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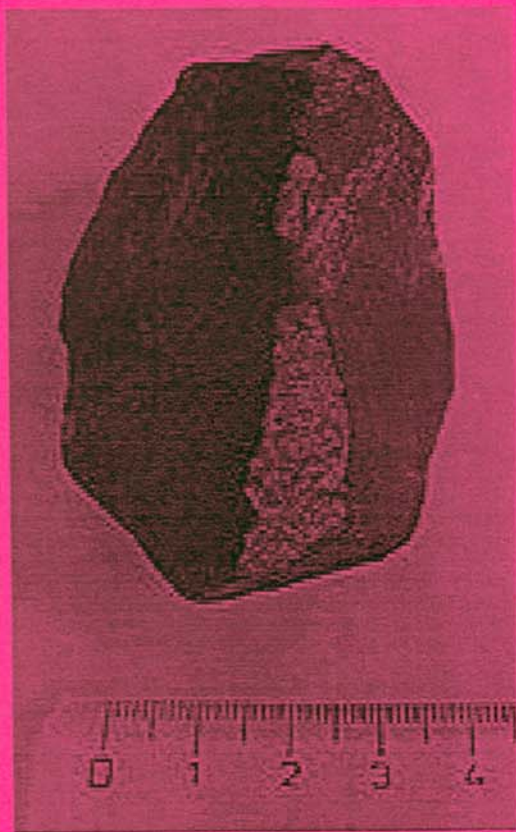

On Saturday, May 6, 2000 at $11^h51^m25^s$ UT, an extremely bright fireball over southern Poland and north-eastern Moravia dropped this 214 g meteorite at the small Silesian village of Moravka. The photographs of the meteorite were taken by Tomas Havlik. The photographs have been taken from the Czech electronic astronomical magazine *Instant Astronomical News* 247, May 9, 2000 (`http://www.ian.cz/detart.asp?id=123`), and were kindly communicated to us by Dr. Pavel Spurný. More details about the fireball and a very similar event on Wednesday, May 10, 2000, can be found in a letter by Dr. Spurný in this issue.

In case of non-delivery, return postage guaranteed. Please return to:
v.u.: Marc Gyssens, Heerbaan 74, B-2530 Boechout, Belgium

WGN, Vol. 28, No. 2/3, April-June 2000, pp. 43–90

Contents

Useful Information

The August issue *(WGN 28:4)*

The *August issue* will be mailed in the first half of August. Contributions are due on *July 21* at the latest. They should be sent to *Marc Gyssens*.

Subscriptions and ordering of publications

Volume 28 (2000) of *WGN* will contain at least 240 pages and costs 35 DEM or 17.90 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription/membership fees. 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.

From the Editor-in-Chief

Marc Gyssens

I have to apologize to our readers that, again, I had to resort to a double issue, personal reasons and the pressure of professional commitments being the cause of this. In this way, however, we can also work away the delay that originated at the end of last year in our efforts to present the readers some definitive results on the 1998 Leonids and first results on the 1999 Leonids.

With the (northern-hemisphere) summer coming up, there is the prospect of lots of observing opportunities (do not forget the Perseids in all the excitement over the Leonids!), and, of course, the IMC in Romania, on which we provide some more information in this issue and repeat the registration form for your convenience. Meanwhile, enjoy this issue!

Letters to WGN

compiled by Marc Gyssens

Meteors, comets, and millennialism

Following on from my article "Meteors, Comets, and Millennialism" in *WGN* 27:6, pp. 318–326, I spotted a piece about the Leonids in the London *Times* for November 16, 1999, which may be of interest in showing how such beliefs persist modernly. Most of the item discusses the NASA project to make airborne observations of the Leonids, and the potential risk of satellite damage a meteor storm might cause, but the final section runs thus:

> *"Such scientific matters are of little interest to the increasing numbers of apocalyptic Christian groups gathered in Israel and the United States. They have been moved to paroxysms of excitement by recent earthquakes in Turkey and Greece, which they believe are portents of a coming Armageddon.*
>
> *Their doomsday predictions, which involve mass destruction and the 'rapture,' when believers ascend to heaven, will be further encouraged by the meteor storm, which, like the star that led the Three Wise Men to the birthplace of Christ, will rise in the east over Jerusalem.*
>
> *Ed Daniels, 54, a former surveyor from Denver, Colorado, who emigrated to Israel two months ago, said that he had seen signs of the 'end time' so frequently during the past year that he was convinced that Armageddon was fast approaching.*
>
> *'I don't think it, I know it,' he said. 'The end time is approaching, and we are expecting the rapture.'"*

I must also comment that, in the UK, the BBC chose November 16 to begin re-broadcasting some old episodes of the science-fiction TV serial "Doctor Who," beginning with the inaugural two episodes of the story "Spearhead from Space," featuring the landing on Earth (in southern England, naturally!) of fragments of an alien intelligence carried inside swarms of artificial meteorites. I suspect this was not entirely by chance. If only real meteorites were so carefully targeted...

Alastair McBeath, March 4, 2000

Some thoughts on the ξ-Bootids

The article on the supposed ξ-Bootids shower by Jürgen Rendtel and George Gliba [1] was most interesting. Little work has been done on February's meteor activity, and it is often regarded as a poor time of year to observe in the northern hemisphere because of the lack of major showers, low sporadic rates, and often the worst of the winter weather. The radio analyses I have carried out in recent years found one of the stronger February echo count peaks around $\lambda_\odot = 315°$ (February 5, 2000), surrounded by more weakly enhanced activity, in the period $\lambda_\odot = 314°$–$318°$ (perhaps extending from $\lambda_\odot = 312°$ to $\lambda_\odot = 320°$), though even this peak is only marginally enhanced compared to the fairly flat activity usually seen. It does not coincide especially well with any of the known minor shower peaks near this time, which might give some further support to the video radiants noted by Rendtel and Gliba.

However, the very large, diffuse radiant found to the north of their studied area (see Figure 1 of [1]) is a near-perfect match for the large, very diffuse Northern Toroidal sporadic source derived primarily from radar data. For details on the various sporadic sources, which are also reflected in visual and other instrumental studies, see "Sporadic Meteors" by Vladimír Znojil in [2; pp. 110–117]. These sporadic source areas are not strictly radiants as we would understand the term for meteor showers, since the streams producing them are far less well-defined than those producing definite showers, but we can view them loosely as radiants for a significant number of sporadic meteors.

The densest part of the Northern Toroidal source for February 5.5 (the midpoint of the period used to derive Rendtel and Gliba's Figure 1) is centered at $\alpha \approx 225°$ and $\delta \approx +34°$, but it extends over an area of $\pm 25°$ in right ascension and $\pm 10°$ in declination. This coincides with the data presented in [1], viewing the more northerly radiant in CrB-Boo as a single unit centered around $\alpha \approx 228°$ and $\delta \approx +35°$. The two main lobes to the east and west of this center could be partially due to the trail orientations used to derive the radiant, but could also be real features in the sporadic source region. In addition, while the other sporadic sources are declining in activity throughout February, the Northern Toroidal source is almost at one of its most active phases (the ill-defined maximum falls around the February-March boundary). This could well account for why the source was picked up preferentially, while the northern branch of the Apex source we would expect to see centered close to $\alpha \approx 225°$ and $\delta \approx +04°$ (with roughly the same spread in right ascension and declination as for the Northern Toroidal source) on February 5.5, was not. It would also account for why this radiant area appeared equally strongly regardless of the assumed meteor velocities (sporadics should to a first approximation show no preferred velocity), and why it was just as obviously present even in the later February results ([1, Figure 4]). These later data show the Northern Toroidal source almost exactly where we would expect to find it once more (from [1, Figure 4] centered close to $\alpha \approx 234°$ and $\delta \approx +35°$; the expected location of the source's center midway through the time interval for this Figure, February 11, would be $\alpha \approx 230°$ and $\delta \approx +36°$).

