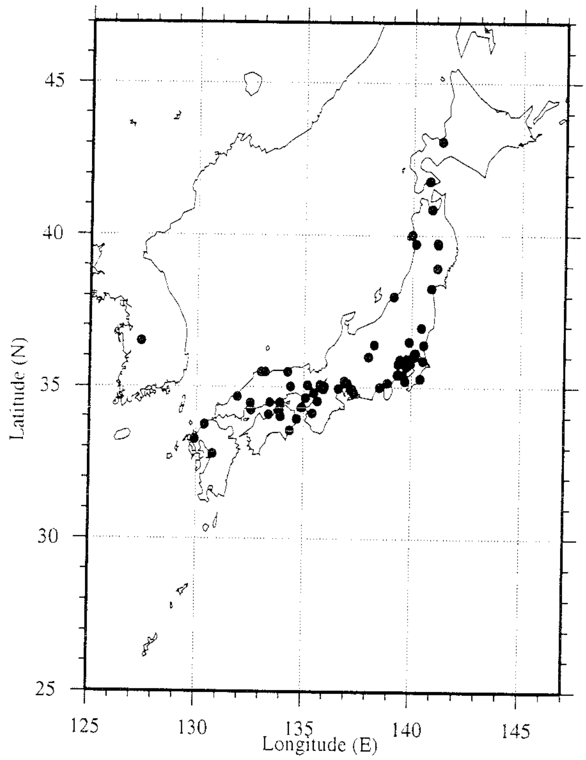

Figure 2 – Japanese observing stations.

European observers

Dirk Artoos (Belgium), Robert (Croatia), Michael Krocil (Czech), Esko Lyytinen (Finland), Didier Favre (France), Patrice Guerin (France), Pierre Terrier (France), Giorgio Bressan (Italy), Valter Gennaro (Italy), Walter Boschin (Italy), Jure Zakrajsek (Slovenia), Enric Fraile (Spain), Dave Swan (UK), Paul Unwin (UK), Jaroslav Grna (Yugoslavia), Udo Langenohl (Germany), Philippe Haake (Switzerland);

Asian and Australian observers (excluding Japan)

Billy (Australia), Bruce Young (Australia), Malcolm Hedley (Australia), Kuneth Werfried (Austria), Ouyang Tiangjing (China), Aundhkar Shrinivas (India), Biswajit Bose (India), Chande Devgun (India), Gaurav Rathod (India), Jaydeep Belapure (India), Mayuresh G. Prabhune (India), Pravin Patil (India), Choi sang in (Korea), Yung Chiech Tsao (Taiwan);

Japanese observers

Atsushi Yabuuchi, Chikara Yamaguchi, Chiyoma Inamitsu, Eiji Kubota, Hideo Nakanishi, Hideto Yoshida, Hidetoshi Takagi, Hirofumi Sugimoto, Hirokazu Miyake, Hironobu Shida, Hiroshi Abe, Hirotoshi Hara, Hiroyuki Hiraga, Hisanori Naito, Izumi Saito, Hidetoshi Kanno, Kayo Miyao, Kazuaki Fukuda, Kazuhiro Suzuki, Kazuhisa Kageyama, Kazuyoshi Kanatsu, Kazuyuki Nagao, Kenji Fujito, Kimihiro Norizawa, Kiyotaka Ohkawa, Koichi Kimura, Kouji Ohnishi, Kunihiko Nakano, Masaaki Ogawa, Masaki Tsuboi, Masami Kurihara, Masayoshi Ueda, Masayuki Kobayashi, Masayuki Yamamoto, Matsumoto Seiki, Michinari Yamamoto, Minoru Harada, Naoki Moriwaki, Rho Ishii, Sadao Okamoto, Satoshi Matsui, Seiichiro Kiyota, Seiji Fukushima, Shigeo Sambe, Taisuke Kondo, Takashi Usui, Takayuki Kawakita, Takuya Ogawa, Tomoko Kumode, Toshiaki Tsuruoka, Toshihide Miyake, Toshihiko Masaoka, Toshiro Sato, Yasufumi Yoshikawa, Yoichi Okamoto, Yoshiharu Ito, Yoshikazu Kato, Yoshiyuki Hamaguchi, Yosuke Utsumi, Yutaka Nakano, Hida high school astronomy club, Hoshino Girls High School Astronomical Culb, IAI Girl's Junior and Senior High School, Ibaraki National College of Technology, Radio Cult, Ikeda/Awa High School, Kyotosangyo University Astronomical Lovers Society (Natsumi Abe, Taku Nakajima), Misato Observatory (Shinji Toyomasu), Numazu National College of Technology, Saitama Prefectural Koshigaya-Kita High School Astronomy Club, Seibudai High School Astro Club, The Astronomy Club at the University of Tokushima, Tokai Shoyo High School Natural Science Club, Tokushima-Kainan astronomical observatory, Tottori-Higashi High School, University of Tsukuba (Hiroshi Ogawa).

3. Analyzing methods

3.1. Activity level

The worldwide data were combined by applying the "Activity Level" index. This index was defined in previous research [8]. The index, "A(t)", is defined by the following formula.

$$A_{\mathrm{site}}(t) = \frac{H(t) - H_0(t)}{D \sin h(t)},$$

$$A(t) = \sum_{i=1}^{N} A(t)_i / N,$$

where H is the hourly number of observed meteor echoes, H_0 is the background hourly rate, D is the average value for a day, N is the number of observing stations and $h(t)$ is radiant elevation at time t. The Activity Level is the number of times that echoes are observed compared to the background echo rate for a day. If there is no meteor shower activity, $A(t)$ is zero.

The $\sin h$ correction factor for geometric dilution is the same as used for correcting visual observations. Since the reflection mechanism is very complex, this factor is not enough to account for instrument-related factors in forward meteor scatter. In the case of the very fast Leonids, however, the situation is simplified because mostly bright meteors (overdense echoes) are detected at frequencies over 50 MHz. Their high ablation altitude causes rapid diffusion, responsible for an apparent echo height ceiling in underdense (specular) reflections. The bright meteors retain high enough electron densities to be detected.

3.2. Reflection time

In a meteor storm like in the 2002 Leonids, individual echoes start to overlap and the meteor count saturates. We therefore applied a new index called "Reflection Time". This index shows the total reflection time of meteor echoes within unit time and is proportional to the total mass flux of meteors. This index has already been used the 2001 Leonid analysis [9]. In 2002, the counts were again often saturated. The Leonid peak structure was estimated using this index. The total reflection time of all echoes within ten minutes was calculated every ten minutes using software developed by Shinobu Amikura. Here, we restrict ourselves to data obtained from the HROFFT software (FFT-software) that was developed by Kazuhiko Ohkawa. This software shows the return from individual stations and enables a clear removal of spurious interference such as aircraft reflections.

4. Results

4.1. Activity level analysis

The observation period was 25 days, from 2002 November 1 to 25. The background level or non-Leonid activity was defined by the data from the 1st to the 13th of November. Figure 3 shows the Activity Level every hour from November 14–21. This graph is calculated from data by 21 observing sites in 10 countries.

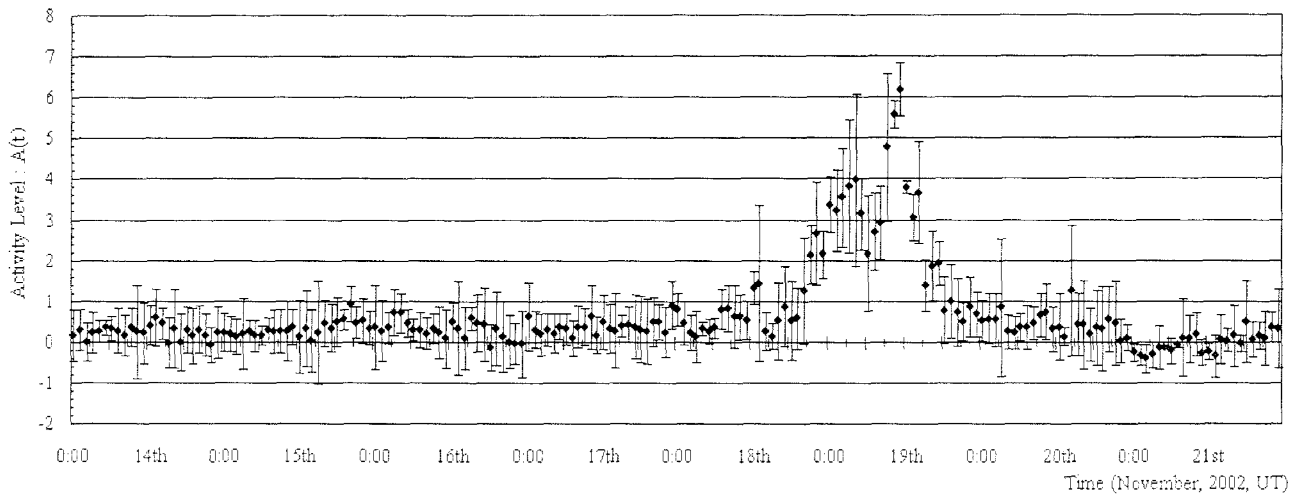

Figure 3 – Leonid meteor activity level provided by 21 observing stations in 10 countries (November 14 to 21).

Japanese observers reported an increase of the number of long echoes starting perhaps as early as November 18 $12^{h}00^{m}$ UT. Visual observers of The Nippon Meteor Society saw an increase of rates starting at 18^{h} UT. Overall, there was enhanced Leonid activity from November 18 12^{h} UT until November 19 21^{h} UT, or about one day, the typical duration of the Leonid filament component [7]. On top of that, two clear peaks are found. The first peak was around November 19 04^{h} UT over Europe and North Africa. This peak corresponds to the anticipated 1766 (7-revolution) dust trail encounter. The second peak was around November 19 11^{h} UT over America, and this peak corresponded to the 1866 (4-revolution) dust trail encounter. Although this graph shows the second peak was bigger than first peak, this may be uncertain because it was difficult to count the number of echoes around the first peak due to saturation of the data. Therefore, upon further analysis of the data the first peak may become bigger and narrower than this value. There was no clear sign of the 1965 dust trail encounter in the RMO data, which was expected for November 17, at $20^{h}10^{m}$ UT (Asher) or $19^{h}30^{m}$ UT (Jenniskens). However, Earth passed the 1965 dust trail at a considerable distance and the predicted peak rate was less than ZHR = 1.

4.2. Reflection time analysis

Reflection time analysis was applied to estimate the time of the European peak. Figure 4 is the reflection time analysis for the Slovenian observing station. The 10 dB count was saturated by long echoes from November 19 $03^{h}40^{m}$ UT until $06^{h}00^{m}$ UT. On the other hand, the 20 dB curve shows a peak at $04^{h}10^{m}$–$04^{h}20^{m}$ UT. This corresponds to the very narrow European peak. The 30 dB curve, on the other hand, does not have enough statistics to show the narrow peak clearly.

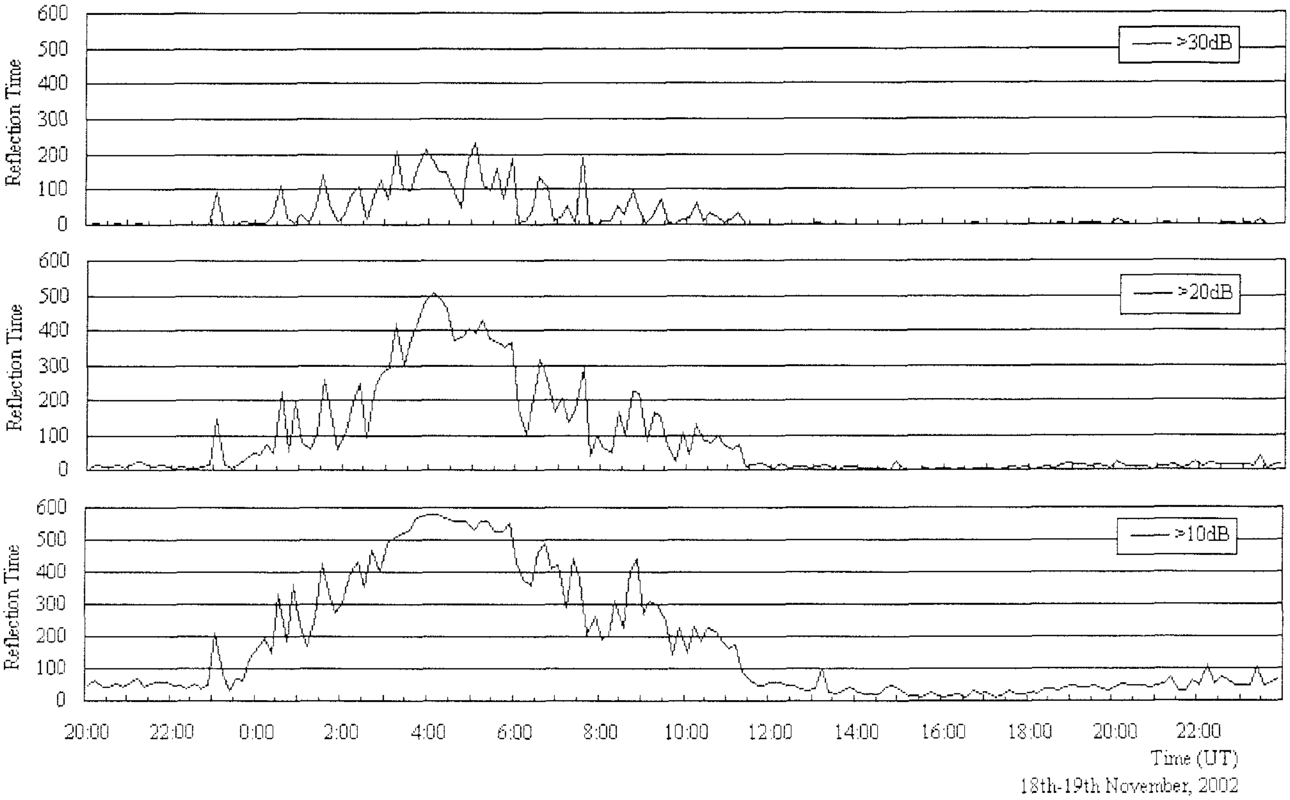

Figure 4 – The reflection time analysis at the Slovenian observing station (by Jure Zakrajšek).

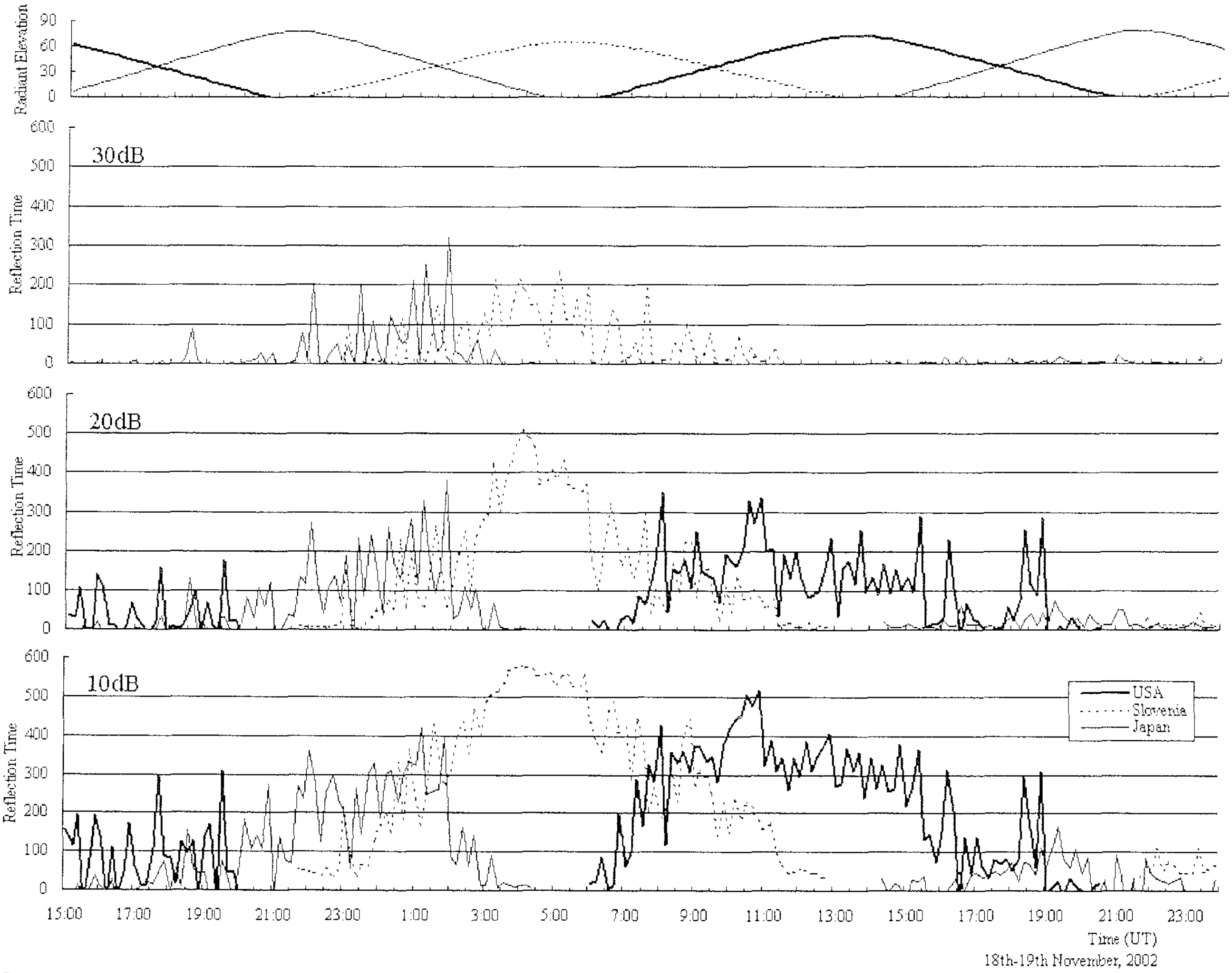

Figure 5 – The global reflection time analysis using Slovenia (Jure Zakrajšek), the USA (Jeff Brower) and Japan (Masayuki Kobayashi).

Figure 5 compares reflection time curves from three different locations from the Slovenia, USA and Japan stations. The background level has been subtracted and results are only shown when the radiant elevation is more than 0°. Most of the variation is due to the rising and setting of the radiant. This figure shows the two narrow storm peaks around 14^h10^m–14^h20^m UT and 10^h40^m–11^h00^m UT. The second storm was also very sharp and rich in faint meteors. Again, the background component dominates the radio reflection returns. The figure does not consider the observing conditions, receiver sensitivity or radiant elevation; hence this figure does not show which peak was the stronger one.

Figure 6 does take into account the observability function (mostly the geometric correction), after subtraction of the background count. The "zenith corrected count" is now proportional to a measure of influx such as the Zenith Hourly Rate, for example. Results from two Global-MS-Net stations are shown, confirming the occurrence of two narrow storm peaks on a much broader background component centered at about 01^h UT (November 19) and extending from November 18 14^h UT to November 19 16^h UT. The two storms sit on the downward slope of this component. The duration and abundance of bright meteors suggests a return of the Filament component.

5. Conclusion

The observed pattern is consistent with the particular stations being insensitive to faint Leonids, while brighter Leonids were distributed in a broader component than the faint ones. We conclude that a broad dust component richer in bright meteors was underlying the two storm peaks. The component was active from November 18 14^h UT to November 19 16^h UT. We demonstrated that it is possible to monitor the Leonid activity with the support of many radio forward meteor scatter stations worldwide. In the near future, our goal is to develop software to compare and combine the data from different stations better. We hope to continue this work for monitoring other meteor showers as well. Our ultimate goal is to expand the work of Global-MS-Net: to find dust trails of long period Earth-threatening comets by monitoring the meteor activity on a 24-h basis. For this analysis and monitoring, many radio observing stations are needed. We hope that many amateur radio observers will continue to participate in this project in the future.