The more southerly radiant in Serpens might be part of the northern Apex source, but it appears to be more velocity dependent, favoring higher velocities (about 70 km/s over about 50 km/s, for instance). The location and meteor velocities might suggest a link with the Coma Berenicids since their atmospheric velocities are 65 km/s, but we would usually expect them to have finished by about January 20. Projecting their December 19 maximum radiant position through to February 5.5, assuming a daily drift of $\Delta\alpha = +0.^\circ8$ and $\Delta\delta = -0.^\circ3$ from [2; p. 270], would yield a position at $\alpha \approx 214°$ and $\delta \approx +10°$, too far west of the detected area.

Checking with various minor stream lists for this Serpens source in [1], I found one potentially interesting shower in A.K. Terentjeva's catalog of minor streams derived from visual and photographic data [3], number 26, the α-Serpentids, detected around February 13–20 from radiants at $\alpha = 233°$ and $\delta = +08°$ and at $\alpha = 237°$ and $\delta = +04°$ (all positions from Terentjeva's works here are for epoch 1950.0), and atmospheric velocities of 62 km/s and 65.4 km/s. These positions are rather south of the February 2000 Serpens radiant, but might be related.

Three others of Terentjeva's minor showers have radiants near the more northerly source in [1]: number 14, α-Bootids, active January 13–20 (much earlier than the data dealt with in [1]), radiants around $\alpha = 208°$ and $\delta = +25°$ and at $\alpha = 213.^\circ5$ and $\delta = +24.^\circ7$, and atmospheric velocities of 3.7 km/s and 62 km/s [3]; number 25, Corona Borealids, active January 21 to February 24, radiants at $\alpha = 237°$ and $\delta = +28°$ and at $\alpha = 255°$ and $\delta = +28°$, atmospheric velocities of 60.4 km/s and 58 km/s [3]; and number 169, η-Corona Borealids, active February 3–26, radiant at $\alpha = 225°$ and $\delta = +25°$, atmospheric velocity of 61.2 km/s [4]. The two CrB showers in particular might indicate the stronger easternmost area in [1] is partly due to a separate minor shower radiant superimposed on part of the Northern Toroidal source.

Overall, the pattern suggested for early February radiants in this part of the sky is perhaps rather complex, consisting of the Northern Toroidal sporadic source, maybe a superimposed separate stream radiant in Corona Borealis, plus a possible further radiant in Serpens. The value of video data in resolving these is clearly demonstrated. I believe this is the first time the Northern Toroidal source has been found in video results, for example. Whether visual observers can usefully make headway with this problem is far from clear. Their apparent failure to discover the Northern Toroidal source or any radiant in Serpens, while seeing one somewhere not far from α Bootis in early February, which remained invisible to the more objective instrumental techniques past or present, is a clear indication of how much care must be taken in drawing conclusions based on only a few visual meteor plots, as emphasized in [1] as well.

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

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

[3] A.K. Terentjeva, *Issled. Meteorov, Resultaty MGP*, No. 1, 1966, pp. 62–132.

[4] A.K. Terentjeva, "Investigation of Minor Meteor Streams", in *IAU Symposium No. 33: Physics and Dynamics of Meteors*, Ľ. Kresák and P. Millman, eds., D. Reidel, 1968.

Alastair McBeath, March 26, 2000

Spectacular meteorite-dropping fireball

Thousands of people observed extremely bright daylight bolide over southern Poland and north-eastern Moravia on Saturday, May 6, 2000, at $11^h51^m25^s$ UT. It was a really huge event—at the maximum, the brightness was comparable with the Sun! Just after the bolide, the meteorite fall was observed at the small Silesian village of Moravka (Ostrava and Beskydy mountain region), and one very nice small meteorite (214.2 g) was immediately found. Very important to us is that we already have three good-quality video records of this event, and thus are able to completely reconstruct the atmospheric trajectory as well as the heliocentric orbit. In this respect, it is the fifth case in history.

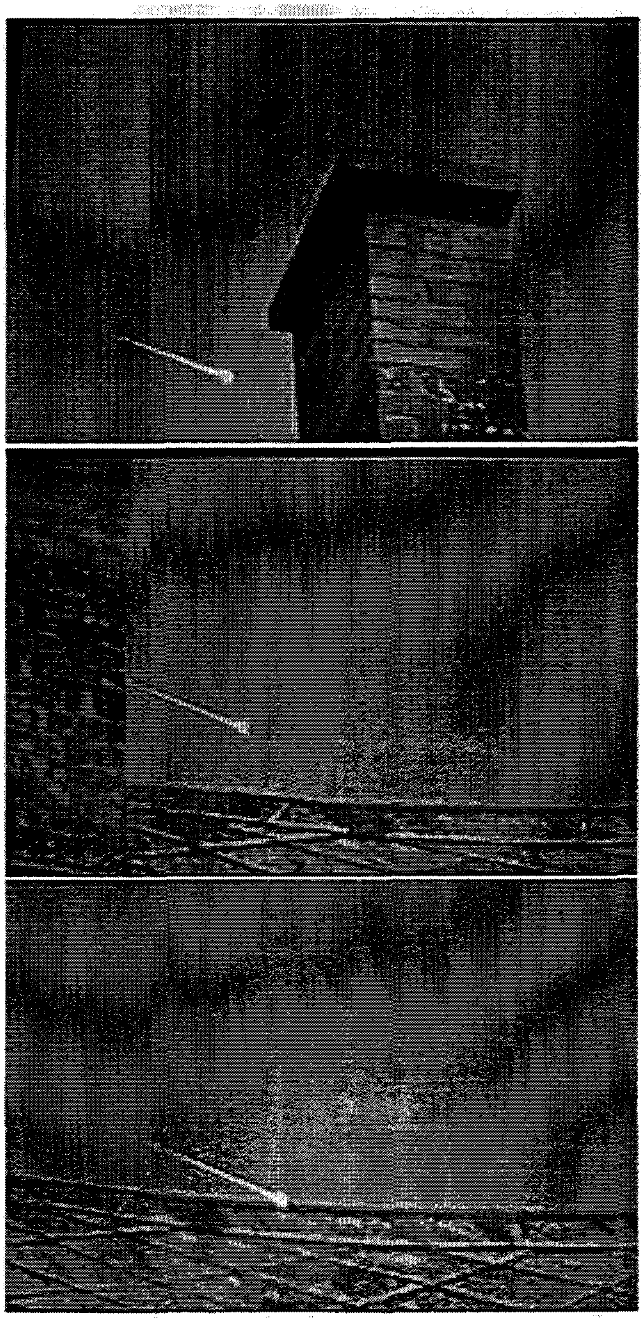

Figure 1 – Three images of a video recording of the Moravka fireball of Saturday, May 6, 2000, made by Jiři Fabik. From the Czech electronic astronomical magazine *Instant Astronomical News* 247, May 9, 2000 (`http://www.ian.cz/detart.asp?id=123`), kindly communicated to us by Dr. P. Spurný.