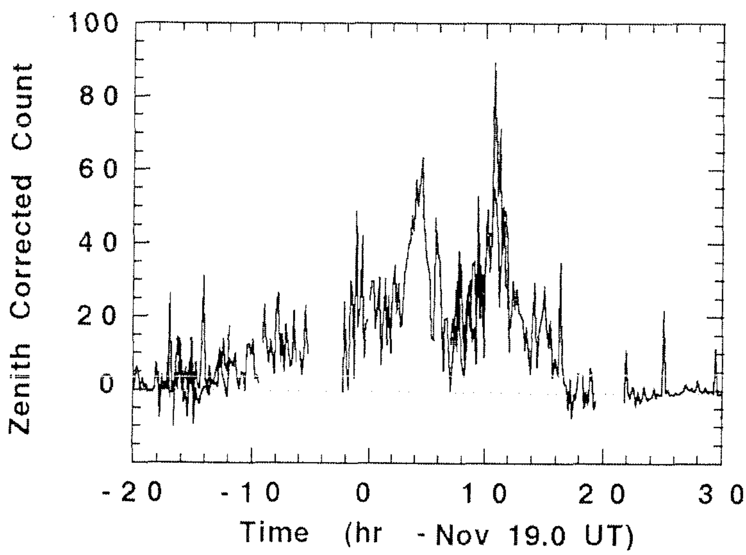

Figure 6 – Meteor reflection count, background subtracted and corrected for observability. From: 10-minute data by Ilkka Yrjölä (Finland) and Jeff Brower (USA).

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References

[1] H. Ogawa, S. Toyomasu, K. Ohnishi, K. Maegawa, "2001 Leonids by Radio Meteor Observation Project all over the world", *WGN* 30 (2002), pp. 105–109.

[2] R.H. McNaught, D.J. Asher, "Leonid Dust Trail Structure and Predictions for 2002", *WGN* 30 (2002), pp. 132–143.

[3] E.J. Lyytinen, M. Nissinen, T. Van Flandern, "Improved 2001 Leonids Storm Predictions from a Refined Model", *WGN* 29 (2001), pp. 110–118.

[4] E. Lyytinen, T. Van Flandern, M. Nissinen, "Leonid Predictions for year 2002", `http://www.ursa.fi/ursa/jaostot/meteorit/leoeng02.html` (2002).

[5] J. Vaubaillon, "Activity Level Predictions for the 2002 Leonids", *WGN* 30 (2002), pp. 144–148.

[6] P. Jenniskens, "Model of a One-Revolution Comet Dust Trail from Leonid Outburst Observations", *WGN* 29, 2002, pp. 165–175.

[7] P. Jenniskens, H. Betlem, "Massive Remnant of evolved Cometary Dust Trail detected in the Orbit of Halley-type Comet 55P/Tempel-Tuttle", *Astrophys. J.* 531, 2000, pp. 1161–1167.

[8] H. Ogawa, S. Toyomasu, K. Ohnishi, K. Maegawa, "The Global Monitor of Meteor Streams by Radio Meteor Observation all over the world", *Proceeding of the Meteoroids 2001 conference* (2001), pp. 189–192.

[9] H. Ogawa, S. Toyomasu, K. Ohnishi, K. Maegawa, S. Amikura, T. Asahina, K. Miyao, "The 2001 Leonids by the Radio Meteor Observing Network in Japan", *WGN* 30 (2002), pp. 120–126.

[10] D.W.R. McKinley, "Meteor Science and Engineering", McGraw-Hill Book Company, New York, 1961.

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Perseids

Global Analysis of the 2002 Perseids

Rainer Arlt and Andreas Buchmann

Population index and activity profiles of the 2002 Perseids are presented. The analysis is based on 23 361 Perseids recorded by 222 observers. The maximum is found at $\lambda_\odot = 140\overset{\circ}{.}109$ (2002 August 13, near 1^{h} UT) with a ZHR or 106 ± 3. No indication of an additional pre-maximum peak as observed in 1988–1999 was found.

1. Introduction

Since 2000 the Perseids have appeared to have returned to normal appearance, after they had shown an additional peak prior to the traditional maximum in 1988–1999. Moreover the traditional maximum varies somewhat in time. The analysis and compilation in Arlt (1999) leads to an average solar longitude of the maximum of $\lambda_\odot = 140\overset{\circ}{.}0$. That paper suggests a maximum ZHR of 90, although we have to bear in mind that some values may be affected by the near pre-maximum of much higher ZHR.

The solar longitude of $140\overset{\circ}{.}0$ corresponds to 2002 August 12, $22^{h}30^{m}$ UT. This time favored European and north African sites. We investigate the 2002 return of the Perseids from global data as available to the Visual Commission of the *IMO* by 2002 September 15. Thanks to electronic communication, a very comprehensive data set of 23 361 Perseids seen during $1154\overset{h}{.}37$ observing hours was already received by that time. We are very grateful to the 222 observers contributing to this analysis. They are:

Ahmad Abdo (ABDAH, $4\overset{h}{.}99$), Haitham Abdel Majid (ABDHA, $4\overset{h}{.}86$), Sana'a Abdo (ABDSA, $5\overset{h}{.}98$), Puya Ahmadifard (AHMPU, $1\overset{h}{.}75$), Ardalan Alizadeh (ALIAR, $2\overset{h}{.}54$), Ahmad Al-Niamat (ALNAH, $1\overset{h}{.}00$), Karl Antier (ANTKA, $2\overset{h}{.}00$), Jure Atanačkov (ATAJU, $14\overset{h}{.}13$), Aleksandar Atevik (ATEAL, $3\overset{h}{.}90$), Javad Azizi (AZIJA, $3\overset{h}{.}54$), Lars Bakmann (BAKLA, $1\overset{h}{.}00$), Lance Benner (BENLA, $3\overset{h}{.}75$), Orlando Benítez Sanchez (BENOR, $18\overset{h}{.}11$), Rafael Benavides Palencia (BENRA, $3\overset{h}{.}53$), Nicolas Biver (BIVNI, $3\overset{h}{.}42$), Luka Blazeković (BLALU, $1\overset{h}{.}32$), Adriyan Bozinovski (BOZAD, $5\overset{h}{.}00$), Jay Brausch (BRAJA, $12\overset{h}{.}00$), Emil Brezina (BREEM, $1\overset{h}{.}29$), Dustin Brown (BRODU, $2\overset{h}{.}17$), Andreas Buchmann (BUCAN, $11\overset{h}{.}87$), William Burton (BURWL, $1\overset{h}{.}00$), Dave Campbell (CAMDA, $0\overset{h}{.}75$), Jose Carlos Millán (CARJO, $5\overset{h}{.}09$), Stefan Cikota (CIKST, $4\overset{h}{.}98$), Stefano Crivello (CRIST, $8\overset{h}{.}31$), Malcolm J. Currie (CURMA, $4\overset{h}{.}66$), Hani Dalee (DALHA, $8\overset{h}{.}23$), Luigi d'Argliano (DARLU, $3\overset{h}{.}13$), Denis Denissenko (DENDN, $7\overset{h}{.}83$), Samer Derbi (DERSA, $3\overset{h}{.}04$), Vincent Desmarais (DESVI, $1\overset{h}{.}63$), Peter Detterline (DETPE, $22\overset{h}{.}60$), Miha Devetak (DEVMI, $8\overset{h}{.}26$), Valentín Díaz Parreño (DIAVA, $0\overset{h}{.}95$), Manuel Diégiez Hern. (DIEMA, $2\overset{h}{.}44$), Veselina Dimitrova (DIMVE, $13\overset{h}{.}19$), Jaka Dobaj (DOBJA, $11\overset{h}{.}67$), Subo Dong (DONSU, $2\overset{h}{.}59$), Audrius Dubietis (DUBAU, $34\overset{h}{.}75$), Tomas Dvořak (DVOTO, $2\overset{h}{.}50$), Vedrana Dzaja (DZAVE, $2\overset{h}{.}42$), Shlomi Eini (EINSH, $3\overset{h}{.}29$), Sven-Erik Enno (ENNSV, $2\overset{h}{.}50$), Dunja Fabjan (FABDU, $6\overset{h}{.}23$), David Fernández Barba (FERDB, $5\overset{h}{.}94$), Jose A. Fernández Arozena (FERJQ, $0\overset{h}{.}95$), Lukas Ferkl (FERLU, $1\overset{h}{.}18$), Daniel Fischer (FISDA, $5\overset{h}{.}50$), Mildred Formosa (FORMI, $1\overset{h}{.}97$), Luigi Furlanetto (FURLU, $3\overset{h}{.}41$), Martin Galea (GALMR, $5\overset{h}{.}64$), Xing Gao (GAOXI, $1\overset{h}{.}75$), Petros Georgopoulos (GEOPE, $1\overset{h}{.}55$), Ivanka Getsova (GETIV, $2\overset{h}{.}07$), George W. Gliba (GLIGE, $3\overset{h}{.}00$), Shelagh Godwin (GODSH, $4\overset{h}{.}67$), Darja Golikowa (GOLDA, $1\overset{h}{.}28$), Cándido Gómez Benítez (GOMCA, $3\overset{h}{.}78$), Hermenedildo González (GONHE, $2\overset{h}{.}67$), Nelida González (GONNE, $3\overset{h}{.}10$), Sylvie Gorkova (GORSY, $10\overset{h}{.}50$), Rosely Gregory (GRERO, $1\overset{h}{.}27$), Eva Grillova (GRIEV, $2\overset{h}{.}96$), Daniel Grün (GRUDA, $11\overset{h}{.}45$), Pavol Habuda (HABPA, $8\overset{h}{.}88$), Cathy Hall (HALCA, $5\overset{h}{.}21$), Jia Hao (HAOJI, $1\overset{h}{.}50$), Amir Hassanzadeh (HASAM, $6\overset{h}{.}48$), Takema Hashimoto (HASTA, $6\overset{h}{.}33$), Harri Haukka (HAUHA, $3\overset{h}{.}05$), Roberto Haver (HAVRO, $11\overset{h}{.}99$), Robert Hays (HAYRO, $8\overset{h}{.}00$), Veli-Pekka Hentunen (HENVE, $1\overset{h}{.}02$), Zoltán Hevesi (HEVZO, $0\overset{h}{.}50$), Ken Hodonsky (HODKE, $8\overset{h}{.}34$), Kamil Hornoch (HORKM, $2\overset{h}{.}15$), Dave Hostetter (HOSDA, $1\overset{h}{.}75$), Jürgen Jänes (JANJU, $4\overset{h}{.}00$), Carl Johannink (JOHCA, $0\overset{h}{.}80$), Tomislav Jurkić (JURTO, $3\overset{h}{.}72$), Javor Kac (KACJA, $18\overset{h}{.}63$), Nikolai Kacharov (KACNI, $2\overset{h}{.}17$), Vaclav Kalas (KALVA, $5\overset{h}{.}38$), Mihkel Kama (KAMMI, $1\overset{h}{.}00$), Esam Kasasbeh (KASES, $4\overset{h}{.}25$), Atsuyoshi Kawamura (KAWAT, $0\overset{h}{.}50$), Soheil Khoshbin Far (KHOSO, $3\overset{h}{.}60$), Gregor Kladnik (KLAGR, $1\overset{h}{.}58$), Radim Kocar (KOCRA, $6\overset{h}{.}00$), Katja Koleva (KOLKA, $4\overset{h}{.}51$), Khalil Konsul (KONKH, $8\overset{h}{.}41$), Petra Korlević (KORPE, $10\overset{h}{.}53$), Jakub Koukal (KOUJA, $37\overset{h}{.}33$), Jaroslav Kovarik (KOVJA, $1\overset{h}{.}50$), Marek Kozubal (KOZMA, $4\overset{h}{.}44$), Dovile Krauleidiene (KRADO, $11\overset{h}{.}84$), Mariya Krumova (KRUMA, $2\overset{h}{.}74$), Vladimir Krumov (KRUVL, $7\overset{h}{.}55$), Maris Kuperjanov (KUPMA,

$4^{h}.15$), Nina Lampič (LAMNI, $5^{h}.37$), Marco Langbroek (LANMA, $5^{h}.75$), Adrian Lelyen (LELAD, $3^{h}.67$), Anna S. Levina (LEVAN, $14^{h}.99$), Chun Li (LI CH, $2^{h}.00$), Xian Li (LI XI, $0^{h}.94$), Yang Li (LI YA, $2^{h}.82$), Michael Linnolt (LINMI, $2^{h}.00$), Andre Lipand (LIPAN, $3^{h}.00$), Madis Lohmus (LOHMA, $1^{h}.12$), Enrique López Hernández (LOPEN, $1^{h}.98$), Robert Lunsford (LUNRO, $13^{h}.73$), Hartwig Lüthen (LUTHA, $3^{h}.42$), Jin Ma (MA JI, $2^{h}.46$), Qiang Ma (MA QI, $0^{h}.97$), Xiaoyun Ma (MA XI, $2^{h}.25$), Alan Macrobert (MACAL, $1^{h}.00$), Jose Luis Maestre García (MAEJO, $3^{h}.49$), Petra Maierova (MAIPE, $5^{h}.50$), Veikko Mäkelä (MAKVE, $2^{h}.00$), Radek Maly (MALRA, $0^{h}.89$), Grigoris Maravelias (MARGE, $5^{h}.85$), José Afonso dos Reis Martins (MARJO, $1^{h}.96$), Pierre Martin (MARPI, $27^{h}.54$), Edgardo Ruben Masa Martín (MASED, $17^{h}.16$), Ashley Matous (MATAS, $2^{h}.50$), Bert Matous (MATBE, $12^{h}.25$), Alastair McBeath (MCBAL, $4^{h}.85$), Huan Meng (MENHU, $3^{h}.23$), Frédéric Merlin (MERFR, $17^{h}.85$), Markko Meriniit (MERMA, $1^{h}.00$), Rein Merendi (MERRE, $1^{h}.73$), Borce Milcevski (MILBO, $3^{h}.63$), Jane Mills (MILJA, $1^{h}.23$), Mariya Milcova (MILMA, $4^{h}.47$), Koen Miskotte (MISKO, $15^{h}.96$), Jan Mocek (MOCJA, $1^{h}.47$), Ali Moosazadeh (MOOAL, $2^{h}.36$), Manuela Moreno González (MORMA, $3^{h}.65$), Thom Morgan (MORTH, $4^{h}.04$), Arash Nabizadeh (NABAR, $4^{h}.43$), Sven Näther (NATSV, $5^{h}.02$), Emil Neata (NEAEM, $2^{h}.25$), Goran Niksić (NIKGO, $6^{h}.77$), Brian Nilsson (NILBR, $3^{h}.99$), Markku Nissinen (NISMA, $4^{h}.63$), Francisco Ocaña Gonzalez (OCAFR, $2^{h}.56$), Masayuki Oka (OKAMA, $2^{h}.50$), Daniel van Os (OSVDA, $4^{h}.82$), Dionisi D. Peñalosa Mauri (PENDI, $1^{h}.50$), Yangwei Peng (PENYA, $1^{h}.34$), Irena Pickova (PICIR, $7^{h}.60$), Carles Pineda Ferré (PINCA, $2^{h}.16$), Senka Pintaric (PINSE, $5^{h}.52$), Pedro Porres Olivas (PORPE, $3^{h}.34$), Lina Hristova Rashkova (RASLI, $1^{h}.53$), Jürgen Rendtel (RENJU, $6^{h}.79$), Mileny Roche Lamas (ROCMI, $4^{h}.00$), Francisco Rodriguez Ramirez (RODFR, $1^{h}.00$), Javier Rodríguez Rodr. (RODJA, $2^{h}.59$), Orlando Rodríguez S. (RODOR, $2^{h}.27$), Javier Ruiz (RUIJA, $2^{h}.73$), Carlos Sánchez Cantó (SANCQ, $2^{h}.00$), Mikiya Sato (SATMK, $1^{h}.50$), Claude Schneider (SCHCL, $1^{h}.50$), René Scurbecq (SCURE, $1^{h}.30$), Ivan M. Sergey (SERIV, $5^{h}.37$), Miguel Serra Martin (SERMI, $5^{h}.92$), Mazyar Seyyednezhad (SEYMA, $5^{h}.00$), Mohammad Reza Shafaroodee (SHAMO, $1^{h}.00$), Sergey Shanov (SHASE, $4^{h}.00$), Quanzhi Shen (SHEQU, $2^{h}.17$), Brian Shulist (SHUBR, $20^{h}.58$), Julia Silina (SILJU, $1^{h}.00$), Maša Sinreih (SINMA, $6^{h}.14$), Hana Sipova (SIPHA, $4^{h}.94$), Urmas Sisask (SISUR, $1^{h}.00$), Andrzej Skoczewski (SKOAN, $7^{h}.12$), George Spalding (SPAGE, $5^{h}.00$), Jiři Srba (SRBJI, $0^{h}.86$), Mark Stafford (STAMA, $3^{h}.80$), Enrico Stomeo (STOEN, $4^{h}.30$), Wesley Stone (STOWE, $9^{h}.00$), Nikola Strah (STRNK, $4^{h}.50$), Pavel Svozil (SVOPA, $1^{h}.37$), David Swann (SWADA, $4^{h}.88$), Richard Taibi (TAIRI, $3^{h}.31$), Indrek Tallo (TALIN, $5^{h}.15$), Marko Toivonen (TOIMA, $4^{h}.28$), Rafaél R. Torregrosa Soler (TORRQ, $0^{h}.58$), Josep M. Trigo Rodriguez (TRIJO, $4^{h}.73$), Arnold Tukkers (TUKAR, $3^{h}.05$), Shigeo Uchiyama (UCHSH, $3^{h}.92$), Julia Uzunova (UZUJU, $4^{h}.89$), Michel Vandeputte (VANMC, $49^{h}.63$), Ruslan Velkov (VELRU, $1^{h}.92$), Valentin Velkov (VELVA, $2^{h}.80$), Vladimir Velkov (VELVL, $4^{h}.35$), Jan Verfl (VERJX, $7^{h}.03$), Dita Vetrovcova (VETDI, $7^{h}.31$), Johanna Vihalem (VIHJO, $1^{h}.42$), Arash Voghoee (VOGAR, $1^{h}.92$), Jaroslav Vošahlík (VOSJA, $4^{h}.69$), William Watson (WATWI, $4^{h}.93$), Heinrich Wiechell (WIEHE, $10^{h}.75$), Jan Woloszcuk (WOLJA, $6^{h}.58$), Oliver Wusk (WUSOL, $8^{h}.55$), Quanzhi Ye (YE QU, $8^{h}.42$), Kim S. Youmans (YOUKI, $2^{h}.03$), Robert Young (YOURO, $3^{h}.50$), Masaaki Yoshimura (YSMMA, $0^{h}.50$), Yin Yue (YUEYI, $4^{h}.00$), Jure Zakrajsek (ZAKJU, $4^{h}.28$), Joseph Zammit (ZAMJO, $5^{h}.87$), Jan Zavitski (ZAVJA, $1^{h}.50$), Liu Zenglin (ZENLI, $3^{h}.92$), Bo Zhang (ZHABF, $4^{h}.14$), Kun Zhou (ZHOKU, $3^{h}.30$), Jin Zhu (ZHUJI, $1^{h}.07$), Ziyi Zhu (ZHUZI, $3^{h}.47$), Jurga Zieniute (ZIEJU, $14^{h}.91$), Vladimír Znojil (ZNOVL, $1^{h}.35$)

from 35 countries:

Belarus, Belgium, Brazil, Bulgaria, Canada, Croatia, Czech Republic, China, Cuba, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iran, Israel, Italy, Japan, Jordan, Lithuania, Macedonia, Malta, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Switzerland, UK, USA.

The distributions of observing periods versus solar longitude and limiting magnitude are shown in Figures 1 and 2. The solar-longitude distribution shows dips for about 15^{h}–18^{h} UT implying that observations from the Pacific and eastern Asia are needed.

2. Observers' perceptions

In a first attempt to construct a rough profile of Perseid activity, we noticed a number of novice observers located in Asia, who had systematically higher rates in both Perseids and sporadics than other groups. It is thus very likely that their limiting magnitudes are underestimated. This fact initiated our search for estimates of the perception of the observers.

Apparent high perception has its cause—in particular with novice observers—in underestimating the limiting magnitude. The ability to spot faint stars in the LM counting areas is not well developed, whereas moving objects like meteors are readily noticed.

Low perception often comes along with long-term observers who have developed a very good ability to distinguish faint stars against the background, but aging has decreased the detection probability of quick events.

A perception coefficient can help reduce extreme ZHR values in a dataset. If the perception coefficient is less than unity, the observer sees "too few" meteors; if it is greater than unity, the observer sees "too many" meteors.

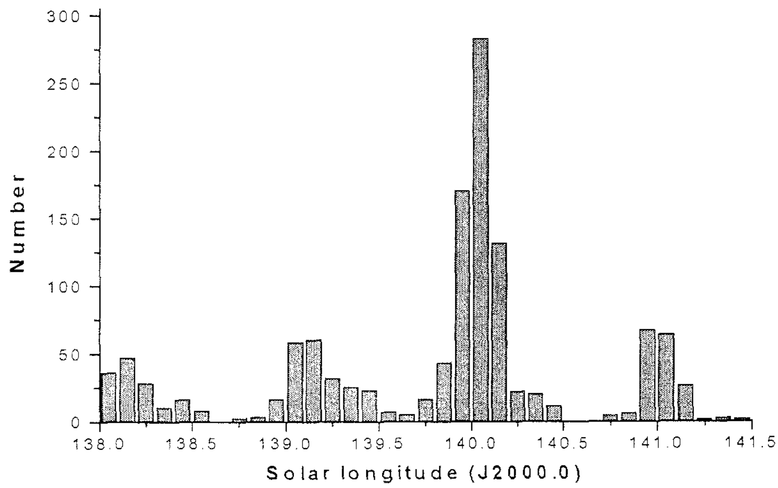

Figure 1 – Distribution of observing periods versus solar longitude. The parts with low numbers are due to the "pacific window" around 15^h–18^h UT.

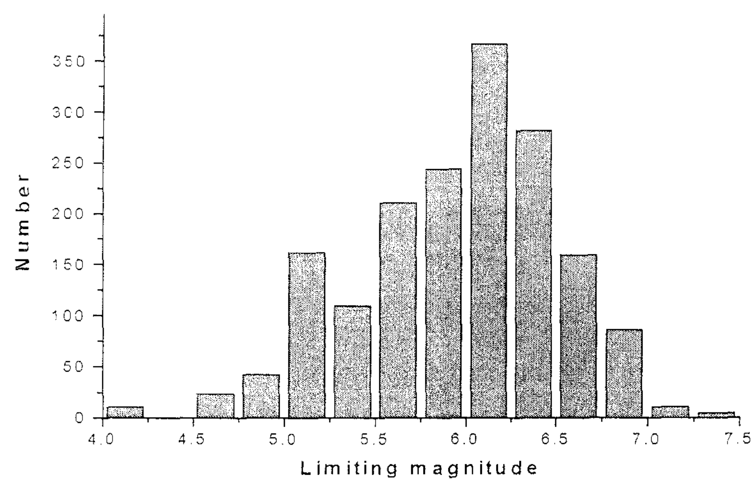

Figure 2 – Distribution of observing periods versus limiting magnitude.

The perception coefficients can be derived in several ways. One is the application of the ZHR averages themselves. If an observer's ZHRs deviate from the average in a systematic way, he can be assigned a perception coefficient. Using the mean ZHRs of a major shower bears the enormous advantage of large meteor numbers involved. Statistically profound results can be obtained. However, the ZHR average from which the deviations are computed must be close to the (unknown) true ZHR, and a relatively large averaging period must thus be used. If the true ZHR was not constant over this period, deviations may result from physical changes in the ZHR, instead of observers' detection properties. Such long averaging periods are typically available for the Perseids in the pre-maximum period of early August. Unfortunately, only a small fraction of observers watches in that period. Even in an extended period from $\lambda_\odot = 130°$ to $137°$, there are only 43 of the total 222 observers for whom a correction would have been found.

Another way was chosen in this analysis. The sporadic meteors provide a fairly constant source of approximately random meteors. Their rates change very little during the month of August (despite a slight diurnal variation which is not very pronounced in August–October). The disadvantage is the smaller number of meteors on which the perception coefficients are based. Nevertheless, the averaging period can be chosen to be very long; it can actually cover the entire activity period of the Perseids.

One might derive an average sporadic hourly rate for the entire data set, but the *Visual Meteor Database* (*VMDB*) includes observations of several types. Records which only discriminate between Perseids and non-Perseids will tend to provide larger sporadic rates than records in which the Working List of Visual Meteor Showers was applied in full. We have thus divided the dataset into these two groups. The group with records according to the Working List delivered an average sporadic rate of $\overline{\mathrm{HR}} = 12.3$. The other group in which showers may be omitted yields $\overline{\mathrm{HR}} = 14.3$. It seems natural that the second group has a higher $\overline{\mathrm{HR}}$. Since the averages are well within the typical sporadic rates of 10–15, we have good reasons to use them as reference values.

Now, the records of each observer are compared with these reference rates, and the resulting perception factors $c_\mathrm{p} = \mathrm{H}_\mathrm{individual}/\overline{\mathrm{HR}}$ are averaged. This, however, is not the end of the story, since the sporadics have a large population index r of roughly $r = 3$ implying an abundance of faint meteors relative to the bright ones. If an observer has overestimated his LM ($c_\mathrm{p} < 1$) and is thus not as good at spotting faint meteors as his LM suggests, he will miss a lot of sporadic meteors. A meteor shower may have a low population index of say $r = 2$. The relative loss of meteors at the faint end will not be that dramatic. We expect that c_p depends on r. A value which is expected to be much less dependent on r is a correction of the LM (since it actually seems to be a difference of meteor-LM and star-LM which we want to reduce). We compute

$$c_\mathrm{p} = \frac{\mathrm{HR}_\mathrm{individual}}{\overline{\mathrm{HR}}} = \frac{r^{6.5-\mathrm{LM}}}{r^{6.5-(\mathrm{LM}+\Delta\mathrm{LM})}} = r^{\Delta\mathrm{LM}}.$$

The equation can be inverted to obtain ΔLM by

$$\Delta\mathrm{LM} = \log c_\mathrm{p} / \log r.$$

A list of 128 observers for whom we obtained perception values in terms of ΔLM is given in Table 1. The selection arose from a minimum number of four observing periods composing the average c_p. Observers reporting closest to the average sporadic hourly rate get $\Delta\mathrm{LM} = 0$. It seems satisfactory that the majority of 67% of the observers have $|\Delta\mathrm{LM}| < 0.5$. Their correction in limiting magnitude is less than half a magnitude. It should be noted here that a large value of ΔLM does not mean the observations are particularly bad. If the observer consistently reports with such an LM offset, then the observations will be equally valuable as those of a $\Delta\mathrm{LM} = 0$ observer. The important point is the continuity in the observing behavior.

Deriving a correction for perception from sporadics has a drawback: systematic deviations from the average ZHRs may be caused by incorrect shower association. An observer might, for example, classify a lot of Perseids as sporadics, because he saw them near the edge of the field of view. Then the Perseid numbers will be too low; the number of sporadic meteors will be too high. This high number of sporadics will result in a $c_\mathrm{p} > 1$ or $\Delta\mathrm{LM} > 0$. Since the correction decreases the rates of all showers and sporadics later on, the Perseid rates will be even lower!

3. Population index

These corrections on the limiting magnitude are not applied to the rate data in first place. Before a computation of the ZHR we have to know about the variations of the population index with time. The determination of the population index, however, also depends on the limiting magnitude. The Δlm are thus applied to the magnitude distributions of the Perseids first.

Table 1 – Perception data in terms of a limiting-magnitude shift Δlm for observers with at least 4 observing periods. Note that these values are based only on the activity period of the 2002 Perseids.

Observer	n_{int}	n_{spo}	Δlm	Observer	n_{int}	n_{spo}	Δlm
SERMI	12	4	−2.100	MASED	104	69	+0.010
TRIJO	18	5	−1.951	HODKE	5	102	+0.014
MORTH	5	4	−1.310	HASAM	8	25	+0.040
MAEJO	11	5	−1.280	FISDA	22	45	+0.050
BRAJA	12	45	−1.270	MCBAL	7	28	+0.050
CRIST	8	13	−1.270	RENJU	6	73	+0.050
NILBR	8	7	−1.210	LINMI	4	25	+0.060
PORPE	21	9	−1.060	LANMA	19	99	+0.080
OCAFR	32	9	−1.040	DOBJA	14	143	+0.085
DENDN	8	20	−0.980	WIEHE	33	62	+0.100
KRUMA	15	7	−0.960	KOCRA	6	33	+0.100
JURTO	10	6	−0.920	BENOR	63	215	+0.120
YE QU	6	7	−0.840	KHOSO	4	12	+0.125
LUTHA	13	14	−0.840	SIPHA	4	25	+0.130
MAKVE	4	5	−0.710	MARGE	7	26	+0.130
MARJO	8	2	−0.640	DUBAU	35	412	+0.147
LUNRO	14	99	−0.609	BUCAN	17	101	+0.150
VELVA	16	12	−0.590	SHASE	4	24	+0.150
EINSH	7	19	−0.550	CARJO	20	36	+0.150
GOMCA	15	10	−0.550	VETDI	10	27	+0.160
HAYRO	8	55	−0.530	OSVDA	19	36	+0.170
WUSOL	12	43	−0.520	MISKO	15	255	+0.180
ZHOKU	10	5	−0.480	SWADA	5	33	+0.180
STOEN	10	28	−0.480	KOLKA	14	75	+0.190
STRNK	5	13	−0.460	MOOAL	4	12	+0.210
SHUBR	22	149	−0.440	HALCA	6	37	+0.240
HAOJI	4	5	−0.420	KRUVL	22	137	+0.240
GALMR	5	25	−0.350	RASLI	9	7	+0.240
STAMA	4	23	−0.350	TUKAR	10	36	+0.240
WATWI	8	22	−0.310	ALIAR	5	21	+0.250
LEVAN	17	111	−0.300	GONNE	17	22	+0.270
RUIJA	11	15	−0.300	ZAMJO	6	51	+0.270
MAIPE	4	27	−0.280	SEYMA	7	27	+0.271
ATEAL	7	17	−0.280	MA XI	5	7	+0.300
ZAKJU	5	46	−0.280	BIVNI	10	36	+0.330
MATBE	13	87	−0.270	PINSE	7	48	+0.340
FABDU	7	53	−0.270	KOUJA	39	351	+0.390
WOLJA	7	41	−0.250	ROCMI	4	25	+0.410
LI YA	8	17	−0.250	BENLA	8	50	+0.430
DERSA	4	14	−0.250	YUEYI	8	52	+0.430
KRADO	10	81	−0.237	JANJU	4	18	+0.460
MARPI	30	300	−0.230	BOZAD	6	35	+0.470
SKOAN	36	43	−0.220	RODJA	12	23	+0.470
HOSDA	5	5	−0.220	DEVMI	9	157	+0.480
STOWE	8	129	−0.200	AZIJA	5	21	+0.520
ZIEJU	15	81	−0.195	CIKST	5	24	+0.520
KACJA	21	192	−0.170	VOSJA	5	20	+0.528
HAVRO	16	106	−0.160	FURLU	10	45	+0.550
VERJX	8	51	−0.150	KOZMA	5	43	+0.570
ATAJU	14	249	−0.144	PINCA	26	12	+0.580
HABPA	9	70	−0.140	SERIV	5	23	+0.630
MERFR	45	155	−0.140	UZUJU	5	121	+0.640
KALVA	8	27	−0.120	VELVL	6	42	+0.670
CURMA	5	54	−0.120	HASTA	7	94	+0.700
PICIR	7	37	−0.100	UCHSH	4	28	+0.730
DIMVE	10	74	−0.100	KOVJA	4	21	+0.780
LELAD	4	11	−0.100	NIKGO	8	47	+0.800
SPAGE	6	15	−0.090	ZENLI	4	37	+0.810
LAMNI	5	65	−0.030	KORPE	9	127	+0.830
MORMA	8	12	−0.020	SANCQ	4	12	+0.930
VANMC	54	534	−0.017	ZHUZI	8	69	+0.950
GORSY	11	62	−0.010	GRUDA	12	87	+0.960
SINMA	7	75	−0.010	MENHU	4	49	+0.960
DETPE	17	169	+0.010	GRERO	5	10	+1.960

An adaptive-window algorithm is used to find a suitable breakdown of the activity period into bins for averaging. The procedure tries to collect an optimum number of meteors in a bin—here 1000. If this would lead to an averaging bin of more than a day (more precisely 1°0 in solar longitude), the one-day population index is used regardless of how low the number of meteors is. If the optimum of 1000 meteors were to be found in a window of less than an hour (yes, this happens in a global analysis), the full hour is used regardless of how much the meteor number exceeds 1000.

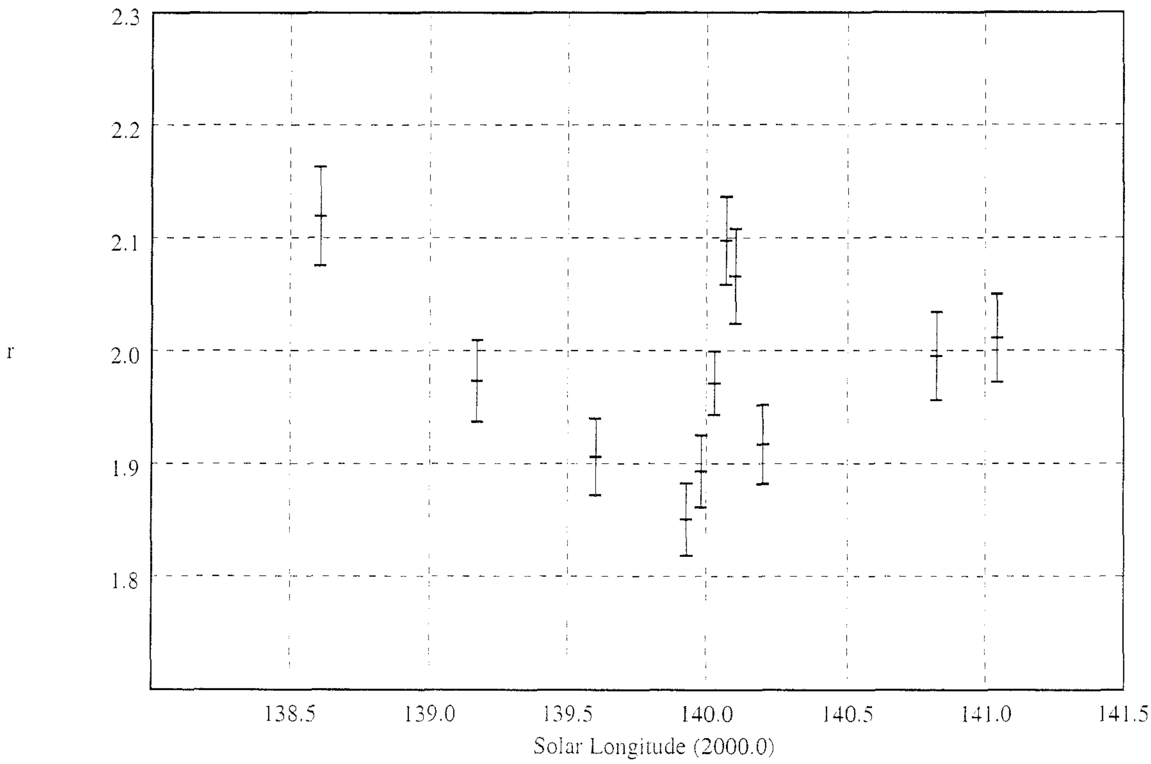

Figure 3 – Population index profile of the 2002 Perseids. The profile was obtained after the application of perception corrections for individual observers as derived from their sporadic meteor rates.

The resulting graph of the time near the maximum of the Perseids is shown in Figure 3. A very clear dip down to $r = 1.85 \pm 0.04$ is found near $\lambda_\odot = 139°90$ (August 12, 20^h UT). We will see later that this minimum occurs before the maximum of Perseid activity. A very quick rise in r follows, and the population index reaches $r = 2.1 \pm 0.04$ near $\lambda_\odot = 140°08$ (August 13, 0^h20^m UT) when we will also find the ZHR maximum in the following Section. The population index returns to $r \approx 1.9$ only a few hours later giving the impression that a broad minimum is superimposed by the above-mentioned maximum of $r = 2.1$.

The changes are significant, but nevertheless one should scrutinize other possible causes than the actual structure of the meteoroid stream. A dependence of r on the radiant elevation was suggested by Bellot Rubio (1995). In this Paper, we will deal with a general correction of the ZHR which turns out to be of limited use; a study of a radiant height dependence of r is due. A sharp r-maximum coinciding with the activity maximum is in fact a rare feature in the Perseid meteor shower.

The full population index profile of the Perseids is shown in Figure 4. It is obvious that the values near the ends of the activity period are quite uncertain, but they do indicate that the population index merges with typical values of sporadic meteors of $r \approx 3$. This does not necessarily mean the population index of the Perseids is 3 near then beginning or end of the activity period. It also means that the contamination of Perseid rates with accidentally aligned meteors becomes larger then. If the Perseid ZHR were exactly 0, a remaining rate of roughly 1 per hour would remain due to chance alignments of sporadics.

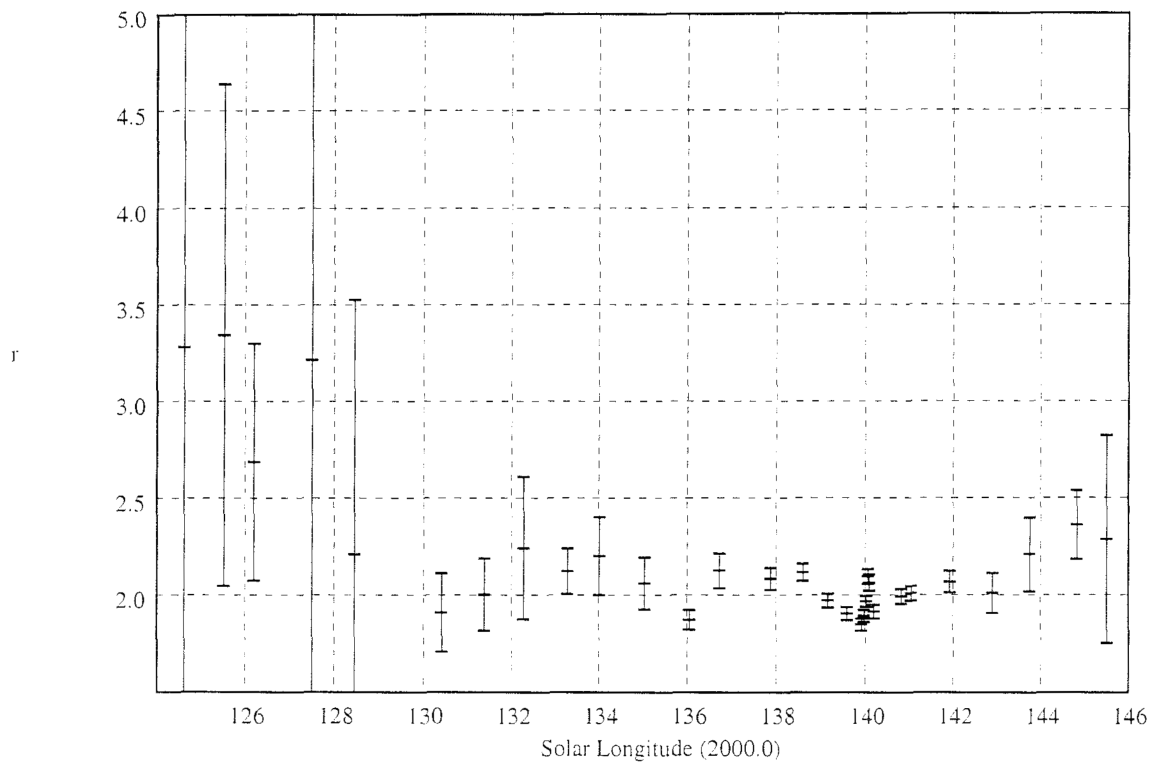

Figure 4 – Full population index profile of the 2002 Perseids. A magnification of this was shown in Figure 3.

4. Activity profile

We can now go ahead and apply the shifts in limiting magnitude, Δlm, to the rate data and use the population index profile of Figure 3 to correct for lm $\neq +6.5$. A very similar algorithm creating variable bin sizes as for the population index is applied. The optimum meteor number is now 500 in order to make possible fine structures visible. The maximum window width is again 1° in solar longitude (roughly one day); as to the minimum width, the window should include at least 1-hour observations regardless of how many meteors are collected in the bin.