We also have a very detailed record of the terminal part of the trajectory, and there is a lot of pieces—more than 20, for certain. We already know that it is a stony meteorite, probably of not very common type. Presently, the meteorite is in the labs in Italy for radionuclides testing.

As it happened, there was another fireball just a few days later, on Wednesday, May 10, 2000, with practically the same brightness! It also occurred during daylight, namely at $17^h15^m25^s$ UT. This fireball flew over the southern part of Moravia and terminated over the north-eastern part of Austria. We have a lot of visual observations from our country and from Slovakia, but none from Austria.

You can see that Mother Nature is nicely joking, because we are very saturated with the first case, and immediately we get another similar one at hand!

Pavel Spurný, Ondřejov Observatory, May 13, 2000

The 2000 International Meteor Conference

Pucioasa, Romania, September 21–24, 2000

Valentin Grigore and Andrei Dorian Gheorghe

Born from the darkness,
It is a meteor, my friends.
Light through self-sacrifice,
Challenge for our beings—
And joy for our eyes.

A.D. Gheorghe

The 2000 *International Meteor Conference* will be held in Pucioasa, Romania, between September 21 and 24. More information about this event can be found at the Internet addresses `http://sarm.romwest.ro/imc2000` or `http://sarm.ccs.ro/imc2000` (mirror site). Also, there is a lot of information about Romania (a survey of Romania, general data, politics, history, culture, education, geography, localities, economics, visas, currency, traveling information, etc.), including many photos and useful links. In particular, there is also information about the *SARM* and Pucioasa. Please, take a moment to access the web site!

As usual, there will be an excursion at the *IMC*. Two places will be visited on the trip, on September 23. The first one is the New Jerusalem Monastery, just near Pucioasa. Here is a very interesting gallery of traditional art combined with modern elements, too. The second place is situated in the mountain resort Sinaia. Here, Prince Carol of Hohenzollern-Sigmaringen built Peles Castle in 1873, a masterpiece of architecture in German neo-renaissance style. Notice that Peles Castle has had electricity and central heating since it was finished in 1883! Part of it is decorated in Florentine style. Rare furniture, sculptures and stained-glass windows give immense satisfaction to the visitor's eye. Very few places in Europe can match this display of exquisite art and architecture of enormous artistic value.

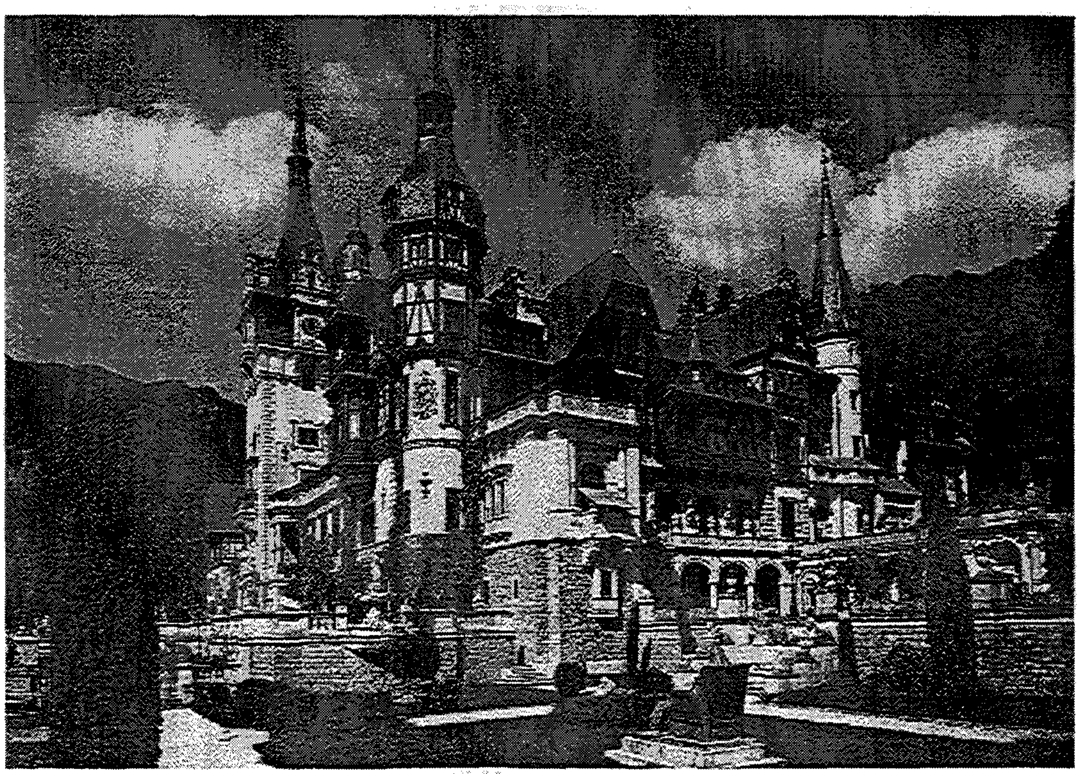

Figure 1 – Peles Castle.

The *SARM* wishes that the participants to this last *IMC* of the millennium perceive this event also as a holiday. In this respect, the walls of the conference hall will be adorned with astronomical photos, graphics, poems, computer art, pictures, sculptures, etc. The holiday character will be strengthened by post-dinner meteor shows in which the *SARM* will offer the participants live electronic and folk music, poetry, drama, mask dance, humor, and even an astral fashion show! It is interesting to note that several cultural organizations in the UK and the US have taken interest in the artistical part of the *IMC*. We intend the last evening (September 23) to have an international character, for which we are waiting for other initiatives from *IMO* members.

We also enjoy a lot of interest from the Romanian media and the town of Pucioasa. We are sure that all our plans will become reality and hope you will not miss this *IMC* holiday!

International Meteor Conference

Pucioasa, Romania, September 21–24, 2000

Registration Form

Each individual participant should fill out a form and return it to *Ina Rendtel, Mehlbeerenweg 5, 14469 Potsdam, Germany*, as soon as possible. Your registration will be guaranteed only after Ina Rendtel has received the minimum pre-payment of 100 DEM (51.13 EUR). If you wish to participate, but cannot yet decide, simply return this form with the proper option checked to stay on the mailing list for further circulars.

Name: ______________________________ Birth date: ____________

Address: ____

____

____

Phone: ____________ Fax: ____________ E-Mail: ____________

- o wishes to register for the 2000 *IMC* from September 21 to 24;
- o intends to participate, cannot yet register, but wishes to stay on the mailing list.

I intend to travel by ________, together with ______________________

Additional requests:

- o I need travel information from ______________ to Pucioasa;
- o I wish to stay in Romania before or after the *IMC* and require additional information re. this matter.

For participants wishing to contribute to the program:

Lecture: ____

Duration: ________min. Required equipment: ______________________

Workshop or discussion: ______________________________

Poster presentation: ______________________ Space: ________ m^2

Either the entire fee of 170 DEM (86.92 EUR) or a pre-payment of at least 100 DEM (51.13 EUR) should be sent to the Treasurer, *Ina Rendtel*. Follow the payment instructions below. Participants paying only 100 DEM (51.13 EUR) have to pay the remaining 70 DEM (35.79 EUR) upon arrival in Pucioasa.