Additional criteria for the selection of data are the radiant elevation which should exceed 10° here, and the total correction factor $C = r^{6.5-\mathrm{lm}} F / \sin h_{\mathrm{R}}$ which should not exceed 8. The symbols F and h_{R} mean the factor for field obstructions (clouds, buildings) and the radiant elevation, respectively. The averaging algorithm again tries to compile an optimum meteor number in each average by an adaptive step size—here 500. Observing periods should not be longer than the bin size for averaging. For example, if the meteor numbers are large, and the averaging window has decreased in width down to about 1 hour, observing periods longer than 1 hour are excluded.

The resulting ZHR profile is shown graphically in Figure 5 and numerically in Table 2. A clear maximum at $\lambda_\odot = 140\overset{\circ}{.}109$ (August 13, $1^{\mathrm{h}}06^{\mathrm{m}}$ UT) can be seen. A smoothing function would place the maximum a bit earlier, say near $\lambda_\odot = 140\overset{\circ}{.}08$ (August 13, $0^{\mathrm{h}}20^{\mathrm{m}}$ UT), actually right there where the maximum in r was. The activity level is slightly higher than the average of previous years: the mean maximum ZHR of 1988–1999 gives 90 (Arlt 1999; excluding the low value of 1995); the profile of Figure 5 suggests ZHR $= 106 \pm 3$. The highest observed ZHR at the time of the traditional maximum occurred in 1988 with ZHR $= 106 \pm 22$ but, at that time, the young Perseid peak prior to the traditional maximum may have blended into the traditional. The same could easily hold for 2002, since the early peak has not been detectable as such since 2000.

Although no significant peak before the traditional maximum is detected near the expected solar longitude of 139.°7–139.°9, a clear activity shoulder near $\lambda_\odot = 139.^\circ4$ (August 12, $7^{\mathrm{h}}20^{\mathrm{m}}$ UT) is visible in Figure 5. This time falls close to the passage time of the descending node of the 109P/Swift-Tuttle's orbit. This suggests the particles' orbits do not deviate much from the cometary one. Nevertheless, since we are 10 years after the perihelion passage of the comet, we think it would be too vague to conclude that fresh material of only a few revolutions age was encountered then.

Another peak occurs near $\lambda_\odot = 140.^\circ91$ many hours after the traditional maximum. This value turns out to be problematic as can be seen from the plots in Figure 6 where the ZHR profile is drawn together with the average radiant elevation of each of the ZHR averages. The mean elevation for the late peak is only 29°! The other features of the ZHR profile do not correlate apparently with the average radiant elevation. Yet the case near $\lambda_\odot = 140.^\circ91$ suggests scrutinization of possible radiant-height effects which are not covered by the $\sin h_{\mathrm{R}}$ correction.

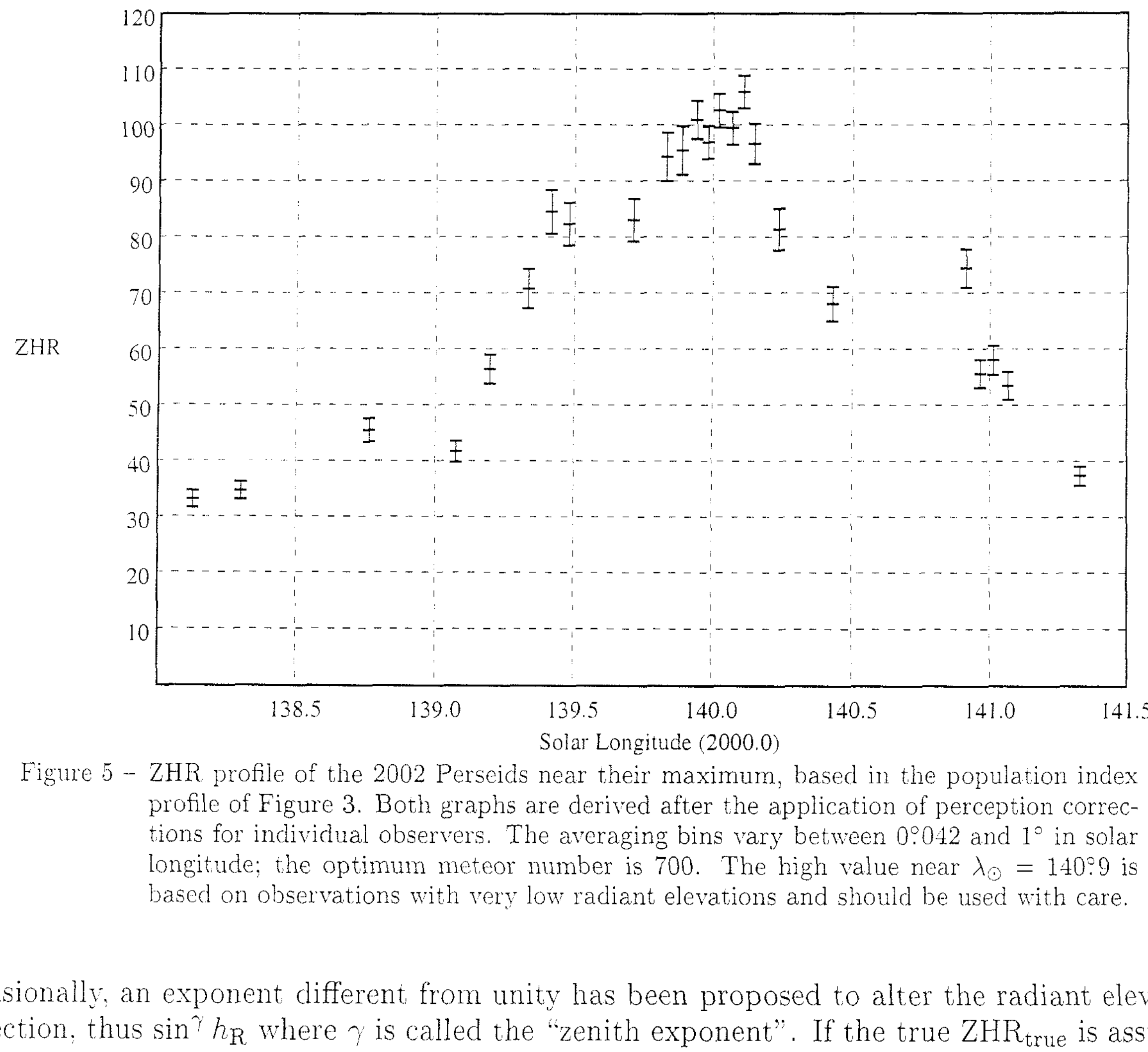

Figure 5 – ZHR profile of the 2002 Perseids near their maximum, based in the population index profile of Figure 3. Both graphs are derived after the application of perception corrections for individual observers. The averaging bins vary between 0.°042 and 1° in solar longitude; the optimum meteor number is 700. The high value near $\lambda_\odot = 140.^\circ9$ is based on observations with very low radiant elevations and should be used with care.

Occasionally, an exponent different from unity has been proposed to alter the radiant elevation correction, thus $\sin^\gamma h_{\mathrm{R}}$ where γ is called the "zenith exponent". If the true $\mathrm{ZHR}_{\mathrm{true}}$ is assumed to be known, the observed HR needs to be corrected for the radiant elevation by

$$\mathrm{ZHR}_{\mathrm{true}} = \frac{\mathrm{HR}}{\sin^\gamma h_{\mathrm{R}}},$$

where HR is the hourly shower meteor rate corrected for limiting magnitude and field obstruction, but not for radiant elevation.

Table 2 – Numerical listing of average ZHR values derived for the 2002 Perseid meteor shower. Solar longitudes refer to eq. J2000.0, r gives the population index from linear interpolation between the values of Figure 3, N_{int} is the number of observing intervals, n_{PER} is the number of Perseid meteors involved in the average ZHR whose errors refer to $\mathrm{ZHR}/\sqrt{n_{\mathrm{PER}}+1}$. The last column, $\overline{\mathrm{lm}}$, is the simple arithmetic average of the limiting magnitudes of the N_{int} observing periods.

$\lambda_\odot$	r	n_{int}	n_{PER}	ZHR	$\overline{\mathrm{lm}}$
112°810	1.82 ± 0.96	2	1	1.6 ± 1.1	+6.34
114°237	1.93 ± 0.98	5	3	1.5 ± 0.8	+6.29
116°327	1.64 ± 0.67	6	4	1.6 ± 0.7	+6.31
117°632	2.84 ± 2.45	9	6	1.8 ± 0.7	+6.06
125°349	3.28 ± 1.80	15	17	4.7 ± 1.1	+5.52
126°330	2.96 ± 1.16	15	25	6.9 ± 1.4	+5.47
127°921	2.67 ± 1.90	7	16	11.8 ± 2.9	+5.86
130°679	1.95 ± 0.20	28	73	8.8 ± 1.0	+5.92
131°598	2.07 ± 0.24	19	72	10.7 ± 1.3	+6.06
133°194	2.14 ± 0.14	21	159	17.3 ± 1.4	+6.20
133°973	2.16 ± 0.16	16	140	21.7 ± 1.8	+5.91
135°023	2.07 ± 0.13	25	182	16.4 ± 1.2	+6.44
136°051	1.94 ± 0.07	45	494	23.8 ± 1.1	+6.28
136°748	2.06 ± 0.08	35	447	22.7 ± 1.1	+6.56
137°814	2.10 ± 0.06	38	475	31.0 ± 1.4	+6.17
138°130	2.10 ± 0.05	51	485	33.3 ± 1.5	+6.15
138°304	2.11 ± 0.05	48	481	34.8 ± 1.6	+6.20
138°762	2.08 ± 0.04	29	474	45.6 ± 2.1	+6.27
139°076	2.00 ± 0.04	69	487	41.8 ± 1.9	+6.09
139°194	1.97 ± 0.04	61	472	56.5 ± 2.6	+5.88
139°333	1.95 ± 0.04	19	407	70.9 ± 3.5	+6.05
139°417	1.94 ± 0.03	14	479	84.7 ± 3.9	+6.22
139°479	1.92 ± 0.03	14	479	82.4 ± 3.8	+6.00
139°713	1.89 ± 0.03	18	485	83.2 ± 3.8	+5.98
139°833	1.87 ± 0.03	19	483	94.5 ± 4.3	+5.60
139°888	1.86 ± 0.03	23	499	95.6 ± 4.3	+5.91
139°941	1.86 ± 0.03	49	895	101.1 ± 3.4	+5.90
139°981	1.90 ± 0.03	86	1122	97.0 ± 2.9	+5.99
140°021	1.96 ± 0.03	81	1169	102.7 ± 3.0	+6.07
140°067	2.08 ± 0.04	84	1193	99.6 ± 2.9	+6.06
140°109	2.05 ± 0.04	98	1382	106.1 ± 2.9	+6.13
140°146	2.00 ± 0.04	39	720	96.8 ± 3.6	+6.20
140°235	1.93 ± 0.04	36	483	81.5 ± 3.7	+6.18
140°430	1.94 ± 0.04	27	497	68.2 ± 3.1	+5.83
140°910	2.00 ± 0.04	32	484	74.5 ± 3.4	+6.34
140°963	2.01 ± 0.04	32	480	55.7 ± 2.5	+6.41
141°013	2.01 ± 0.04	22	483	58.1 ± 2.6	+6.52
141°068	2.01 ± 0.04	28	469	53.6 ± 2.5	+6.45
141°331	2.03 ± 0.04	51	487	37.6 ± 1.7	+6.27
141°976	2.07 ± 0.06	40	486	27.3 ± 1.2	+6.21
142°694	2.04 ± 0.09	41	397	18.1 ± 0.9	+6.22
143°791	2.21 ± 0.18	23	115	11.9 ± 1.1	+6.31
144°872	2.36 ± 0.22	34	174	10.3 ± 0.8	+6.19
146°046	2.18 ± 0.75	4	17	5.4 ± 1.3	+6.46
146°837	2.55 ± 2.18	3	5	5.0 ± 2.1	+6.25

The best idea of the true ZHR we have is a profound average of individual ZHRs from observations with high radiant elevations for which the possible γ-correction will be marginal. We thus replace the true ZHR by the average from observations with $h_R > 50°$ and have

$$\overline{\mathrm{ZHR}}_{50°} = \frac{\mathrm{HR}}{\sin^{\gamma} h_{\mathrm{R}}}.$$

The exponent γ can be found by a linear fit through the logarithmic data points

$$\log \frac{\mathrm{HR}}{\overline{\mathrm{ZHR}}_{50°}} = \gamma \log \sin h_{\mathrm{R}}.$$

Since the value of the "true" ZHR varies, we constructed a new activity profile with the observing periods having $h_R > 50°$ and—in order to reduce possible other systematic errors—with a maximum correction of $C < 5$. Because of the reduced number of observing periods resulting from these restrictions, maximum and minimum window sizes are larger than for the profile of Figure 5; we used 8° and 0°08 respectively. The optimum meteor number was set to 500. We can now compare these "true" ZHRs with the individual rates, uncorrected for radiant elevation.

Since the perception correction and the radiant elevation correction are competing effects, we used the original observing periods without applying Δlm. All the observers for whom Δlm was found to be larger than ± 0.8 were deleted. The total number of 1807 observing periods reduced to 1498 periods.

The individual values of $\log \sin h_R$ and $\log \mathrm{HR}/\overline{\mathrm{ZHR}}_{50°}$ taken from the entire period are plotted in Figure 7. If there were only a $\sin h_R$ correction between the hourly rates and the ZHRs, we should find the dots on a line with a slope of 1. Despite the enormous scatter in the data points, we can try to fit a regression line; its slope is equal to γ. The result is $\gamma = 1.17 \pm 0.03$. Another run with the total number of perception corrected, individual observing periods delivered $\gamma = 1.16 \pm 0.03$. This means that we are not facing selection effects such as "low-perception observers detected while observing chiefly at low radiant altitudes".

A value for γ close to unity means that the deviations from the simplest geometrical correction $\sin h_R$ is small. Let us remember that the major things changing on a meteor when the radiant is low at the horizon will be its magnitude and its path length. The first change will have an immediate effect on the population index. The modification of the ZHR formula thus appears to be a less favorable place to apply non-geometrical radiant-height corrections.

5. Summary

The global analysis of the 2002 Perseid meteor shower, as presented in this Paper, is based on a dataset of more than 23 000 meteors recorded by 222 observers. We find a smooth activity profile with its maximum (highest point) at $\lambda_{\odot} = 140°109$ corresponding to August 13, $1^{\mathrm{h}}06^{\mathrm{m}}$ UT. The maximum ZHR was 106 ± 3. The activity graph has a clearly skewed shape with a longer duration of high rates before the maximum. However, a pre-maximum peak as observed in 1988–1999 was not detected.

A test of non-geometrical corrections for the radiant height altering the correction to $\sin^{\gamma} h_R$ was done using the entire activity period of the shower. A merely geometrical correction implies $\gamma = 1$; we found an average of $\gamma = 1.17$. This $\gamma > 1$ suggests that observations at low radiant elevations underestimate the activity slightly. However, an activity *peak* near $\lambda_{\odot} = 140°9$ was produced by low-radiant-height observations. This behavior indicates $\gamma < 1$. Dependences of the physics of meteors on the radiant elevation cannot be addressed clearly with the γ-exponent. A radiant height dependent r-value should be the first thing to look into.

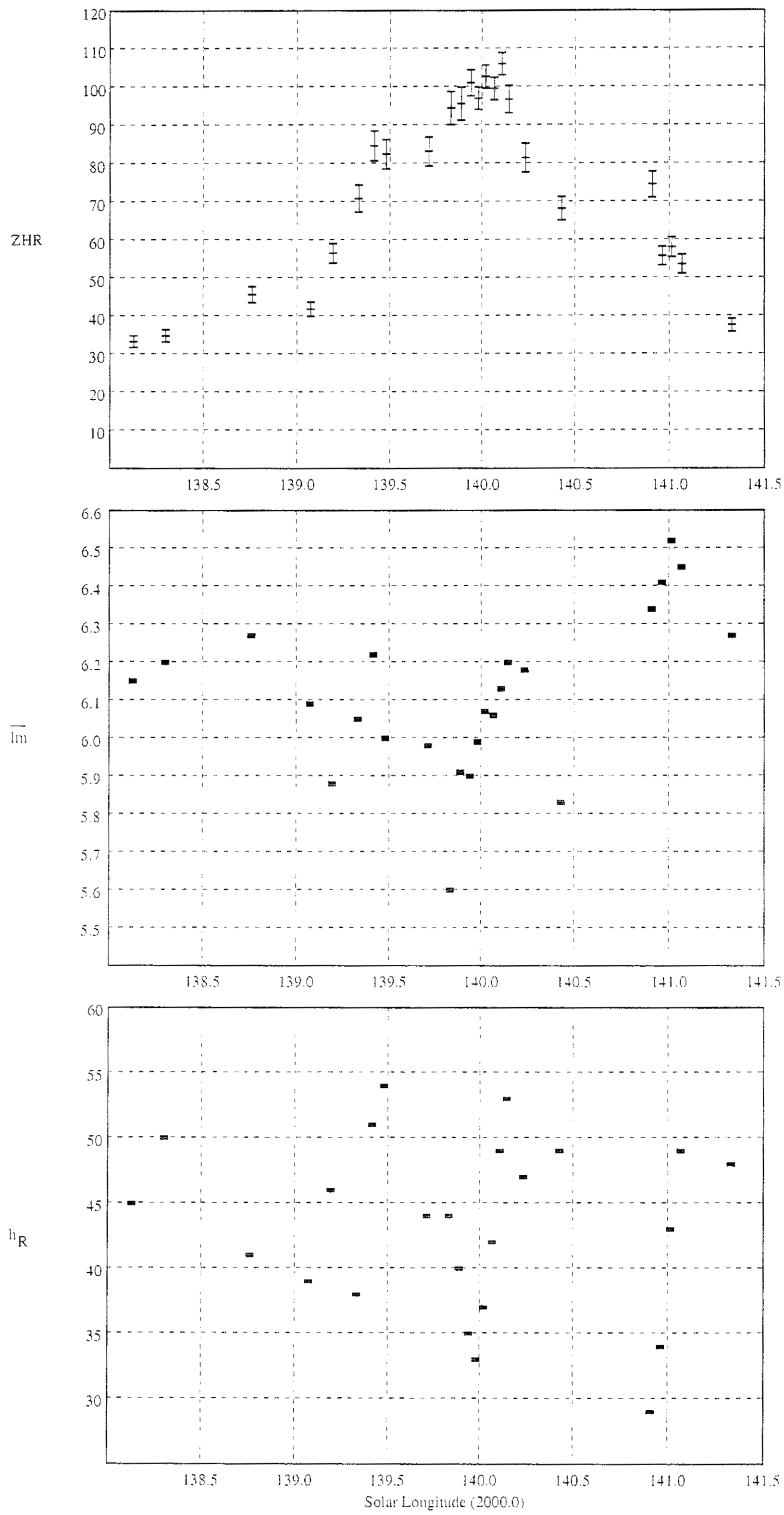

Figure 6 – Combination of the profile of Figure 5 with the corresponding average limiting magnitudes and radiant elevations.

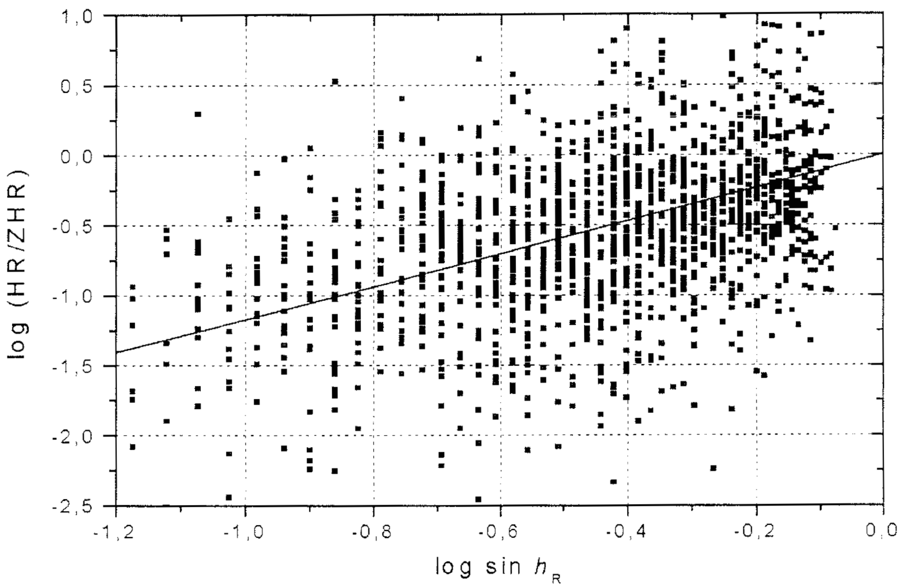

Figure 7 – Scatter plot and fit to determine the exponent γ in the radiant elevation correction, $\sin^\gamma h_\mathrm{R}$. The left value of 0.0 corresponds to 90° radiant elevation (which is not reached by any of the observing periods). The value of −1.2 corresponds to 17°5, while −0.6 stands for 33°. The slope of the fit line gives $\gamma = 1.17$ here.

References

Arlt R., 1999, "Global Analysis of the 1998 Perseid Meteor Shower", *WGN* 27:5, pp. 237–249.

Bellot Rubio L.R., 1995, "Effects of a dependence of meteor brightness on the entry angle", *Astron. Astrophys.* 301, pp. 602–608.

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Global Electrophonic Fireball Survey: a Review of Witness Reports—I.

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Despite more than 300 years since its first scientific description, the phenomenon of electrophonic sounds from meteors still eludes complete physical explanation. According to accepted knowledge, the sound itself is created by strong electric fields on the ground induced by the meteor. Nonetheless, there is no convincing theory that can fully explain how a meteor can generate such a strong electric field. The extreme rareness of the phenomenon has prevented a substantial experimental work so far; thus, consequently, it remains on the margins of scientific interest. This is quite unfortunate since these electric fields suggest the existence of a highly complex electromagnetic coupling and charge dynamics between the meteors and the ionosphere. Therefore, the existing theoretical work relies mostly on the witness reports. The Global Electrophonic Fireball Survey (GEFS) is the first systematic survey of witness reports of these sounds with a standardized questionnaire designed exclusively for this phenomenon. Here we present the overall picture of the phenomenon that emerged after almost 100 reports collected by GEFS. It becomes clear now that the lower meteor brightness limit is about magnitude −2, suggesting a bias in the existing electrophonic sounds catalogues toward brighter meteors. In contrast to the current belief that such low brightness electrophonic meteors produce transient sounds, we find that they can also produce sustained sounds. The current theories cannot accommodate these results. We revive the old idea that the electrophonic sounds can be created by the *corona discharge* mechanism, in addition to the existing prevalent suggestion of resonant vibration of objects on the ground.

1. Introduction

Audible sounds from meteors can be divided into two groups: *normal* and *anomalous* (*electrophonic*) sounds. Normal sounds are acoustic waves produced either by a hypersonic shock front or by a terminal burst and they propagate at the speed of sound. Hence they display a noticeable time delay between the visual appearance of the meteor and an audible detection on the ground. In contrast, anomalous sounds lack this time delay, which means that the light and the sound are observed simultaneously. The exact mechanism of their production by a meteor is still not known due to the extreme rareness of this phenomenon.

The first written record of distinction between the normal and anomalous sounds dates back to the 17th century. Even though the concept of electromagnetic (EM) waves was unknown at that time, almost instantaneous propagation of the anomalous sounds over a large distance was suspected to be somehow connected to the "electric matter". Nevertheless, the existence and reality of anomalous sounds was often denied by scientists, especially when the real nature of meteors was discovered in the 19th century. Since then, these sounds have been mainly ignored by the scientific community, despite the persistent emergence of witness accounts. Consequently, the anomalous meteor sounds have become the oldest unexplained astronomical phenomenon.

Over the years, scarce theoretical research has managed to establish a connection between the EM waves and anomalous sounds. In the first extensive study of these sounds, Romig & Lamar (1963) concluded that these sounds are most probably similar to the *brontophonic sounds* (simultaneous with, or slightly preceding, the lightning stroke) and *aurora sounds* (another poorly studied phenomenon—sounds simultaneous with bright auroras). They concluded that the sound is created by *corona discharge* on sharp conductors, including plant leaves. Keay (1980) narrowed the frequency region for these EM waves to the ELF/VLF (between 30 Hz and 3 kHz) region. He also conducted experiments on human subjects and concluded that the ELF/VLF electric fields are capable of exciting ordinary objects around the observer, from metals to dielectrics, into a resonant vibration which then produces a sound in the same frequency range as the EM waves (Keay & Ostwald 1991). This has become a widely accepted theory and the corona discharge mechanism has been mainly forgotten.

The term "electrophonic sound" was used for the first time in 1937 as a description for sensation of a sound caused by electrical current through the head (Stevens 1937). A few years later the term "electrophonic bolide" entered meteor astronomy as a description of a bright meteor accompanied by anomalous sound (Dravert 1940).

All this, however, merely moved the problem from how to create a sound to how to create a strong ELF/VLF radiation from a meteor. Sound can be created from the ELF/VLF waves only if the electric field at the ground is of at least several hundred V/m. Considering the large distance between the observers on the ground and a meteor, the electric fields in the vicinity of the meteor should be many magnitudes larger than on the ground (due to inverse square dependence on distance for frequencies of kHz and higher and approximately exponential dependence on distance for lower frequencies) (Wang, Tuan & Silverman 1984). This problem has been studied theoretically by several authors (for an older review see Bronshten 1991) (Beech & Foschini 1999), including Keay (1980). Nonetheless, the first instrumental recording of the electrophonic sounds combined with a video and VLF observations during the 1998 Leonids showed that none of the existing theories can explain the data (Zgrablić et al. 2002).

Even though all these theories have been based solely on witness reports, there has been no attempt to collect them with a standardized questionnaire. The existing catalogues of electrophonic sound reports (Romig & Lamar 1963 , Kaznev 1994, Keay 1993a) are usually extracted from other sources, mainly from the fireball catalogues, and then statistically analyzed. Considering how little we understand the nature behind this phenomenon, the witness reports are still a valuable source of information. Two years ago, we initiated the Global Electrophonic Fireball Survey (GEFS) to collect these reports in a standardized form (Vinković et al. 2000). After receiving almost 100 reports, we present here a review of the collected data. Some reports of special interest (such as the Leonids or meteors with complete trajectory) are presented in more detail. Due to the limited space in the Journal, we can not present the complete reports, but they can be accessed at the GEFS web-page `http://www.gefsproject.org` or obtained from us on request.

2. Statistical analysis of the reported electrophonic sounds

Witness reports were collected by the following methods: through the on-line HTML data submission form, e-mail using a text version of the form, or informal e-mails. All of them were transformed into the standardized survey form described by Vinković et al. (2000). A single report often includes more than one person. Before we started preparing this review, we received 91 reports of electrophonic meteors.

The reports are designated as `GEFSYYYY_MM_DD_NN`, where `YYYY_MM_DD` is the date of the electrophonic event (year, month, day) and `NN` is numeration in a case of more than one event in a day. We consider one location as one event, no matter how many observers are involved. If the auditory perception of electrophonic sounds does not differ among observers, they will have more or less the same psychophysical reaction regarding the sound description when exposed simultaneously to the same sound. Therefore the sound is considered as one event instead of being interpreted as several events based on the perception of multiple observers.

The geographical locations of the electrophonic meteors include:

> Australia, Belgium, Canada, Croatia, Denmark, England, Finland, France, Germany, Israel, Mexico, Mongolia, The Netherlands, Norway, Scotland, Singapore, Sweden, and the USA

The oldest event is from the year 1952. The complete trajectory is calculated in three occasions. It is interesting to note that 34 reports are associated with the Leonids and seven with the Perseids. Among them, there is one very interesting account of numerous electrophonic sounds from the 1966 Leonids. In addition to the reports of electrophonic sounds from meteors, there are three reports of (most probably) aurora sounds (`GEFS1964_11_00_02`, `GEFS2001_11_23_01`, and `GEFS2001_12_14_01`) and one report of an electrophonic sound from the Space Shuttle reentry (mission STS-109) over central Texas (San Antonio). These four reports are not included in the analysis shown below.

Here we statistically evaluate the data for specific segments of the GEFS form. We would like to emphasize that most of the reports have very valuable information provided in the *additional remarks* section of the form.

2.1. Personal information

The GEFS reports are sometimes not submitted by the witnesses themselves, but rather by a person who collected various reports of sighted meteors and recognized reports of electrophonic sounds among them. Such reports are sources of the events with known meteor trajectory described in the next section; thus, the name of person who submitted the data is not necessarily the name listed under *personal information*. If the specific permission to use the witnesses' name as a reference to the submitted GEFS data was not obtained then their name is omitted. If one GEFS report contains several qualitatively different witness reports, the word "multiple" is used as personal information and the names (or initials) are provided in conjunction with their GEFS data. The level of meteor observing experience among the witnesses varies from *not experienced* to *highly experienced*. Most witnesses had never heard a sound from a meteor before, as expected.

2.2. Description of the observing site

The location of observing sites is usually described as a geographical feature, thus the given coordinates correspond to these features and are not precise. The meteorological conditions are described as *clear sky* and *calm* (windless or light breeze) in 84% of reports with provided weather conditions. This is not surprising since such conditions increase the possibility of spotting a meteor and noticing an unusual sound.

2.3. Details of the sound from the meteor

The exact month of the electrophonic event is provided in 73 reports but the day in only 47 (mainly because of very old events). The time is specified in 70 reports, usually an estimate of the hour, with only 32 reports specifying minutes or better.

Descriptions of reported electrophonic sounds match descriptions in the existing electrophonic catalogs (e.g. Keay 1993a, Kaznev 1994). Keay (1993b) classified the electrophonic sounds into three groups: *smooth* (with 71% rate of occurrence), *staccato* (18%), and *sharp* (11%). This classification applied to the GEFS reports is shown in Table 1. Our rate of occurrence of smooth and staccato sounds is different, more than expected from Keay (1993b). This is probably due to different methods used for counting sound events.

In addition, some observers may not hear the sound or agree on its duration or direction. The reported duration of sounds varies from less than a second to more than 10 seconds. Sound is recognized as coming from *all directions* in 19 reports (27%), *no direction* in 10 (14%), and from *the meteor* in 41 (59%). Air is often mentioned as the direction or source of the sound. Three reports (`GEFS1998_11_16_02`, `GEFS1998_11_17_04`, `GEFS2001_11_18_08`) have an exact object identified as a possible sound source.

In 76 (84%) cases, the meteors were spotted simultaneously with their sound. Observers could not decide about a specific meteor that produced the sound in 8 (9%) cases because of high meteor activity. The electrophonic meteors were spotted prior to the sound in 2 (2%) cases, but the sounds did not exceed the duration of their meteor. In 5 (5%) reports, the meteors were spotted after the sound. In two of such cases (`GEFS1972_00_00_01`, `GEFS1969_06_00_01`), the electrophonic sound prompted the observers to look toward the sky.

Correlation of the sound with the meteor's light maximum reveals that: in 29 reports witnesses *could not decide*, 48 (76%) reports indicate *simultaneous* sound and light maximum, 6 (10%) reports indicate a sound *before*, and 9 (14%) *after* the light maximum (one report has two sounds with different correlations). Since some reports deal with multiple sounds with the same type of correlation, the percentages shown here suffer from large error bars.

Table 1 – Phenomenological classification of electrophonic sounds. The percentage shows the rate of occurrence in the GEFS catalog. According to Keay (1993b), the sounds can be classified as smooth, staccato, *and* sharp. This classification would correlate the sound frequency and duration with the meteor ELF/VLF radiation of the same frequency and duration. In our study, we consider the possibility of corona discharge as a source of some electrophonic sounds and apply a different classification according to two mechanisms of sound production: vibration *or* discharge.

sound type	rate	sound description
		classification according to Keay (1993b)
smooth	40.5%	hissing, buzzing, whuss, whoosh, fizzing, bottle rocket, sjhh, pchiu, steam escaping from cooker, sss, swishing, voom, high-pitched whistle, whispering, sheewu
staccato	47.0%	rustling, crackling, wood burning, phtt - like electric arc, sizzling, white noise, shaking bulb with broken filament, zzz, firework, frying bacon, tzz, foam being ripped, like static, lit match, thrumming, small single engine 'Cesna' airplane, butter in hot pan, hot metal in water, cards being shuffled, ice breaking up, electric flutter
sharp	12.5%	pop, thwuck, tic, boom, whump, clap, kweik
		classification according to our study
vibration	51.3%	hissing, buzzing, fizzing, whuss, pop, thwuck, sjhh, tzz, bottle rocket, shaking bulb with broken filament, sss, tic, steam escaping from cooker high-pitched whistle, swishing, small single engine 'Cesna' airplane, whispering, thrumming, boom, whump, voom, sheewu, clap, kweik
discharge	48.7%	rustling, sizzling, whoosh, crackling, white noise, 'htt - like electric arc wood burning, firework, frying bacon, zzz, pchiu, foam being ripped, lit match, butter in hot pan, like static, hot metal in water, cards being shuffled, ice breaking up, electric flutter

In a case of one Perseid meteor, fading of the meteor's trail is described as correlating with the loudness of a sizzling sound that ended with a "pop" (GEFS1995_08_10_01).

Two out of six reports of sound before the light maximum are actually marked as "cannot decide", but their audio/video recordings show the sound preceding the final meteor flash (GEFS1998_11_17_04 and GEFS1998_11_17_05). This demonstrates that it is very hard for an observer to make such a time estimate. These two recordings belong to the 1998 Leonids and show that a meteor can induce an electrophonic sound when it has an altitude of $\sim$ 100 km (Zgrablić et al. 2002).

The same two 1998 Leonids were also monitored with ELF/VLF radio receivers and there was no electric ELF/VLF signal above 500 Hz during these two electrophonic events. However, such signals were detected from other Leonid meteors during the same observational campaign (Garaj et al. 1999). This result is basically confirmed by Shawn E. Korgan from the NASA INSPIRE Team I-01 (GEFS2001_11_18_08). He was recording the atmospheric VLF activity when he heard electrophonic sounds from meteors. The recordings did not show any VLF activity correlated with the sound events. This is consistent with the detection of geomagnetic disturbances below 10 Hz detected during the reentry of an artificial satellite accompanied by electrophonic sounds (Verveer, Bland & Bevan 2000) and with the electric field disturbances below several hundreds of Hz correlated with the activity of 2001 Leonids (Trautner et al. 2002).

In eight occasions, the observers associated meteor fragmentation with an electrophonic sound. Six of these are very transient in duration: "pop", "boom" and "crack". This suggests a sudden release of large amounts of electric charge. Considering the mobility of electrons and ions, this burst of charge has to be either in excess of electrons or highly anisotropic (or both) in order to create a net long-range electric field. It remains a mystery, however, why this process does not happen, or at least not with the same energy scale, during any other similar meteor fragmentation in nature.

Table 2 – Distribution of the electrophonic meteor magnitudes. The rate of occurrence derived by Kaznev (1994) is also given. It has been argued by other authors that the low brightness meteors can not produce sustained electrophonic sounds, thus we also show the sound descriptions.

magnitude		rate by	magnitude	sound descriptions
range	rate	Kaznev	descriptions	
-1 to -5	36.8%	11.3%	-2 or more, not so bright to 2, max -2 to -3, -1 with -3 end flare, -1 in twilight, bright, clearly visible, bright at Sirius, twice Sirius	crackling, sizzling like bacon frying, sizzling "sss", soft hissing, hissing followed by a crack, ffffffffp, short burst of static, short sharp crack, broken filament shaking in blub, "thwuck", pop, crackling, swoosh, woosh, high pitched whistle, fizzing with crackling, loud high-pitched hissing, faint hissing, crackled/hissed, pop
-5 to -10	41.3%	19.7%	very bright, -5 or so, $-6.5 \pm 0.5^*$, -6 to -7, $-5 \pm 1^*$, firework/flare, fireball, seen in evening, -8 to -10, brighter than Venus	"phtt" like electric arc, lit match, steam escaping from cooker, crackling fireworks, sizzling/crackling, "sSHheewwuu", fizzing/hissing, swishing, hissing, crackling, whuss, pop, "sjhhhhh..", hiss, sizzling ending with pop, single engine "Cesna" airplane, like static/crackling, "sss" with a slight "zz"
brighter than -10	21.9%	69.0%	brighter than the full moon, like full moon, bright as moon, extremely bright, lit up the whole sky, lit up the ground, brightest ever seen, $-12 \pm 1^*$, -15 to -20, -9 to -13	whistling with buzzing, whisper, sizzling, rustling like a rocket, wood on fire, white noise, thrumming, lit match, "sss" followed by pop, "voom", pop, whoosh like rustling, hissing/fizzing

*Absolute magnitude

Another interesting unusual phenomenon related to an electrophonic fireball is reported in GEFS1977_09_00_01: a warm "puff of wind...towards the end of the duration of the sound". Similar tactile phenomena like "oscillations and shaking of the air" (Kaznev 1994) or " oppression of air" (Romig & Lamar 1963) have been reported since the beginning of the history of electrophonic phenomenon. In 1719, Sir Edmund Halley dismissed "hearing [meteor's] hiss" and "the warmth of its beams" as "the effect of fancy" (Halley 1719).

Appearance of smell simultaneously with a bright meteor has a similar history. There is one (GEFS1969_06_00_01) GEFS report mentioning a smell of sulphur, one of ozone (GEFS0000_11_00_02), and one of "lightning" (probably also ozone) (GEFS1998_08_12_01). Such phenomena have been documented in the electrophonic catalogs (Kaznev 1994). The smell of sulphur and onion was reported during the 1833 Leonids (Olmsted 1833). More recently, a "foul metallic, chemical or sulphurous odor" was reported to accompany the flight of the Tagish Lake meteorite in 2000 (Brown, ReVelle, & Hildebrand 2001). These phenomena are even more rare than electrophonic sounds. The tactile sensations could be explained by vibrations of human hair in oscillatory electric fields (Carstensen 1986), while the smell comes from the ozone production (and some other chemicals) by corona discharge (Romig & Lamar 1963, Aubrecht, Stanek & Koller 2001). Nevertheless, these explanations remain a speculation since a comprehensive study of those phenomena has never been performed in the meteor astronomy.

2.4. Details about the meteor

Thirty eight reported meteors (events) are identified as *sporadic* (48%), 34 as *Leonids* (43%), 7 as *Perseids* (9%), and one as possible Delta-Aquarid. One of the Leonids is probably misidentified (`GEFS1998_11_16_01`) because the radiant was below the horizon at the time of the event. The range of electrophonic meteor magnitudes shown in Table 2 is of a special interest for theoretical work since it carries information about the energetics of electrophonic events. The range of magnitudes is divided into three groups: between -1 and -5, between -5 and -10, and -10 or brighter. Sometimes it is not easy to make a magnitude estimate; thus, we provide their descriptions to show our method. The distribution is compared with the statistical results of Kaznev (1994) who had a sample of 71 electrophonic meteors with known magnitudes.

Our results are clearly different from Kaznev's distribution. Almost 80% of our meteors are no brighter than -10, compared to about 30% by Kaznev. This suggests that our survey is far less biased toward extremely bright meteors, in contrast to all other existing electrophonic catalogues. This is understandable because most of their electrophonic meteors were extracted from catalogues (or reports in the literature) of very bright fireballs. From the theoretical point of view, it is very interesting that the lower brightness limit for electrophonic meteors can be as low as approximately -2. One can argue that these meteors can have much brighter absolute magnitude, but their height above horizon clearly shows that this is not the case (one of them is also photographed, see next section). Keay (1992) (see also Keay 1994) argues, in the context of his theory, that electrophones from the magnitude -7 or fainter meteors should be very transient in nature, lasting for a tenth of a second or so. Again, the reports shown in Table 2 demonstrate that this is not the case for many of such sounds.

The velocity of meteors is described as *very slow* in 5 reports (6%), as *slow* in 38 reports (42%), as *fast* in 40 reports (45%), 5 as *very fast* (6%), and one meteor as *stationary* (1%). Meteor fragmentation is reported for 32 events (38%) and it did not occur in 53 events (62%). The distribution of meteor height above horizon, its azimuth, and angle between its path and horizon is shown in Table 3. For comparison, distribution from Kaznev (1994) is also shown. Our statistical sample is big enough to notice some interesting statistical averages.

The distribution of height above horizon of the electrophonic meteors from Kaznev peaks at about 45% in the 30–60° region. Our survey shows only 30% of meteors in this region. However, 45% of our meteors are above 60°, while Kaznev reports only 25%. Even though people tend to overestimate this angle, this mismatch is significant because such overestimates appear in both surveys and they are statistically averaged. This suggests that something else is responsible for shifting our distribution closer toward the zenith.