Date and signature: ______________________________

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

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

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

Ongoing Meteor Work

Global Electrophonic Fireball Survey

D. Vinković, Ž. Andreić, S. Garaj, D. Kovačić, M. Mladinov, and G. Zgrablić

The electrophonic sound from a meteor is a rare, mysterious, and poorly understood natural phenomenon. Investigations done so far suggest the ELF/VLF radio waves as a source of this sound, but many other questions about the ELF/VLF emission and its transformation into sound lack satisfactory explanation. Thus, it is not surprising that most of our knowledge about the phenomenon is still based on eyewitness reports. The purpose of the *Global Electrophonic Fireball Survey* (*GEFS*), accessible at `http://gefs.ccs.uky.edu`, is to collect these reports and provide a more systematic approach in the study of this phenomenon with a possibility for more extended activities. Due to the rareness of these sounds, contributions from experienced meteor observers are essential for this study.

1. Introduction

Very bright meteors (fireballs) are sometimes accompanied by sounds heard simultaneously with their passage. A large distance to the meteors and limited speed of sound suggest that these simultaneous sounds cannot be explained by ordinary sound propagation. The ordinary sound from a meteor (sonic boom) travels a few minutes before it arrives to an observer on the ground.

On the other hand, simultaneous (or anomalous or electrophonic) sounds require propagation with the speed of light, which suggests that they are actually electromagnetic waves transformed somehow into sound in the vicinity of the observer.

It is amazing that, even though the physical distinction between the ordinary and anomalous sounds was recognized more than three hundred years ago [1], we are still lacking a satisfactory explanation of the phenomenon of electrophonic sounds. In the 20th century, a number of theories have emerged [2–4], but all of them either fail to explain the variety of the electrophonic sound properties or have serious physical shortcomings.

Nevertheless, the current widely accepted theory says that the electrophonic sounds are created by ELF/VLF radio waves [5] emitted from a meteor [4]. It has been shown in laboratory experiments [4,6] that the ELF/VLF electric fields are capable of producing sound, but the overall problem remains, since we still have to explain how it is possible for a meteor to create such a strong ELF/VLF emission.

The usually invoked explanation of this emission [4,7] requires physical parameters which are very often not fulfilled by the electrophonic fireballs [8].

As we can see, there are many open questions in the study of electrophonic fireballs. It is not clear how meteors can produce a strong ELF/VLF emission and what are the limiting factors in this process, how exactly the sound can be generated by the ELF/VLF radio waves, and thus we do not know if some specific weather conditions or objects are more favorable for electrophonic sound detection.

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2. Where and how to report an electrophonic sound

There have already been some activities within the *International Meteor Organization* (*IMO*) related to these issues [9], including an electrophonic catalog by C.S.L. Keay [10].

The *IMO* can have substantial influence on the study and promotion of this phenomenon. This is due to its members, experienced meteor observers from all over the world, and due to the *IMO Fireball Data Center* (*FIDAC*), which has become a major source in studies of the physical parameters of fireballs.

Fireballs are quite a rare event and just a fraction of them will yield electrophonic reports. Thus, it is important to have in mind that all possible electrophonic reports are very valuable. Since our knowledge about electrophonic sounds is very limited and mostly based on eyewitness reports, it would be very useful for any future work in this field if the reports are collected in a systematic and unique way. This was the motivation for introducing the *Global Electrophonic Fireball Survey* (*GEFS*) by the Center for Computational Sciences at the University of Kentucky. The initial purpose of *GEFS* is collecting eyewitness reports of electrophonic sounds from meteors, with the possibility of extended research efforts in the future.

The reports are collected via an HTML data submission form from the website

`http://gefs.ccs.uky.edu/GEFS_Form.html`,

or by e-mail to

`gefs@ccs.uky.edu`,

or by ordinary mail (see the form at the end of this text) to the following address:

Global Electrophonic Fireball Survey,
University of Kentucky,
325 McVey Hall (CCS),
Lexington, KY 40506-0045,
USA.

Some additional information and references related to electrophonic sounds can be found on the *GEFS* homepage `http://gefs.ccs.uky.edu`.

It is important to emphasize that even simple reports with specified month and year of an electrophonic sound event are already valuable. In this case, we can look for correlation between the months during a year and rate of electrophonic appearance, or we can assume to which meteor shower the observed meteor belongs. That gives us the meteor's properties, and we can check if one type of meteor is more efficient in the production of electrophonic sound than another. Nevertheless, the observer should provide as much detail about the event as possible.

The form has four parts. They are dealing with the contact information about the observer, description of the place where the observer heard the sound, specifics of the sound that the observer heard, and the meteor which produced the sound.

- *Personal information*:

  It will be asked that the observer specify name and contact information, and give some information about his or her meteor observation experience.

- *Description of the observing site*:

  It will be asked that the observer provide the location of the place where the sound was heard as precisely as possible; describe in detail the observing site, including the meteorological conditions at the moment of the electrophonic event; describe also the outlook and objects around the observer, since this could be important for the generation of the sound; and describe everything that is found unusual about the site.

- *Details about the electrophonic sound*:

  It will be asked that the observer specify the date and time of the electrophonic observation as precisely as possible; describe the sound, its duration, and possible direction from which it came; if the observer was not alone, specify how many people were there and how many of them also heard the sound; and if the meteor that could be the source of that sound was sighted, describe the moment when the sound was heard relative to the meteor light maximum.

- *Details about the meteor*:

  It will be asked that the observer provide as much information about the meteor as possible, how fast it was, color, fragmentation, duration, and position in the sky.

All data collected by *GEFS* will be made public through the *GEFS* internet site, *WGN*, and special newsletters, with full reference to witnesses.

It is important to spread the awareness about this phenomenon, since people have the tendency to ignore it due to the sound experiences in their daily life. The man-made noises have probably masked many electrophonic sounds during modern times, and people do not find these sounds unusual any more.

Thus, it is not surprising that we can find some of the most detailed descriptions of the electrophonic sounds in more than 200 year old manuscripts, but we are still tumbling in their explanation.

References

[1] Geminian Montanari from Bologna, Italy, in 1676, quoted by sir Edmund Halley in "An Account of Several Extraordinary Meteors or Lights in the Sky," *Phil. Trans. Roy. Soc. London* 29:341, 1714, pp. 159–164.

[2] V.A. Bronshten, "Electrical and Electromagnetic Phenomena Associated with Meteor Flight", *Solar Sys. Res.* 25, 1991, pp. 93–104.

[3] M. Beech, L. Foschini, "A Space Charge Model for Electrophonic Bursters", *Astron. Astroph.* 345, 1999, pp. L27–L31.

[4] C.S.L. Keay, "Anomalous Sounds from the Entry of Meteor Fireballs", *Science* 210, 1980, pp. 11–15.

[5] *The International Telecommunication Union's definition of the low frequency electromagnetic (ELF) radio wave band is 30 Hz–3 kHz, and the very low frequency (VLF) band is 3–30 kHz. This differs from the nomenclature used in articles about the electrophonic sounds where the ELF band begins at 300 Hz.*

[6] C.S.L. Keay, P.M. Ostwald, "A Laboratory Test of the Production of Electrophonic Sounds", *J. Acoust. Soc. Am.* 89, 1991, pp. 1823–1824.

[7] V.A. Bronshten, "A Magnetohydrodynamic Mechanism for Generating Radio Waves by Bright Fireballs", *Solar Sys. Res.* 17, 1983, pp. 70–74.

[8] V.Yu. Kaznev, "Observational Characteristics of Electrophonic Bolides: Statistical Analysis", *Solar Sys. Res.* 28, 1994, pp. 49–60.

[9] Ž. Andreić, L. Beg, K. Korlević, "No Evidence in Change in Ionospherical Radio Emission on Frequencies 1.23–10.6 kHz During and After the Meteor Flight", *WGN* 21:2, April 1992, pp. 69–71, and subsequent letters: C.S.L. Keay, *WGN* 21:3, June 1992, p. 80; K. Korlević, *WGN* 21:3, April 1993, p. 81; G.W. Wolf, *WGN* 21:4, August 1992, pp. 143–145.

[10] C.S.L. Keay, "Electrophonic Sounds Catalog", *WGN Observational Report Series* 6:2, 1993, pp. 151–172.

Global Electrophonic Fireball Survey:

Data Submission Form

It is not necessary to fill out the form completely. Just provide as much information as you can remember or have available.

If you are not sure about the precision of your data, skip it or mention this as a comment at the end of this form.

Personal information

First name, middle name(s) initials, last name[1]	
Address[2]	
Country	
Phone number[2]	
E-mail[2]	
Level of meteor observing experience	___ not experienced ___ somewhat experienced ___ moderately experienced ___ highly experienced
Have you ever heard a sound from a meteor before?	___ no ___ yes

[1]This information will be publicly available *only* with your approval; see end of this form.
[2]This information will *not* be publicly available.

Description of the observing site

Location of the observing site (give exact coordinates, if known)	general description: long.: lat.: elev.:
Describe in detail the meteorological conditions at your observing site (temperature, humidity, wind, rain, clouds, etc...)	
Describe in detail your observing site (vegetation, buildings, fences, and—especially—any metal objects in your vicinity, etc...)	
Describe in detail your outlook and clothing during observation (especially important is your haircut, glasses and metal objects)	

Specify all electrical equipment at the observing site and in its vicinity	
Additional remarks about the observing site	

Details about the sound from the meteor

Specify date and time of your sound observation	month: day: year: local time:
How would you describe the sound you heard?	
How long did the sound last?	
Which direction did the sound come from (the meteor, the ground, some object, air, all directions)?	
How many observers in your vicinity heard a sound from that meteor, and how many observers did not hear it?	___ observers heard sound ___ observers did not hear sound
Did you see the meteor that could be connected with the sound?	___ yes, simultaneously with the sound ___ yes, a moment before the sound ___ yes, a moment after the sound ___ I can not decide which meteor was connected to the sound ___ no *if yes*, what was the correlation with the light maximum? ___ I cannot decide ___ the sound appeared *simultaneously* with the light maximum ___ the sound appeared *before* the light maximum ___ the sound appeared *after* the light maximum
Did you notice any other unusual phenomena which might be related to the meteor (electric or magnetic effects, strange odors, unusual animal behavior, strange air glow, etc...)?	

Details about the meteor

(if you have seen or detected the meteor)

Meteor shower (or sporadic)	
Meteor magnitude	
Velocity (enter exact value if known)	___ very slow (___ km/s) ___ slow ___ fast ___ very fast ___ static
Color	
Fragmentation	___ no ___ yes
Duration	
Height above horizon (from 0° to 90°)	
Azimuth (from 0° to 360°) (N = 0°, E = 90°, S = 180°, W = 270°)	
Angle between meteor path and horizon (from 0° to 90°)	

Additional remarks

At the end, we would like to thank you for your patience and cooperation. If you have any additional comments, remarks, or suggestions, please mention them here.

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The Observation of Lunar Impacts

Costantino Sigismondi and Giovanni Imponente

The intense activity of cratering on the Moon and in the inner regions of the solar system was accomplished during the first 10^9 years [1]. Occasionally, some impact events occur even nowadays. In Section 1, we treat, from a historical point of view, the Earth-based observation of lunar impacts. In Section 2, we consider the visibility conditions of such events evaluating the luminosity of the background upon which an impact shines. In Section 3, the luminosity of an impact is discussed. The occurrence of lunar impact events outside of meteor shower periods is calculated using the hourly rate of the sporadic meteors and their population index. The evidence of a larger rate of impacts of meteoroids in the past under these hypotheses is presented in the last section.

1. Evidence of lunar impacts

The first important evidence of lunar impacts has been the observation recorded on June 18, 1178 (Julian calendar), by a few men after sunset and registered in the chronicles of Gervase of Canterbury [2]. They observed the upper horn of a crescent moon to have split with fire and sparks emanating from the division point. This report was interpreted to be a description of events related to the formation of the lunar crater Giordano Bruno [3].

On November 18 and 19, 1999, several impact events of initial magnitude between +3 and +7 were recorded with a video tape and by naked eye near the center of the Moon's dark limb. Those flashes resulted from Leonid impacts on the Moon, because the center of the 1899 dust trail would have passed 0.0002 AU from the selenocenter around $4^{\rm h}49^{\rm m}$ UT [4].

The Giordano Bruno crater event is reliably exceptional, while the last ones are more frequent. The observation from Padua, Italy, of a probable lunar impact during the total eclipse of the Moon on January 21, 2000, done by one of the authors (CS), confirms that assertion.

2. Luminosity of a lunar impact

Except for the very rare events such as the one reported by Gervase, it is necessary to have a dark background upon which the flashes of lunar meteors can be visible. Hence, there are three favorable conditions for observing such a phenomenon:

1. in the ash-grey light of the Moon, close to New Moon;
2. far from the dark limb around First or Last Quarter;
3. during a total eclipse.

The last condition is the most favorable one, but also the least frequent one.

In the case of the lunar Leonids the Moon phase was 62%, while for the Giordano Bruno event, it was 11% [5].

Ash-grey light

The maximum brightness of the Moon due to the ash-grey light occurs during a total eclipse of the Sun. That value has been measured in order to study the coronal aureola phenomenon [6], and it is $10^{+9.3}$ fainter than the solar disk. It means that the Moon in ash-grey light shines like a magnitude -3 star, say its surface brightness B during the total eclipse of September 22, 1968, was equal to about +13 per square arcsecond.

Total lunar eclipse

It is well known that a total lunar eclipse is measurable by de-focusing a star and comparing its image with the eclipsed Moon. Typically, the eclipsed Moon shines as a magnitude 0 star, but exceptionally it shines as a magnitude +3 star [7]. Hence, for the surface brightness B, we typically find +16 per square arcsecond.

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The First or Last Quarter of the Moon

The second case is intermediate with respect to the previous ones. The dark quarter of the Moon is illuminated by a quarter of the Earth, and therefore the amount of light coming from the Earth is about half that of the New Moon case. It corresponds to a surface brightness of about +14 per square arcsecond.

We emphasize that all those surface brightnesses are calculated for the *dark* area of the Moon. For naked-eye observations, however, if the bright part of the Moon is not artificially occulted, because of the atmospheric glare and the bleaching of the eye, the effective luminosity background is even brighter than that of the ash-grey light.

3. The number of lunar meteors calculated by the sporadic rate

We assume that the 5 lunar events recorded by videotape during the 1999 Leonid shower belong to the same ensemble of meteors with equal population index $r = 2.5$ and similar normalization factor such that the ZHR $\approx$ 4000.

Analogously to the formula that gives the number of observed meteors versus the limiting magnitude, already corrected by the position of the radiant, we have

$$N_{\rm obs} = {\rm ZHR} \times r^{-(6.5-{\rm lm})} \times \Delta t_{\rm h},$$

where r is the population index and $\Delta t_{\rm h}$ de effective observing time in hours, and we can affirm that the total amount of the lunar Leonids observed around the peak time should be very bright fireballs if they fell onto the Earth. Therefore, the following equation, integrated over 2 hours of observation, is valid:

$$N_{\rm obs} = 2 \times {\rm ZHR} \times r^{-x}.$$

For $N_{\rm obs} = 5$ in two hours of registration, $ZHR \approx 4000$, and for the Leonids' population index $r = 2.5$ we obtain $x \approx 8$.