We propose two explanations. The first explanation is that a larger number of smaller meteors appear in our sample. Indeed, there is a slight increase in the angle for the -5 to -10 meteors compared to the -1 to -5 meteors, but the statistical uncertainty is too large for any conclusive differentiation. The second explanation is that smaller meteors cannot produce a very strong EM signal. This would imply that they have to be closer to the observer, that is closer to the zenith. Since all of our meteors are bright enough to be visible from a large distance, this explanation seems plausible.

However, the azimuthal angle shows a very random distribution of observers around meteors. One quarter of meteors appear in each of four 90° intervals, which is also noticeable in Kaznev's distribution. The angle between the meteor path and horizon also shows similarity to Kaznev's results, with approximately 50% of meteors with available data in the 0–30° region, 25% in the 30–60° region, and 25% over 60°.

Table 3 – Statistical analysis of the meteor path in the sky. An event represents one observing site. If an angle is not clear cut between two statistical regions (e.g. 30° for the hight above horizon) then the event is counted as 0.5 in both adjacent regions, or 0.33 when spanning over three regions. The results are compared to the values by Kaznev (1994).

	Angle (deg)	Events	Rate	Rate by Kaznev
Height above horizon	0-30	18.7	23.9%	31.6%
	30-60	23.8	30.6%	43.9%
	60-90	35.5	45.5%	24.5%
Azimuth	315-45(N)	14.3	25.6%	22.4%
	45-135(E)	15.3	27.4%	28.5%
	135-225(S)	15.8	28.3%	22.3%
	225-315(W)	10.5	18.8%	26.8%
Angle between the meteor path and horizon	0-30	25.7	52.4%	44.5%
	30-60	11.7	23.8%	32.5%
	60-90	11.7	23.8%	23.0%

3. Reports of special interest

A couple of reports attract special attention either because they have been extensively documented by observers or they deal with an interesting type of meteor. We present details about the electrophonic sounds from Leonids, a photo of one low brightness electrophonic meteor and meteors with estimated trajectory. More about all these events can be found at the GEFS homepage.

3.1. Electrophonic sounds from Leonids

The Leonids, and meteors with similar properties like Perseids, are the biggest theoretical challenge in explaining the electrophonic phenomenon. Not only are there low magnitude electrophonic Leonids which disintegrate at altitudes above 80 km, but there are also sustained sounds from the Leonids. A sustained sound should last for a large fraction of a second in order to be perceived as such by the observer. After taking into account their high velocity, we see that the electrophonic signal can start at exceptionally high altitudes of $\sim$100 km. These altitudes have been also obtained by the instrumental recordings of electrophonic sounds from the 1998 Leonids (Zgrablić et al. 2002).

Altogether there are 34 reports of sounds from the Leonids. One report is about the 1964 Leonids, two about 1966, one about 1989, 10 about 1998, one about 2000, 17 about 2001, and two are without a specific year. The sound duration is usually overestimated by the witnesses, thus durations of $\sim$ 3 seconds are not surprising. The sound description ranges from high-frequency sounds like "hissing", "sizzling", "crackling", "fizz", "swoosh", or "white noise", to low-frequency sounds like "(deep) pop", "boom/popping", or "clap". The magnitudes range from as low as $m = -2$ to "bright enough to light up the ground" or "the whole sky". One case of a meteor of magnitude -2 is also described in Drummond, Gardner & Kelley (2000) (GEFS1998_11_17_01).

Details about GEFS1998_11_17_04 and GEFS1998_11_17_05 are available in Zgrablic et al. (2002). As already mentioned above, the VLF radio signal did not accompany these two electrophonic meteors, as it did not the meteors in GEFS2001_11_18_08.

The reports GEFS1966_11_17_01 and GEFS1966_11_17_02 represent the first documented report of electrophonic sounds known to us from the famous Leonid meteor storm of 1966. The first observation took place in Texas, USA, from about 05:30 until 07:00 local time, when the radiant was 70–80° above the horizon. According to the witness Willis Jarrel Jr., "the sounds came intermittently from the beginning of the observation until the end". It was not possible to connect particular meteors with the sounds, except in one case of an extremely bright fireball. This demonstrates again the existence of low magnitude electrophonic Leonids. The sounds were lacking directionality.

They are described as "a velvet silky rustling sound like a lady walking in a pleated dress where the fabric rubs against itself" and "some sounded like a short distorted hiss, with a pronounced sibilant tone". These sounds had shorter duration than the one connected to the bright fireball and were described as similar to the other sounds but "lower in pitch and much more edgy and crackling". The witness notes that he has better than average hearing, which explains his experience of a large number of electrophonic sounds. The witness has also provided photos of the observation site (second-story open-air deck on a house). The photos and additional details about the event are available on the GEFS homepage.

He also notes that he woke up and went to a window for no reason, probably because of a "stimulus of some sort". Even though the existence of a "stimulus" sounds unrealistic, this is not a unique report of this sort (Kaznev 1994) and can not be ignored. Possible physical explanation could be that the witness was exposed to frequent bursts of strong electric fields, as implied by the large number of electrophonic sounds. According to laboratory experiments, animals, especially, and humans can be sensitive to the short pulses of electric fields (Buskirk, Frohlich & Latham 1981). Thus the reality of such "stimulus" remains an open question for future research.

The second observation of the 1966 Leonids was from Kansas, USA, from about 01:00 to 04:00 local time. The witness recalls hearing approximately 20 "noisy" meteors that night. They sounded like "an electric flutter or sizzle" with one half of a second duration. The magnitudes are described just as "all magnitudes".

3.2. Photo of a low-magnitude electrophonic meteor

Electrophonic meteors with magnitudes as low as -2 make a significant fraction of the electrophonic sound reports (see Table 2). Since they represent a challenge to the theoretical modeling of the phenomenon, here we present a photo of one of them.

The report GEFS1972_04_23_01 belongs to Eisse Pieter Bus from The Netherlands who was performing visual and photographic meteor observations on the night of 1972 April 22-23, at the Observatory of the University of Groningen at Roden. At 01:12:47 UT, a magnitude -2 meteor passed through the constellation of Corona Borealis. The meteor was photographed by the camera during a one minute exposure time (see Figure 1). Since Corona Borealis was $\sim 65°$ above the horizon at that time, the absolute meteor magnitude was close to the estimated apparent -2.

The witness recalls hearing a cracking sound during the whole flight of the meteor with a duration of ~ 5 seconds. The sound did not have direction. "It was in the middle of [his] head like a sound in a stereo headphone". The meteor did not have a light maximum, but it showed "a wake that moved slowly from the left to the right (about 20° to the left and right). Close behind this wake, but not connected, a persistent trail was visible with a lifetime of about 1 second". The witness emphasized that he has "seen hundreds of bright ... and very bright meteors but [he has] never heard a meteor with a sound nor [he has] seen a meteor with a wake again".

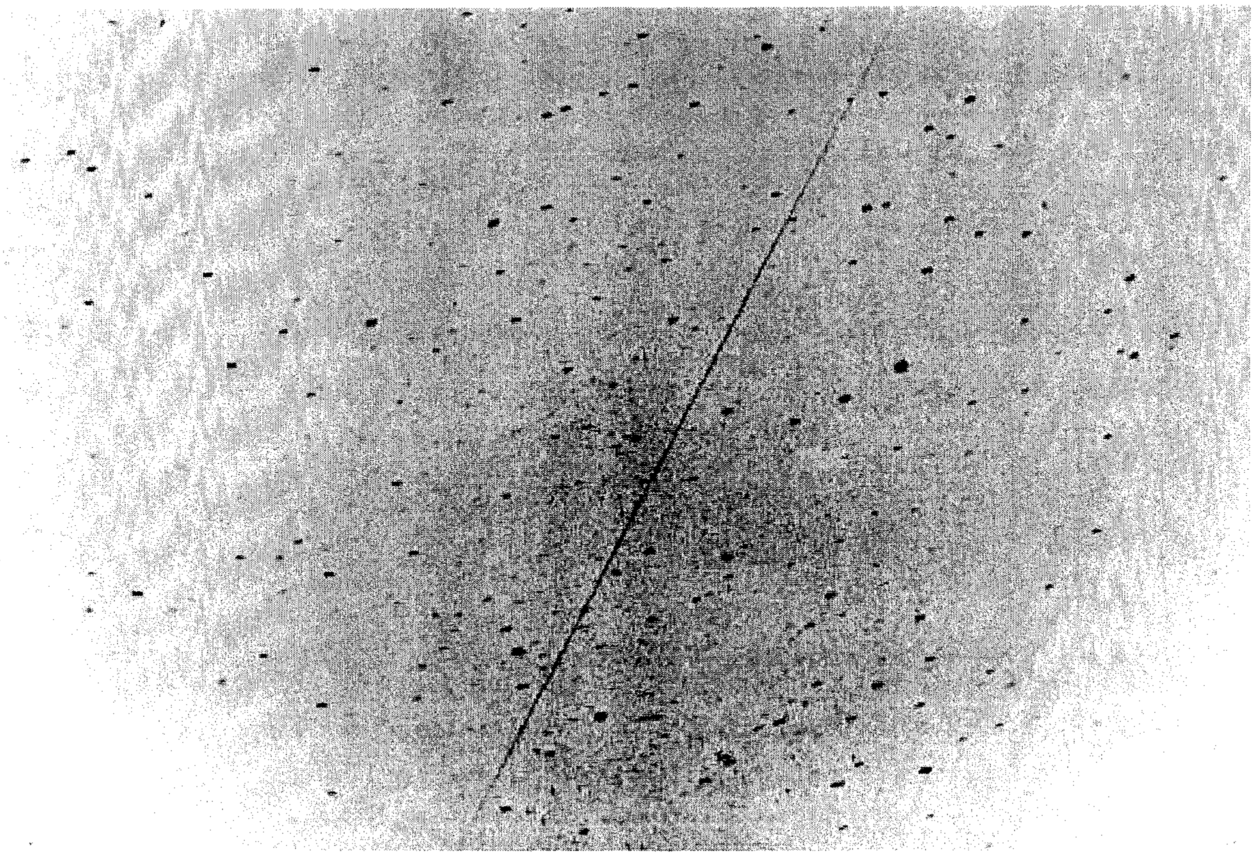

Figure 1 – A magnitude −2 electrophonic meteor on 23 April 1972, at 01:12:47 UT photographed from the Observatory of the University of Groningen at Roden, the Netherlands. The meteor's direction is from South to North, the exposure time was 01:12:17 UT–01:13:17 UT with an Exa 1a 2.8/50-mm camera and Kodak-Tri-X film of 400 ASA. Courtesy of Eisse Pieter Bus.

3.3. Fireball over north England, 2000 January 9

The witness reports of this event were collected by Alastair McBeath, who analyzed them and posted the results to the IMO-News e-mail list. All the information presented here is part of these results and published in McBeath (2000). The electrophonic event is cataloged as GEFS2000_01_09_01.

The fireball occured on 2000 January 9 over north England, UK, at around 01:56 UT. The estimated visible trajectory started above Appleby in Cumbria (02°30′ W, 54°35′ N) and ended ∼ 10 km offshore due east of Seaton Sluice, Northumberland (01°15′ W, 55°05′ N). The entry angle was $33 \pm 3°$ from the horizontal, which gives the atmospheric path length of approximately ∼ 110 km, with the mean atmospheric velocity of 22 ± 3 km/s. The estimated brightness was between −15 and −20.

There was several reports of acoustic signals, one of which is recognized as an electrophonic sound. A whoosh sound, "like a rustling", was reported by an observer located on top of a hill called Eston Nab (01°07′ W, 54°33′30″ N), at the closest distance from the ground track of approximately ∼ 60 km south-east. It is interesting that the noise was associated with the breaking up during the flight when "three large lumps, glowing like red-hot brick" separated off the main body, two of which were significantly smaller than the third.

The Earth's magnetic field in the vicinity of the meteor is useful information for a future theoretical work. The magnetic field components (National Geophysical Data Center, The World Data Center for Solid Earth Geophysics, Boulder, http://www.ngdc.noaa.gov/seg/wdca/) on that day at location 02° W, 55° N and 50 km altitude are $Z = 44\,994$ nT (vertical, direction down), $H = 17\,181$ nT (horizontal), with magnetic declination of 4°46′ W (model IGRF2000). Variations from these values along the fireball path are ∼ 1% or less.

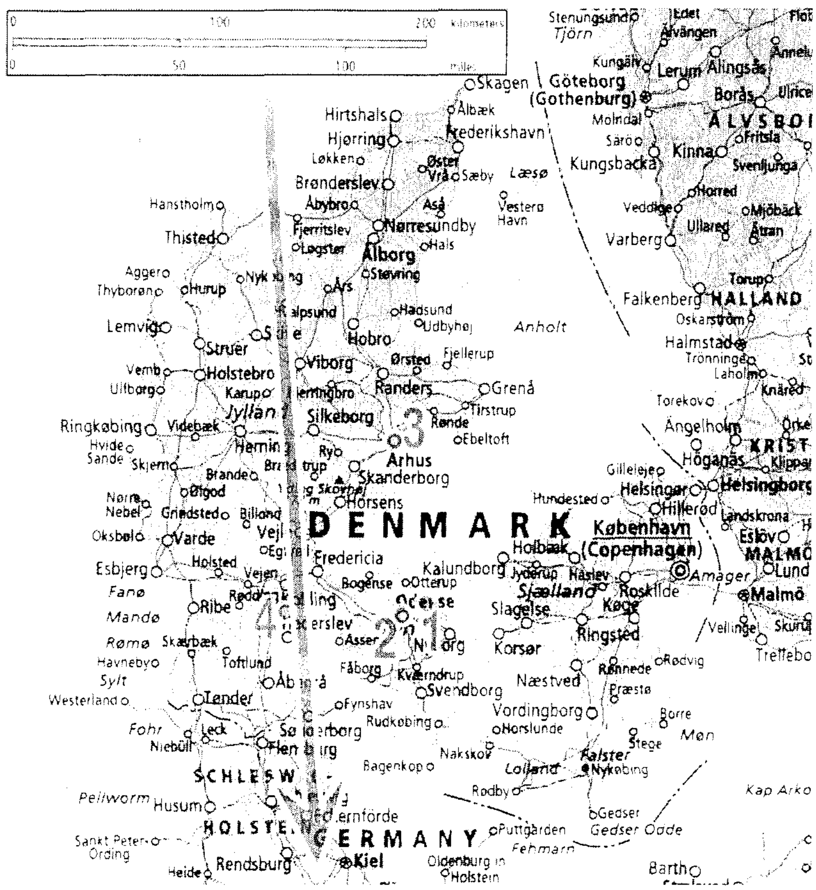

Figure 2 – Electrophonic fireball over Denmark on 1999 December 20. The ground track is a rough estimate. The electrophonic sound events are marked by points and numbers. See text for their description and more details about the fireball. Courtesy of Holger Pedersen.

3.4. Fireball over Denmark, 1999 December 20

The witness reports of this event were collected by the Tycho Brahe Planetarium, Copenhagen and provided to Holger Pedersen by its director Bjoern Franck Joergensen. The information presented here was obtained from a statement by the Planetarium and from the IMO-News e-mail list, where several e-mails related to the event were posted. Additional details about the electrophonic sound report were provided to the GEFS by Holger Pedersen and cataloged as GEFS1999_12_20_01.

The fireball occured on 1999 December 20 over Denmark, at around 19:15 UT. The exact trajectory is not determined. According to Lars Bakmann (Meteor Section Astronomical Society, Denmark) the meteor was passing zenith above Sønderborg (09°47′ E, 54°54′ N) with the azimuth of $170 \pm 20°$ (direction from the north to south). The azimuth favors larger angles, since the fireball was visible from Göteborg (Sweden) and the Oslo area (Norway). The trajectory was very shallow, often described as "almost parallel to the horizon". The altitude is uncertain. If the visible part of the flight started at an altitude of $\sim$ 110 km over the sea between Denmark and Norway and terminated at an altitude of $\sim$ 40 km above the region of the town Kiel in Germany, the ground track would be $\sim$ 400 km, and the angle of flight would be $\sim 10°$ with the horizontal. The mean atmospheric velocity was $\sim$10 km/s. All these numbers are rough estimates, including the meteor's magnitude of -5 ± 1^m.

Five witnesses at four different locations reported acoustic signals recognized as electrophonic sounds:
(1) observer from Munkebo (10°34′ E, 55°27′ N) heard "a subdued, hissing sound ... [like] a boat which gently slides through the water";
(2) observers from Odense (10°23′ E, 55°24′ N) heard a hissing sound when "a couple of small pieces detached";
(3) observer from Århus (10°13′ E, 56°09′ N) heard a faint hiss;
(4) and observer from Christiansfeld (09°29′ E, 55°21′ N) also heard a hiss.

The meteor ground track and location of electrophonic events is shown in Figure 2. The magnetic field components at 10° E, 56° N and 50 km altitude are $Z = 45\,700$ nT (vertical, direction down), $H = 16\,594$ nT (horizontal), with magnetic declination of 0°01′ E (model IGRF95).

3.5. Fireball over Croatia, 1997 November 3

The witness reports of this event were collected by Korado Korlević, Višnjan Observatory, Croatia, and the information presented here is the result of his analysis. When interviewing the witnesses (usually by phone), he recognized electrophonic sound events on several occasions and made a note about their location and the name of the observer but no other details. This fireball is cataloged as GEFS1997_11_03_01.

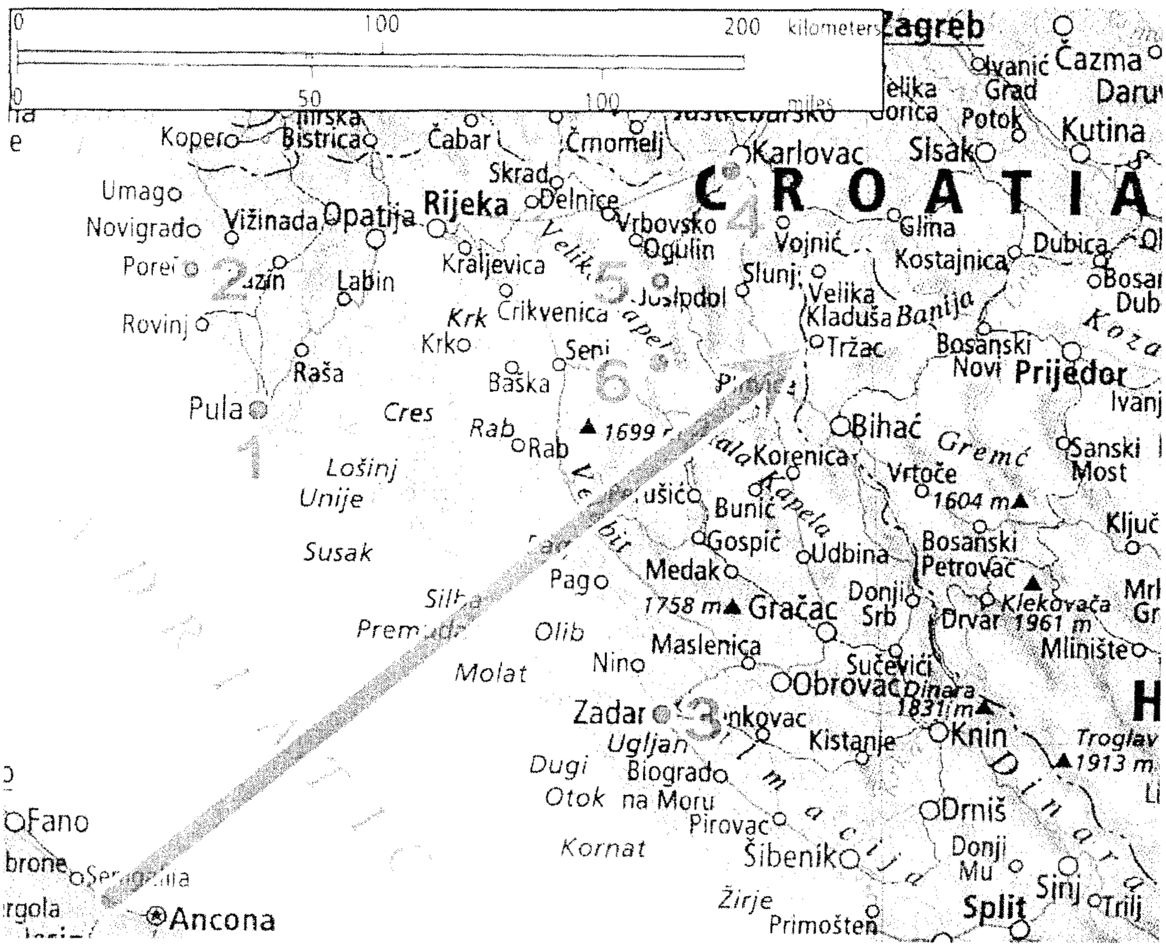

Figure 3 – Electrophonic fireball over Croatia on 1997 November 3. The electrophonic sound events are marked by points and numbers. Their locations are: (1) Pula (13°51′ E, 44°52′ N), (2) Poreč (13°36′ E, 45°13′ N), (3) Zadar (15°15′ E, 44°07′ N), (4) Duga Resa (15°30′ E, 45°27′ N), (5) Josipdol (15°17′ E, 45°12′ N), (6) Dabar (15°19′ E, 44°57′ N). See text for more details about the fireball. Courtesy of Korado Korlević.

The fireball occurred on 1997 November 3 over the Adriatic Sea and Croatia at 16:08:20 UT. The estimated visible trajectory starts over the Italian Adriatic coast (13°13′ E, 43°43′ N), close to Ancona, and ends over the border between Croatia (CRO) and Bosnia and Herzegovina (BH) (15°45′ E, 44°59′ N) at an altitude of 30–40 km. The angle between the trajectory and horizontal is $\sim$ 15° with $\sim$ 250 km of ground track. The meteor displayed multiple fragmentation over Velebit mountain. Fragments burned out quickly except for one of them which continued the flight parallel to the main body. The final fragmentation happened between Drežnik Grad (CRO) and Tržica (BH) with rapid deceleration (duration of the final flight was 3–4 seconds). The mean atmospheric velocity, excluding the final deceleration, was 20–25 km/s. Witnesses described the meteor as brighter than a full Moon.

The electrophonic sounds were reported from six different locations. The sounds are described as rustling or "like a rocket", but there are no details about particular events. The meteor ground path and locations of electrophonic events are shown in Figure 3. The magnetic field components at 14° E, 44° N and 50 km altitudes are Z = 39 522 nT (vertical, direction down) and H = 22 618 nT (horizontal), with magnetic declination of 1°18'E (model IGRF95).

4. Conclusion

The analysis described in this study revealed two important facts: i) electrophonic sounds can appear even for meteors of a visual magnitude lower than previously thought, and ii) the estimated heights at which electrophonic meteors enter the atmosphere can reach high values (even 100 km) which has implications on the theories of meteor ELF/VLF generation. From the theoretical standpoint, these new facts demonstrate that very little has changed since the early work in this field in the 1960's (Bronshten 1991).

Moreover, it has become widely accepted that the electrophonic sounds are created exclusively by vibration of ordinary objects exposed to the ELF/VLF electric fields, even though there are experiments which show corona discharge with the same value of electric fields. Thus, the catalogs like GEFS are still very useful and can be used for testing the existing theories.

The most important result, coming from the GEFS witness reports, is the lower limit on the magnitude of electrophonic meteors. The catalogues of electrophonic sounds studied so far have been observationally biased toward very bright fireballs, since such meteors are often individually studied and attract a lot of attention. The brightness limit often cited in the literature is about -10 for sustained sounds and about -7 for more transient sounds (Keay 1992, Beech & Foschini 1999). However, Kaznev's analysis of electrophonic meteors already pointed toward the existence of sounds from meteors of magnitude as low as -2. The GEFS reports show that such low brightness electrophonic meteors (dimmer than -7) really exist and represent a large fraction of the electrophonic sound events; moreover, they can produce sustained sounds instead of only transient sounds.

It is also important to notice that there are Leonids among these low brightness meteors. They ablate at very high altitudes, and sustained sounds from them indicate that the electrophonic effects may already start to appear at altitudes of about 100 km. These are also altitudes of the beginning of night-time ionosphere. This is consistent with the instrumental recording of the electrophonic sounds from the 1998 Leonids (Zgrablic at al 2002). An increase of height above the horizon of meteors in the GEFS reports, compared to Kaznev's results, could indicate that the EM effects from low brightness meteors are not as strong as from very bright fireballs. Presented examples of bright fireballs with the known trajectory show that the electrophonic sounds can be induced even at distances over 100km from the fireball's ground track.

The results presented here are a big challenge for the theory. Any future work will require more experimental/observational results and multidisciplinary research.

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References

Aubrecht L., Stanek Z., Koller J., 2001, "Corona discharge on coniferous trees—spruce and pine", Europhys. Lett. 53, pp. 304–309.

Beech M., Foschini L., 1999, "A space charge model for electrophonic bursters", Astron. Astrophys. 345, pp. L27–L31.

Bronshten V.A., 1991, "Electrical and electromagnetic phenomena associated with the meteor flight", Sol. Syst. Res. 25, pp. 93–104.

Brown P., ReVelle D.O., Hildebrand A.R., 2001, "The Tagish Lake Meteorite Fall : Interpretation of Fireball Physical Characteristics", ESA SP-495, Proceedings of the Meteoroids 2001 conference, Ed. B. Warmbein, pp. 497–507.

Buskirk R.E., Frohlich C., Latham G.V., 1981, "Unusual animal behavior before earthquakes: a review of possible sensory mechanisms", Rev. Geophy. Space Phy. 19, pp. 247–270.

Carstensen E.L., 1986, "Biological effects of transmission line fields", Proceedings of a Special Symposium on Critical Emerging Issues in Biomedical Engineering, IEEE, Ed. C. J. Robinson and G. V. Kondraske, New York.

Dravert P.L., 1940, "Electrophonic bolides of Western Siberia", Byull. Tsentr. Komis. po Meteoram, Kometam i Asteroidam Astrosoveta, Akad. Nauk SSSR, 18, pp. 1–2.

Drummond J.D., Gardner C.S., Kelley M.C., 2000, "Catching a falling star", Sky&Telescope 99, June 2000, pp. 46–49.

Garaj S. et al., 1999, "Observational detection of meteor-produced VLF electromagnetic radiation", FIZIKA 8, pp. 91–98.

Halley E., 1719, "An account of the extraordinary meteor seen all over England, on the 19th of march 1718/9. With a demonstration of the uncommon height thereof", Phil. Trans. Roy. Soc. London 30, pp. 978–990.

Kaznev V.Yu., 1994, "Observational characteristics of electrophonic bolides: statistical analysis", Sol. Syst. Res. 28, pp. 49–60.

Keay C.S.L., 1980, "Anomalous sounds from the entry of meteor fireballs", Science 210, pp. 11–15.

Keay C.S.L., 1992, "Electrophonic sounds from large meteor fireballs", Meteoritics 27, pp. 144–148.

Keay C.S.L., 1993a, "Electrophonic Sounds Catalog", WGN Observational Report Series 6, pp. 151–172.

Keay C.S.L., 1993b, "Electrophonic Meteor Fireballs Require Further Study", Meteoroids and their parent bodies, Astronomical Inst., Slovak Acad. Sci., Bratislava, Ed. J. Stohl and I.P. Williams, pp. 315–318.

Keay C.S.L., 1994, "Audible fireballs and geophysical electrophonics", Proc. Astro. Soc. Australia 11, pp. 12–15.

Keay C.S.L., Ostwald P.M., 1991, "A laboratory test of the production of electrophonic sounds", J. Acoust. Soc. Am. 89, pp. 1823–1824.

McBeath A., 2000, "SPA meteor section results: January-February 2000", WGN, Journal of the International Meteor Organization 28, pp. 232–236.

Olmsted D., 1991, "Observations on the meteors of Nov. 13th 1833", The Acoust. Soc. Am. 89, pp. 1823–1824.

Romig M.F., Lamar D.L., 1963, "Anomalous sounds and electromagnetic effects associated with fireball entry", RAND Memo., RM-3724-ARPA.

Stevens S.S., 1937, "On hearing by electrical stimulation", J. Acoust. Soc. Am. 8, pp. 191–195.

Trautner R. et al., 2002, "ULF-VLF Electric field measurements during the 2001 Leonid storm", Proc. ACM Berlin, 29 Jul–02 Aug 2002, ESA-SP-500, submitted.

Verveer A., Bland P.A., Bevan A.W.R., 2000, "Electrophonic Sounds from the Reentry of the Molniya 1-67 Satellite over Australia: Confirmation of the Electromagnetic Link", Meteorit. Planet. Sci. 35 Suppl., pp. A163..

Vinković D. et al., 2000, "Global Electrophonic Fireball Survey", WGN, Journal of the International Meteor Organization 28, pp. 48–53.

Wang D.Y., Tuan T.F., Silverman S.M., 1984, "A note on anomalous sounds from meteor fireballs and aurorae", J. Roy. Astron. Soc. Can. 78, pp. 145–150.

Zgrablić G., et al., 2002, "Instrumental recording of electrophonic sounds from Leonid fireballs", J. Geophys. Res.—Space Phys. 107(A7), 10.1029/2001JA000310.

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SPA Meteor Section Results: November–December 2001

Alastair McBeath

Abstract: Information presented to the *SPA Meteor Section* from November and December, 2001 is given, except that from near the Leonid peaks already discussed in (McBeath 2002a & b). A surprisingly strong radio peak was found on November 14-15 ($\lambda_\odot \sim 233°$), well in advance of the Leonid maxima, and chiefly in the European and North American data. Japanese results in (Ogawa 2002b) indicated this probably originated in enhanced bright Leonid rates. December 1-2 brought another spectacular, widely-seen, fireball for UK, northern France and Low Country observers around $22^h40^m \pm 5$ m UT, when part of a Russian Proton rocket booster returned to Earth. The Geminid maximum was well-seen visually and by radio. Visual observers enjoyed ZHRs of 90+ all night on December 13-14 (from at least 23^h–11^h UT in these results), with many radio observers concurring on their highest echo counts found sometime between about 20^h–9^h UT then. The peak was not sharply-defined using either technique however, although visual rates were registered as marginally highest on December 14 at $6^h \pm 1$ h UT ($\lambda_\odot = 262.^\circ 29 \pm 0.^\circ 04$; ZHR $= 108 \pm 9$), while the radio analysis yielded a mean peak time of $6^h36^m \pm 1$ h UT on the same date ($\lambda_\odot = 262.^\circ 31 \pm 0.^\circ 04$). The Ursids were barely discernible either to our visual or radio reporters. On December 21 and 22, ZHRs were no better than 5 ± 3 over Europe or North America, and several experienced watchers returned zero counts on both dates. Notes concerning a supposed meteorite fall in Snowdonia, North Wales at some point between October 21 and December 10, 2001 are also given.

1. Introduction

Moonlight conditions favoured both major showers during November and December, 2001, as well as the Ursids in December, though most of the protracted Taurid maximum was lost to the Moon. Even the weather was cooperative for once, helping boost the visual tallies in Table 1. Most of the Leonid activity recorded by Section observers between November 16-17 and 18-19 has already been reported (McBeath 2002a & b) and is not repeated here, though Table 1's totals do include all the data supplied. The observers' lists below cover only those people reporting outside this interval, or those whose Leonid results arrived too late for inclusion in the earlier article.

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

Month	Visual	STA	NTA	LEO	Meteors	Radio	Video	Trails
November	$487.^h4$	159	321	67251	70982	$6631.^h7$	$421.^h5$	6640
December	$196.^h4$	5441	63	44	6758	6121^h	$382.^h3$	2735

Excepting those from Dirk Artoos and the Belarus observers (these latter forwarded by Rainer Arlt), the radio results came via Chris Steyaert as *Radio Meteor Observation Bulletins* 100–102, November, 2001 to January, 2002 inclusive. The observers included:

Enric Fraile Algeciras (Spain), Dirk Artoos (Belgium), the Belarus observers (Ivan Bryukhanov, Aleksei Gain, Roman Grabovski, Aleksei Kosinski, Sachar Lapizki, Timur Radyuk, Stanislav Schikun, Vladislav Syrtsev, Valentina Tamello), Mike Boschat (Canada), Maurice de Meyere (Belgium), Didier Favre (France), Ghent University (Belgium), Patrice Guerin (France), Rafael Haag (Brazil), Stan Nelson (New Mexico, USA), Hiroshi Ogawa (Japan), Jean Richard (France), Ton Schoenmaker (Netherlands), Dave Swan (England), Istvan Tepliczky (Hungary), Pierre Terrier (France), Ouyang TianJing (China), Garfield Tsao (Taiwan), Bruce Young (Australia), Ilkka Yrjölä (Finland).

The raw radio data were examined as normal in these reports (McBeath 2001). Figures 1 and 2 give graphs illustrative of these analyses.

Aside from Steve Evans' video data, kindly forwarded directly, all the remaining video results came from *Arbeitskreis Meteore* (*AKM*) observers. These video and the *AKM* visual observations used here were taken from their journal *Meteoros* 4 : 12 (2001) and 5 : 1 to 5 : 3 (2002) inclusive, sent in by Ina Rendtel. Steve Evans' data is also summarized in the *AKM* journals. The video operators' list follows. It includes all the *AKM* observers (in Germany only where not noted), as these data arrived only after (McBeath 2002a) had been published for the Leonid maxima. Two teams of German *AKM* observers had travelled to China and New Mexico, USA for the Leonids too:

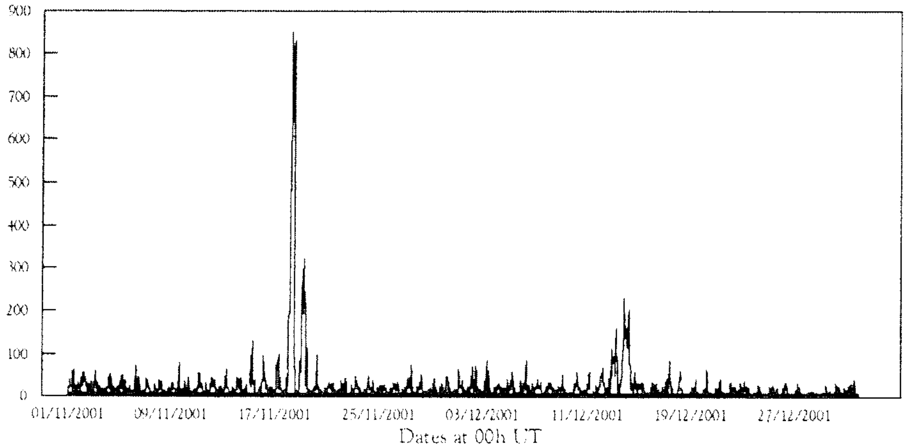

Figure 1 – Raw hourly radio meteor percentage reflection time echo counts (×10) from November and December, 2001 in data collected by Ghent University. The Ghent system was in continuous operation throughout this time, the few short breaks generally being due to interference. This graph shows the overwhelming dominance of the Leonid storm on November 18 compared to all other meteor activities. The Geminid rates show up clearly too in December, but even at their best, they were still significantly below even the post-maximum November 19 Leonid enhancement!

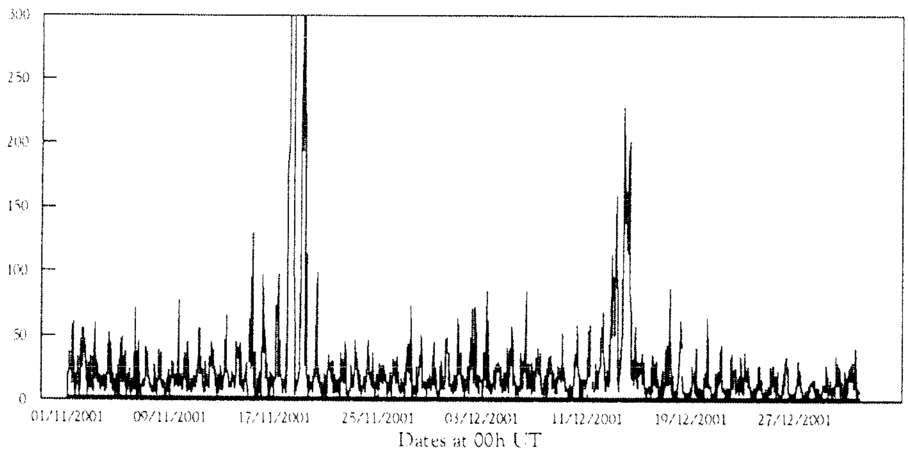

Figure 2 – The same graph as Figure 1, but re-scaled in its y-axis to show the lesser diurnal and minor shower activities outside the Leonid storm epoch.

Orlando Benitez-Sanchez (Canary Isles), China team (from Aachen: Georg Görgen & Jan Hattenbach), Steve Evans (England), André Knöfel, Detlef Koschny (Netherlands), Sirko Molau (Germany and South Korea), New Mexico, USA team (from Hannover: Thomas Kurtz, Michael Theusner, Gerd Weidemann), Mirko Nitschke (Germany and South Korea), Steve Quirk (Australia), Jürgen Rendtel, Ulrich Sperberg, Rosta Stork (Czech Republic), Jörg Strunk (Germany and South Korea).

The visual watchers (excluding those whose Leonid results have already been discussed) included:

> *American Meteor Society* (*AMS*) members, in the mainland USA if not noted (from summaries in the *AMS* journal *Meteor Trails* 14 (March, 2002), provided by Bob Lunsford): James Bedient, Chester Czescik, James Fox, Thomas Giguere (Hawaii), Vincent Giovannone, Keith Gleason, Bill Goodart, Robin Gray, Robert Hays, Edwin Jones, Dhanajay Joshi (India), Gene Kispert, Jer-Nan Lou (Taiwan), Pierre Martin (Ontario, Canada & USA), Paul Martsching, Jim McGraw, Michael Morrow, William Sager, Krisztian Sarneczky (Hungary), Richard Schmude, Chris Stephan, David Swann, Istvan Tepliczky (Hungary), Robert Togni, Neil Tryhus, William Watson; *AKM* members (in Germany only if not stated): Rainer Arlt, Pierre Bader, Lukas Bolz (Germany & South Korea), Frank Enzlein (Germany & Mongolia), Christoph Gerber (Germany & Turkey), Bernd Heinrich (South Korea), Wolfgang Hinz (Mongolia), Martin Hörenz (Mongolia), André Knöfel (Australia), Hartwig Lüthen (Germany & South Korea), Sirko Molau, Sven Näther, Jürgen Rendtel (Germany & Mongolia), Manuela Rendtel (Mongolia), Mario Scheel, Ulrich Sperberg, Heinrich Wiechell (Germany & South Korea), Roland Winkler, Nikolai Wünsche, Oliver Wusk and Florian Zschage (China); John Bonsor (Scotland), Jay Brausch (North Dakota, USA), Michael Brooke (England), Chris Chambers (Wales), Steve Evans (England), Mike Feist (England), Shelagh Godwin (England), Philip Heppenstall (England), Marco Langbroek (Netherlands), Bob Lunsford (California, USA), Tony Markham (England), Alastair McBeath (England), Simon McBeath (England), Ann McCracken (England), Dave McCracken (England), Tom McEwan (Scotland), Neil Mortimer (England), Richard Pearce (Scotland), Robin Scagell (England), Jonathan Shanklin (England), George Spalding (England), Rich Taibi (Maryland, USA), Matthew Waldie (England).

2. November

Little visual work was carried out in the first half of November, when the full and waning Moon was at its worst, and the Taurid maxima passed unrecorded, except by radio, as a result. The minor radio peak at $\lambda_\odot = 219°$ was found in 55% of the datasets during its extended spell ($\lambda_\odot = 218°$–$220°$; October 31–November 2), but that at $\lambda_\odot = 224°$ saw little consensus regarding a distinct maximum. Something was noted at some stage during this peak's $\lambda_\odot = 222°$–$227°$ extension (November 4–9) by most observers, however. The $\lambda_\odot = 227°$ maximum was picked up in 50% of the results, some showing a continuation into the following day. The majority of reporters picked up the $\lambda_\odot = 230°$–$231°$ (November 12–13) peak too. Overall, these radio data suggest a weak to normal Taurid maximum occurred in the first two weeks of the month, as the activity patterns detected were not beyond the bounds of what has been found at this time previously, but they were not among the better early November ones either.