To calculate the probability to have similar events out of the maxima of meteor showers, one needs to consider the hourly rate HR and the population index $r_{\rm spor}$ of the sporadic meteors: HR ≈ 10 and $r_{\rm spor} = 3.4$ [8]. This yields the equation

$$N_{\rm exp} = 10 \times 3.4^{-x} \times \Delta t_{\rm h}.$$

With $x \approx 8$, the expected value of sporadic lunar impacts to be observed in two hours is $N_{\rm exp} \approx 1/900$.

In this calculation, we have considered background conditions similar to the ones of the lunar Leonids of 1999, with the Moon phase at 62%. If we consider the illumination conditions during a lunar eclipse, we can reach a background which is 2 to 3 magnitudes per square arcsecond fainter. That fact implies an improvement of the detection of the lunar meteor of a factor given by $r^2_{\rm spor}$ to $r^3_{\rm spor}$, which is in the range 10–30.

Consequently, during the totality of a lunar eclipse (about two hours) occurring when no major shower is active, $N_{\rm ecl} = 1/90$ to $1/30$ lunar impacts are expected to be visible up to magnitude +8.

This number should be reduced significantly if we assume a non-homogeneous distribution of the matter inside the meteor stream to which we refer our calculation. Since the Moon approached the core of the 1899 dust trail much closer than the Earth, this is a real possibility. As a limiting case, we consider the effective ZHR = 150 000 at 0.0002 AU from the center of 1899 dust trail (as in the 1966 Leonids shower [9]). For this limiting case, all computed probabilities should be divided by 30–40.

4. Kinetic energy assessment

We consider the temperature-kinetic energy relation for an object at given impact velocity $v =$ 41 km/s, obtained averaging the geocentric velocities of all known meteor showers. We evaluate the luminosity due to the transformation of kinetic energy into radiation. The kinetic energy in calories (C_M) can be obtained by dividing the kinetic energy $Mv^2/2$ computed in Joules by 4.18. Such an amount of calories corresponds to an increment of temperature (neglecting the melting heats) of $\Delta T \approx C_M/M$ if M is expressed in grams in the latter equation. Combining both equations, we see that the mass cancels out, and we find $\Delta T \approx 2 \times 10^5$ K.

In what follows, we consider a 10 g ice meteoroid. Applying the Stefan-Boltzmann law of black-body emission at a given temperature, we receive from a mass at 2×10^5 K on the Moon the following amount of radiation:

$$W_M = \frac{\sigma T^4 \times A_M}{4\pi\, d^2_{\text{Moon}}} \approx 3 \times 10^{-8}\ \text{W/m}^2,$$

where $A_M \approx (M/\rho)^{2/3}$ is the area of the incoming meteoroid (yielding $A_M \approx 5$ cm^2 in our case), and $d_{\text{Moon}} \approx 3.84 \times 10^8$ m is the average Earth–Moon distance.

To calculate the visual magnitude, we must take into account that the eye is sensitive in a range of wavelengths far from the peak for a temperature of $T \approx 2 \times 10^5$ K, which means a reduction of a factor 10 for the effective temperature visible (say 20 000 K), corresponding to a reduction of 10^4 in the detected intensity. Therefore, the energy flux of such an event of mass $M = 10$ g is $W_M \approx 3 \times 10^{-12}$ W/m^2, i.e., a magnitude

$$m = -2.5 \log \frac{3 \times 10^{-12}}{3.7 \times 10^{-9}} = 7.7,$$

where 3.7×10^{-9} W/m^2 is the visual energy flux corresponding to a magnitude 0 event [10]. The final value of the above equation corresponds to the observed magnitudes of lunar Leonids [4].

Given the formula [11]

$$m_E = 40 - 2.5 \log(2.732 \times 10^{10} M^{0.92} v_{\text{G}}^{3.91}),$$

where m_E is the magnitude, M the meteoroid mass in grams, and v_{G} its geocentric velocity in km/s, we can relate the mass M of a lunar meteoroid to its magnitude m_E if it would fall in the Earth's atmosphere. For a meteor with $v_{\text{G}} = 41$ km/s and $M = 10$ g, we have $m_E = -4.2$.

Using the formula giving the number of meteors brighter than the limiting magnitude lm, $N_{\text{obs}} =$ ZHR $\times\, r^{-(6.5-\text{lm})}$, we can obtain the expected hourly number of meteoroids larger than mass M by substituting m_E from the previous equation for "lm." Moreover, we assume that this number is the same for the Moon. (This last assumption neglects all the geometrical effects due to the perspective of the line of sight. It is like considering that we can observe only the events occurring on the central zone of the Moon disk, and here we assume the same hourly rate observed from the Earth.)

For the 1999 Leonids, we expect $N_{\text{exp}} = 4000 \times 2.5^{-10.7} \approx 0.2$ per hour. Assuming ZHR = 150 000, because the Moon passed closer to the central zone of the meteor stream $N_{\text{exp}} \approx 8$ per hour, in agreement with the observations.

For the sporadic rate we expect a much smaller number, namely $N_{\text{exp}} = 10 \times 3.4^{-10.7} \approx 2.1 \times 10^{-5}$ per hour. During a total lunar eclipse of 2 hours, we expect only $N_{\text{exp}} \approx 4.1 \times 10^{-5}$ events, say $N_{\text{exp}} \approx 1/24000$. This value is only one order of magnitude smaller than the one derived in Section 3.

5. History of cratering in the inner solar system

Assuming that the impact rate of meteoroids has remained constant during the last 5 billion years, we can estimate the expected value of craters larger than diameter D on the Moon's surface. We compare this number with the observational evidence.

A crater of diameter $D \approx 4$ km—which corresponds to 2 arc seconds at the Moon's distance—and depth $a \approx 100$ m is obtained from the impact of a meteoroid of mass M and velocity $v_{\rm G}$. For simplicity, we assume that the kinetic energy of the incoming body is almost able to raise the material contained in the the crater to a height of $4D$ (for the Copernicus crater, surrounded by a great radial structure visible at Full Moon, this value is largely underestimated). Hence,

$$Mv_{\rm G}^2/2 = g_{\rm Moon}M_{\rm Crater} \times 4D,$$

where $g_{\rm Moon}$ is the gravitational acceleration for the Moon ($g_{\rm Moon} \approx 1.42$ m/s^2), and $M_{\rm Crater}$ is the mass of the matter removed to form the crater. We find

$$M = \frac{2g_{\rm Moon}\rho_{\rm Moon}\pi a(D/2)^2 \times 4D}{v_{\rm G}^2},$$

and, assuming again $v_{\rm G} = 41$ km/s and $\rho_{\rm Moon} \approx 2$ g/cm^3 (the lunar density), we finally obtain $M \approx 7.4\times10^7$ kg. According to the formula in [11], such a meteoroid falling on the Earth should produce a fireball of $m_E = -20$. The number of sporadic meteors brighter than $m_E = -20$ scaled for the Moon's surface $A_{\rm Moon}/A_{\rm obs}$ gives us the expected number of craters larger than 4 km above the Moon's surface. Here, $A_{\rm obs}$ is the area from which an observer can see a meteor trail occurring at an altitude of $h = 80$ km in the Earth's atmosphere:

$$A_{\rm obs} \sim 2\pi R_{\rm Earth}h$$

($R_{\rm Earth} = 6378$ km is the Earth's radius and $R_{\rm Moon} = 1739$ km is the Moon's radius). Hence, we find

$$\frac{A_{\rm Moon}}{A_{\rm obs}} = \frac{R_{\rm Moon}^2}{R_{\rm Earth}h} = 5.93.$$

Integration with the above scaling factor over 5×10^9 years, which is about 4.4×10^{13} hours, yields

$$N_{\rm exp} = 5.93 \times 4.4 \cdot 10^{13} \times 10 \times (3.4)^{-26.5} \approx 20.$$

This expected number is lower than the number of craters visible even with an amateur equipment, and it demonstrates that in the past the impact rate was larger than today. If we compare with the extrapolated number of craters without considering the outflows of basalt of the maria, the evidence becomes even more striking.