As has become common in recent years, the majority of the visual results concentrated on the period nearest the predicted Leonid maxima. These have been tackled in (McBeath 2002a & b), and although some observations arrived only after this examination was completed, all the most detailed reports (including the short-interval meteor count breakdowns and magnitude distributions) were featured earlier, so this later data does not significantly alter those initial findings. One correction is needed. Ton Schoenmaker helpfully wrote to amend a mistake in his radio graph (in Figure 6 of (McBeath 2002a); Figure 1 in (McBeath 2002b)), where I had accidentally applied the correction for dead time to his results twice, so the Leonid peak was made to seem abnormally spiky in his data. This is corrected in Figure 3 here, with my apologies to Ton, and thanks for his understanding and forbearance.

Some further comments around the Leonids are in order, as a surprisingly strong radio peak was found in 55% of the results from November 14-15 ($\lambda_\odot \sim 233°$), well before the first Leonid maximum on November 18. This occurred primarily in the European and North American data. There are too few visual results available in our files from then to be conclusive as to a potential source, but the higher radio counts occurred during the Leonid radiant's normal diurnal visibility. In this regard, it is interesting that (Ogawa et al. 2002b) reported enhanced numbers of longer-duration echoes over Japan on the UT evenings of November 15 and 17, noting that Japanese visual observers also detected increased numbers of bright to fireball class Leonids at the same time, with a distinctly reduced quantity of such meteors on November 16. Our results here do not confirm a repeat event on November 17, but it seems probable an increased Leonid bright meteor flux on November 15 was the main cause for the spike in radio rates our observers found. Unfortunately, we are lacking visual or radio reports to confirm or comment further on the possible $\sim 21^{\mathrm{h}}$ UT sub-peak after the second Leonid storm maximum on November 18, also reported by (Ogawa et al. 2002a & b).

After the Leonids, few visual observers remained active, but enough to spot some low α-Monocerotid rates near their expected November 21 maximum (ZHRs ~ 5 at best), when 69% of our radio operators also detected the normal minor $\lambda_\odot = 238°$–$239°$ (November 20–21) peak. The final weak radio maxima within the $\lambda_\odot = 240°$–$248°$ spell were recovered too, with an unusual degree of consistency favouring $\lambda_\odot = 248°$ (November 29-30; 92% of datasets) for once. A slightly less-well confirmed minor enhancement was noted at $\lambda_\odot = 245°$ (November 26-27) in 67% of the results, in addition.

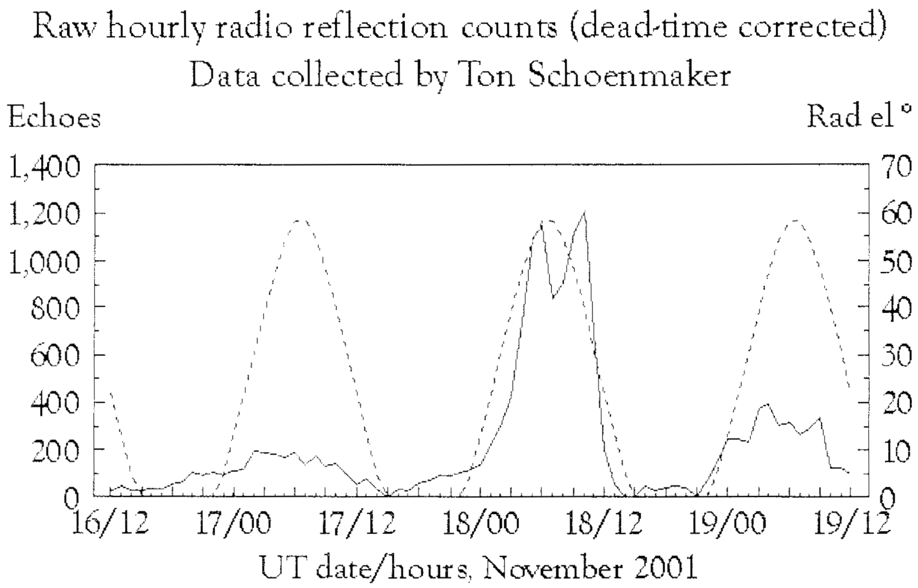

Figure 3 – Raw radio meteor echo counts collected by Ton Schoenmaker, corrected for system-saturation dead time, between midday on November 16 to midday on November 19, 2001. The thick, irregular line, keyed to the left-hand y-axis, shows the total echo counts per hour. The finer, symmetrical line, keyed to the right-hand y-axis gives the Leonid radiant's elevation in degrees for Ton's site in the Netherlands. This replaces the incorrect graphs in Figure 6 and Figure 1 of (McBeath 2002a & b) respectively. (Note too that the original captions in both references should have mentioned Ton's data as being corrected for dead time where more than 10% per hour was lost to system-saturation. This no longer applies to the graph here, where all hours with dead time have been corrected.)

3. December

A bright, fragmenting, fireball around $22^{\mathrm{h}}40^{\mathrm{m}} \pm 5$ m UT on December 1-2 began the month spectacularly. Twenty-nine reports were received by the SPA from places across southern England and northern France (further sightings were made elsewhere, particularly in Belgium and the Netherlands according to other correspondence). More correctly, most observers recorded seeing what seemed like a procession of between three to five, white, yellow or orange fireballs following one another closely along the same track in the sky, shedding fainter red-orange sparks or a sparkling trail, which passed on a roughly (west-south-?)west to (east-north-?)east track. Even the early descriptions sounded more like a man-made object re-entering the Earth's atmosphere than a naturally-occurring meteor, as the event had a very long apparent trail across the sky (some people suggested it had crossed from horizon to horizon, though these instances seem to have referred to the local, not the true, horizon) and was moving extremely slowly. Best-estimates for its visible flight suggested times of around 30 s to 40 s. Later investigations showed it had been due to the atmospheric re-entry of a metal casing from the fourth stage of a Russian Proton rocket, launched from the Baikonur Cosmodrome in Kazakstan about 4.5 h earlier. Unfortunately, the full Moon was in the sky at the time too, so consequently few of the observers were able to provide accurate details of the object's apparent flight path through the stars. This is also a problem that has been apparent during similar man-made fireballs before, even without the Moon, where the long, very slow, trajectory alone can be most confusing. Several people commented on losing track of where the flight had begun for example, and extra confusion was caused by the multiple nature of the event. Brightness estimates indicated individual fireballs within the procession were at least magnitude -3 to -6, but again, the moonlit, multiple nature of the event made such estimates even more difficult than normal, and it is likely one or more was significantly brighter than this, in the magnitude range ~ -7 to -10, as some reports noted clear moving shadows being cast, despite the Moon! A further, almost identical, re-entry fireball "cluster" was seen from sites across the midwestern USA at $4^{h}18^{m}$ UT on December 1-2, due to another part of the same rocket launch (the third stage), according to reports published among the Cambridge Conference Network e-notices for 2001 December 4 (CCNet 129/2001).

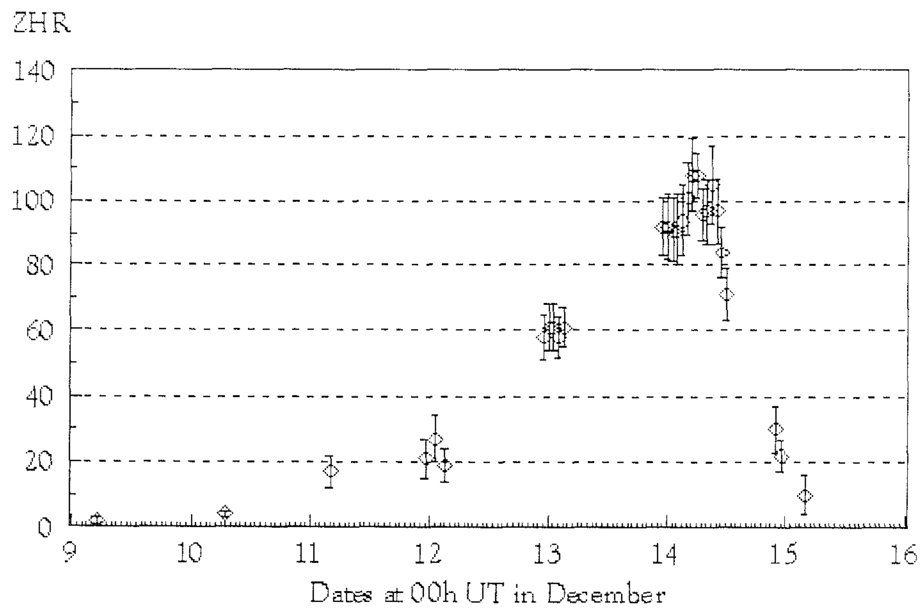

Figure 4 – Mean Geminid ZHRs for December, 2001, calculated using $r = 2.6$, for observations made where lm = +5.5 or better, cloud cover less than 20%, and the radiant elevation was at least 25°, with standard error bars appended.

Visually, the first week of December was lost to full Moon other than this, but some early Geminids were apparent as soon as the Moon had waned to last quarter by December 7. Little was seen of the minor showers peaking during the first half of December by this method, although the normal pre-Geminid lesser radio maxima were all recovered. Observer activity picked up as anticipated towards the expected Geminid peak, and some excellent coverage right through the shower was possible this year between December 9 to 15, as Figure 4 demonstrates. Figure 5 shows more detail from the time nearest the shower's expected maximum, 4^{h} UT on December 14 (McBeath & Arlt 2000). The highest visual rates were indeed on December 14 in these results, but slightly later than expected at $6^{\mathrm{h}} \pm 1$ h UT ($\lambda_{\odot} = 262.^{\circ}29 \pm 0.^{\circ}04$), with a ZHR of 108 ± 9. It is unclear how significant the dip in rates at $8^{\mathrm{h}} \pm 1$ h UT and the subsequent secondary peak at $9^{\mathrm{h}}30^{\mathrm{m}} \pm 30$ m UT may be, as the dip began during the handover between European and North American watchers, when relatively few people were active. The preliminary IMO data (Rendtel 2001) showed ZHRs holding fairly steady between $\sim 23^{\mathrm{h}}$–4^{h} UT on December 13-14, at 115–120. Rates then fell slightly to 108 ± 3 at the $4^{\mathrm{h}}25^{\mathrm{m}}$ and $5^{\mathrm{h}}05^{\mathrm{m}}$ UT datapoints, before recovering marginally to 112 ± 5 by $6^{\mathrm{h}}10^{\mathrm{m}}$ UT, peaking once more by the $8^{\mathrm{h}}05^{\mathrm{m}}$ UT point with a ZHR of 117 ± 6. Most radio observers concurred on finding their highest echo counts at some point between $\sim 20^{\mathrm{h}}$–9^{h} UT on December 13-14, allowing for radiant visibilities at the various sites, but there is no convincing evidence for any sub-peaks between datasets, and there is considerable scatter in individual results about the mean peak time, suggested by closer analysis as at $6^{\mathrm{h}}36^{\mathrm{m}} \pm 1$ h UT on December 14 ($\lambda_{\odot} = 262.^{\circ}31 \pm 0.^{\circ}04$). Overall, the differences in visual rates are small enough that a generally uniform rates plateau overnight on December 13-14 seems the most plausible explanation, without a sharply-delineated maximum, which the radio results would tally with equally.

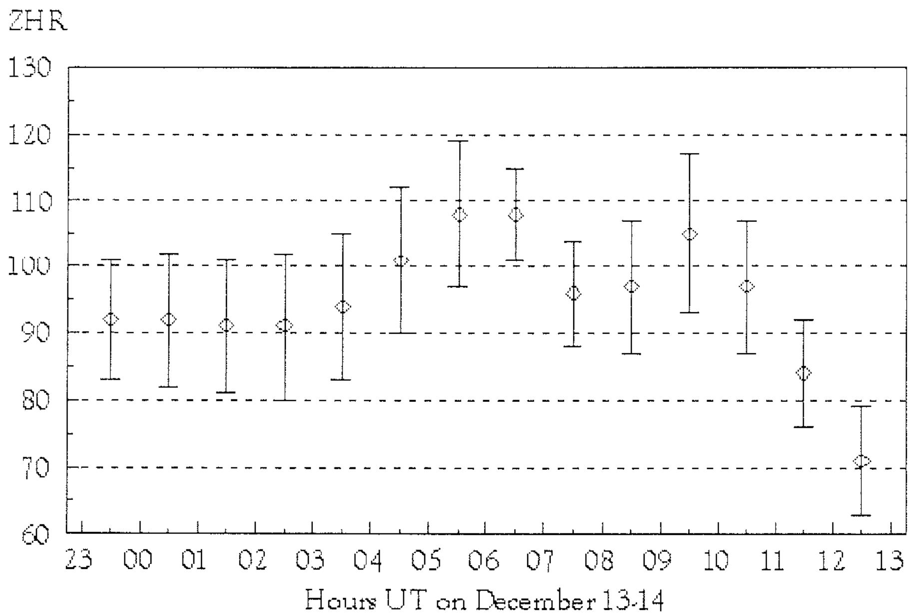

Figure 5 – A close-up of the Geminid ZHRs from Figure 4 closest to the shower's maximum.

Tables 2 and 3 provide details on the global Geminid and December sporadic magnitude and train distributions respectively. The Geminids were pleasingly bright as seen by most observers, but without producing many fireballs, as has been found several times in recent years. No Geminids brighter than magnitude −5 were reported to us during complete observations, and only a couple of magnitude −6 events were spotted by casual observers.

Table 2 – Global magnitude distributions for the 2001 Geminids and December sporadics seen in good sky conditions (cloud cover < 20%, $LM = +5.5$ or better), including mean LM and corrected mean magnitudes.

Shower	-3^-	-2	-1	0	$+1$	$+2$	$+3$	$+4$	$+5^+$	Tot	LM	$\overline{m}_{6.5}$
GEM	11	26.5	36	76.5	159	228.5	304	206	87	1134.5	+5.89	+2.96
SPO	2	5	3	6	28	59	96	70	48	317	+5.92	+3.54

Table 3 – Global train percentages and mean durations in seconds per magnitude class for the Geminids and December sporadics. Train details were available for 1016.5 Geminids and 273 sporadics from the magnitude distributions.

Magnitude	-3^-	-2	-1	0	$+1$	$+2$	$+3^+$	Tot	%
GEM train %	50	28	29	17	4	1.5	0	40	3.9
GEM train duration (s)	1.1	1.0	0.5	0.6	0.5	1.0	-	-	-
SPO train %	0	40	33	0	16	6	13	23	8.4
SPO train duration (s)	-	2	0.5	-	0.9	0.8	0.5	-	-

Despite this relative paucity of brighter fireballs, the observers were generally happy with what they saw. In the UK, December 13-14 favoured sites in south-east England especially with clearer skies, the clearance moving slowly westwards and slightly north as the night progressed, too slowly for some unfortunately, while north of East Anglia endured chiefly cloudy skies. These more northerly locations had enjoyed a better night on December 12-13 however, which was some compensation, especially as watchers further south had overcast skies that night. The observers' notes below are all from December 13-14.

Steve Evans in East Anglia ran his video camera for six hours after skies cleared during the late evening, to become completely clear by midnight, and he carried out some casual visual observing while checking the camera was running smoothly. He saw rates of about one Geminid a minute, including one of the magnitude -6 fireballs, at 3^h15^m UT, although typically it was without the camera field!

Further west in Oxfordshire, George Spalding found skies only cleared completely at about 1^h20^m UT, but it was clear and cool after that, with temperatures dipping to freezing after the clouds departed. Geminid rates were good, and watching was possible until shortly before dawn twilight grew too strong, though George felt activity was not perhaps quite so high as in 1996 (which was one of the very best Geminid returns seen from the UK in recent times).

West again, and further north, in Staffordshire, Tony Markham discovered the clouds persisted until at least 3^h UT, but had melted away when he next checked at 5^h30^m UT. This left time for a few variable star observations from his home, but too little time to get to his preferred meteor watching site, away from the houses and streetlights, before the sky was too bright. Despite that, he still picked up a couple of casual Geminids with little effort.

East of the UK, Marco Langbroek in the Netherlands already had clear, cold skies as darkness fell, the skies which would later help our southern UK observers so well. Marco was able to observe for a couple of hours over midnight UT, having to be up for work early next day. He enjoyed the excellent rates he saw, all the better for getting them from close to home for once, under an unusually transparent sky with a LM of +6.4, exceptionally impressive for that site, as he commented.

In the USA, two of our longer-standing observers there, Jay Brausch and Bob Lunsford enjoyed surprisingly similar conditions to one another for their watching—cool, icy weather, with some thin cirrus clouds at times—despite being in very different parts of the country, northern midwest and extreme southwest respectively, roughly 2000 km apart. Both also had to observe complete with colds, along with quite a proportion of our other watchers. Both spotted around 260 to 275 meteors in four hours as well, with LMs of +6.1 to +6.4 for the most part.

The post-Geminid minor radio peaks were noted much as expected, although there was little trace of any Ursid signature close to the predicted maximum on December 22, at 12^h UT (McBeath & Arlt 2000). This problem was repeated in the visual observations, where ZHRs were just 5 ± 3 for our European and North American watchers overnight on December 21 and 22. Several experienced observers recorded zero counts then too, despite clear skies. The preliminary Japanese Ursid data (Ogawa 2001) suggested ZHRs of 15 ± 6 were seen from $\sim 11^h$–13^h UT on December 22, perhaps with a tail persisting to $\sim 15^h$ UT (ZHRs $= 12 \pm 5$). Looking closely at the radio data, there is some slight support for a very weak maximum detected between $\sim 11^h$–13^h UT on December 22, albeit this remained unconvincing, and was not found in many datasets. A curious Ursid epoch this year certainly.

One last odd item concerned a supposedly substantial meteorite fall in Snowdonia, North Wales at some undefined date between October 21 and December 10, 2001. This featured in the local press there only on January 24, 2002 ("Western Mail" for that date), and described a roughly rectangular, water-filled trench of unspecified depth, some 10 m–20 m long, and about 1 m wide, which had apparently suddenly appeared on an open hillside. A rock outcrop near one end was claimed as showing signs of having been forcibly struck by some object, while the other end was in a boggy area immediately adjacent to a mysteriously undisturbed post-and-wire fence-line, ~ 1.2 m tall.

It was also claimed that rocks had been flung up to 100 m away from the trench, although there was no photographic evidence produced to support this, and no attempt to identify the nature or location of these rocks appeared to have been made. Unfortunately, the site is in the Snowdonia National Park, an area popular with walkers, runners and mountain bikers, and is regularly overflown by military aircraft as well, so a terrestrial explanation seemed more likely from the outset. A lightning strike was also suggested as an alternative possibility.

Atrocious winter weather prevented a hoped-for visit by investigators from the UK Spaceguard Centre and Liverpool John Moores University during January and February, 2002, and whether any investigation was ever carried out remains unknown, as nothing more has been forthcoming since. No bright fireball observations have been associated with this event either, nor were any nearby sonic booms reported during the October-December interval, that might have resulted from a bright fireball hidden by clouds.

Acknowledgments

Many thanks as always are sent to all our contributors for making this report possible. I would also like to thank especially Mike Feist of the Foredown Tower Astronomy Group, and John Lambert, for their considerable assistance in rounding-up many of the December 1-2 fireball reports.

References

McBeath A., "The Forward Scatter Meteor Year: 2001 Update", *WGN 29:3 (2001)*, pp. 85–92.

McBeath A., "SPA Meteor Section Results: 2001 Leonids", *WGN 30:3 (2002a)*, pp. 59–70.

McBeath A., "Erratum on SPA Meteor Section Results: 2001 Leonids", *WGN 30:4 (2002b)*, p. 110.

McBeath A., Arlt R., "2001 Meteor Shower Calendar", IMO, 2000.

Ogawa H., "The Visual Observational Result of Ursids 2001 in Japan (Nippon Meteor Society)", IMO-News e-mailing list, 26 December 2001.

Ogawa H., Toyomasu S., Ohnishi K., Maegawa K., "The Leonid 2001 Project by Radio Meteor Observations All Over the World", *WGN 30:4 (2002a)*, pp. 105–110.

Ogawa H., Toyomasu S., Ohnishi K., Maegawa K., Amikura S., Asahina T., Miyao K., "The 2001 Leonids by the Radio Meteor Observing Network in Japan", *WGN 30:4 (2002b)*, pp. 120–126.

Rendtel J., "IMO Shower Circular: Geminids 2001", IMO-News e-mailing list, 28 December 2001.

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