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Leonids

Successful Hybrid Approach to Visual and Video Observations of the 1999 Leonid Storm

Peter Jenniskens, Chris Crawford, and Steve Butow

A new hybrid technique of visual and video meteor observations is described. The method proved particularly effective for airborne observations of meteor shower activity. Results from the 1999 Leonid *Multi-Instrument Aircraft Campaign* (*MAC*) are presented, and the profile shape of the 1999 Leonid storm is discussed in relation to meteor shower models. We find that the storm is best described with a Lorentz profile. Application to past meteor outbursts shows that the current multi-trailet model of a dust trail is slightly shifted and we crossed deeper into the 1899 epoch trailet than expected.

1. Introduction

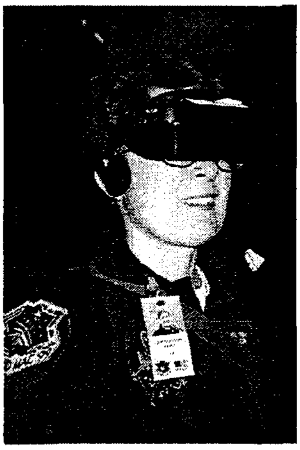

Figure 1 – Observer Jane Houston with video head display.

The requirement for near-real time flux measurements from aircraft has led to the development of a hybrid technique of visual and video meteor observations. The method has a team of visual meteor observers view the video output of intensified cameras using video head displays (Figure 1). The cameras are mounted behind optical windows, pointed at relatively low altitude. The cameras make it possible to conveniently observe part of the sky with a well defined field of view. Last year, during the 1998 Leonid *Multi-Instrument Aircraft Campaign* (*MAC*) mission [1], we discovered that meteor rates are highest near the horizon [2]. We further boost the meteor count by visually inspecting the tapes rather than using automatic detection software programs. The results enable a precise analysis of the 1999 Leonid storm rate profile.

2. The method

During the 1999 Leonid MAC mission, a team of eight visual observers first demonstrated this new approach onboard the *Advanced Ranging and Instrumentation Aircraft* (*ARIA*), operated by the USAF/452nd Flight Test Squadron.

A counting tool was developed that records the detection of Leonid shower or sporadic meteors with the click of a mouse button. The tool has six entrance ports, which recorded the counts from one of six different intensified cameras. The four cameras considered here had a field of view of $39° \times 29°$ and were mounted at an elevation of 22° behind BK7 optical glass windows.

Each observer was assigned a mouse bearing a unique machine-readable identification number; each camera had its own designated computer port. The mice were chosen for their ergonomic design and their light-response buttons. The observer began each observing session by plugging the mouse into the computer port corresponding to the camera being used by the observer; the mouse was unplugged at the end of each viewing session. This permitted the computer to identify the starting and ending times of each viewing session, and determine which observer was watching from what camera at all times. Rotating the observer/camera pairings enabled calculation of individual observer and camera coefficients of perception from systematic differences in the counts.

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During the 1999 Leonid meteor storm, ARIA flew from the UK to Israel, from Israel to the Azores, and from the Azores to Florida in three consecutive nights. The peak of the storm occurred while enroute from Greece to Italy. Near-real time flux measurements were automatically transferred to a communication station onboard the aircraft, where the counts were sent to NASA/Ames Research Center by e-mail, telephone, or direct internet access using INMARSAT satellite telephone lines. From NASA/ARC, the counts were further distributed to operation centers, such as the NASA and USAF sponsored LEOC at Marshall Space Flight Center and ESA's orbital debris center at ESOC, Darmstadt.

Shortly after the mission, several observers gathered at NASA/Ames Research Center to view in the same manner the video tapes that were recorded by four similar intensified cameras onboard the twin *Flying Infrared Signature Technology Aircraft* (*FISTA*) during the peak night, about 150 km from ARIA.

3. Results

A total of 33 000 video Leonids were recorded in this manner, which accounts for about 3/4 of all Leonids on video. This compares with 277 172 Leonids that were observed by 434 visual observers worldwide and gathered by the *International Meteor Organization* [3]. Both data sets will be discussed together. The video data will be shown by black points, the previously published visual data by open squares. Although the number of video meteors is 8 times less than the visual record, the measurements are performed under much better controlled conditions, from which a more precise result can be expected.

Figure 2 shows the peak of the storm. Individual points are 1-minute intervals. No smoothing was applied. Each interval is an independent measurement. The video data are very smooth. The curve is featureless. A small depression at the peak can not be trusted because it is not present in the ARIA and FISTA data in the same way. We suspect that muscle fatigue in the button-pressing fingers started to become a problem at about that time. In hindsight, it appears that the technique works well for rates between ZHR = 5 and ZHR = 5000, but the technique will need modifications to conveniently cope with higher rates.

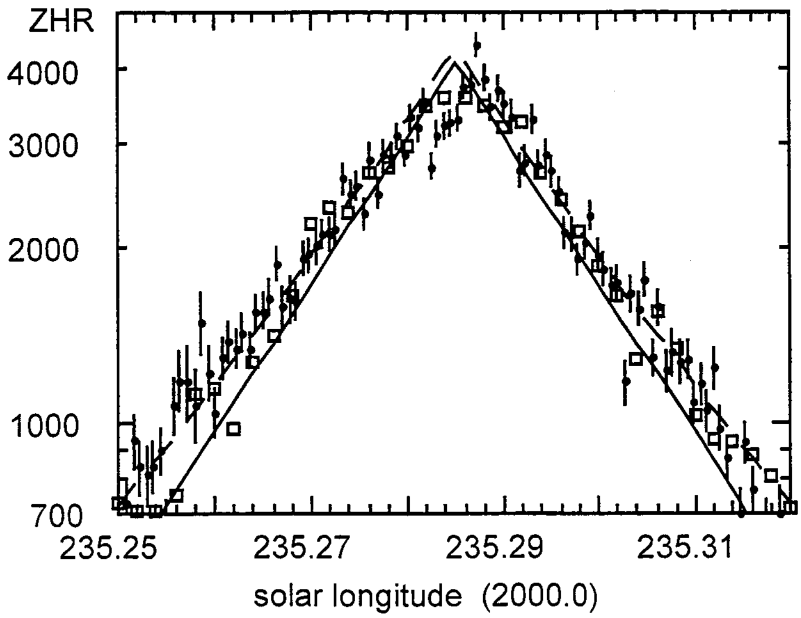

Figure 2 – The peak of the 1999 Leonid storm. Open squares are data from [3]. The solid line shows the storm component (main peak), while the dashed line is the sum of all components.

In this paper, our video rates are scaled to the visual Zenith Hourly Rates calculated by Arlt et al. [3]. Arlt's rates represent independent intervals of 2.8 minutes. We are not concerned with the absolute values, but with the shape of the curve. Hence, all data are plotted on a logarithmic scale, so that any scaling is a mere shift in the graph. It is a compliment to visual and video observers to see how well both data sets agree! The peak is confirmed at solar longitude $\lambda_\odot = 235\overset{\circ}{.}285 \pm 0\overset{\circ}{.}001$, or about 2^h02^m UT.

We do not confirm *"additional clear enhancements"* [3] in the visual rate profile, which Arlt et al. were quick to assign to features in shower models. These are probably the result of imperfect corrections for observer perception, observing conditions or other factors that affect visual observations. For the same reason, the features in the profiles from individual locations in [3] cannot be trusted. In the remainder of the paper, we will concentrate on the gross features of the curves that are confirmed by both video and visual results.

When plotted on a logarithmic scale, as in Figure 2, it is clear that the slopes of the storm peak are linear and well represented by an exponential equation as in [4]:

$$\mathrm{ZHR} = \mathrm{ZHR_{max}} \times 10^{-B|\lambda_\odot - \lambda_\odot^{\max}|}. \qquad (1)$$

From a least-squares fit, we find $B = 24 \pm 2$ per degree of solar longitude for ZHRs larger than 700. A slightly larger value of $B = 25 \pm 1$ (and $\mathrm{ZHR_{max}} = 4100$) results when a composite of such curves is fitted to the profile that also accounts for other more shallow features. This value is slightly less than the value of $B = 30 \pm 3$ derived from the 1866, 1867, 1966, and 1969 Leonid storm profiles [4], when the Earth crossed deeper into the respective trailet.

Above solar longitude $\lambda_\odot = 235\overset{\circ}{.}38$ (and below $\lambda_\odot = 235\overset{\circ}{.}20$), rates level off significantly in both video and visual data (Figure 3). A similar background structure to the main peak was observed in the 1866 and 1966 profiles [4]. The slopes are near linear again on a logarithmic scale, with B $= 2.5 \pm 0.2$. Combined with other components, we have $B = 3.0 \pm 0.3$, slightly less than found before (B = 4–6 [4]). This structure appears to be centered within $0\overset{\circ}{.}01$ from the center of the storm peak, and has $\mathrm{ZHR_{max}} = 200 \pm 10$.

From the visual data [3], we conclude that the magnitude distribution index does not seem to change over the peak. This implies that the magnitude distribution index of the background component and main peak are the same (as we concluded earlier from the 1866 and 1966 profiles [4]). And that suggests strongly that both components are part of one and the same profile. We may be able to verify that from the video record in the future, but will take this as a fact for the remainder of the paper.

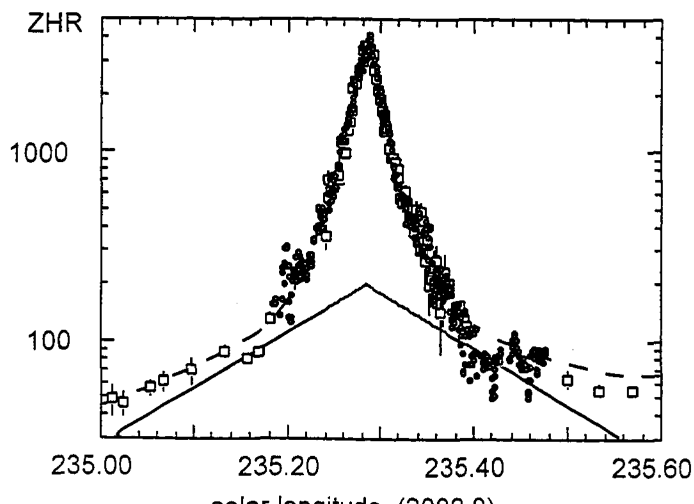

Figure 3 – Background to the main peak.

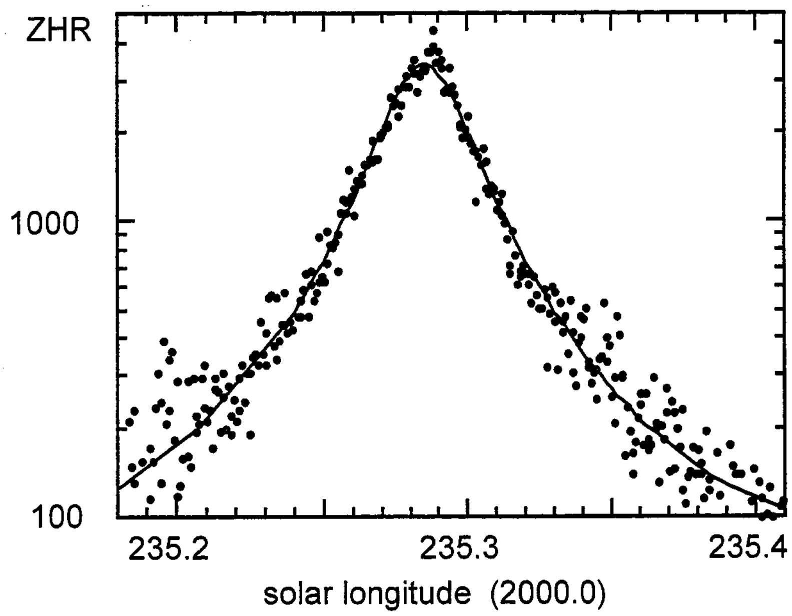

Figure 4 – Fit of a Lorentz profile to the meteor storm profile. For clarity, error bars are not shown.

4. Discussion

In the past, shower profiles have been described in terms of Gaussian and exponential shapes [3]. Now, we find that the Lorentz profile, known from damped oscillators, has a shape very similar to the peak and background combined:

$$\mathrm{ZHR} = \mathrm{ZHR}_{\mathrm{max}} \times \frac{(W/2)^2}{(\lambda_\odot - \lambda_\odot^{\mathrm{max}})^2 + (W/2)^2}. \tag{2}$$

In the above equation, W is the classical width of the profile at half the peak intensity (in degrees). Indeed, the main peak above ZHR = 300 is best fitted with a Lorentz profile of width $W = 0.^\circ 036 \pm 0.^\circ 002$ and $\mathrm{ZHR}_{\mathrm{max}} = 3300 \pm 100$, the line shown in Figure 4. Even if we ignore the background component, the tail of the curve falls right on when the peak is fitted.

Past meteor storms show a similar good fit, which implies that each dust trailet itself has a Lorentzian cross section. This condition is necessary to account for the fact that we passed the dust trailets at different distances from the center in 1999, 1966, and 1866. If the dust distribution in a trailet follows a Lorentz function as a function of r, the distance from the trailet center, then

$$\mathrm{ZHR}(r) = \mathrm{ZHR}^{\mathrm{t}}_{\mathrm{max}} \times \frac{(W_{\mathrm{t}}/2)^2}{r^2 + (W_{\mathrm{t}}/2)^2}. \tag{3}$$

In that case, the cross section is also Lorentzian if we pass the center of the trailet along the Earth's orbit in a direction $X = \lambda_\odot$ (now in AU, with roughly 2π AU = 360° neglecting curvature of the Earth's path) at a distance $Y = Y_0$ (measured in a direction perpendicular to Earth's orbit). Because, by substituting $r^2 = Y_0^2 + (X - X_0)^2$,

$$\mathrm{ZHR}(X) = \mathrm{ZHR}_{\mathrm{max}} \times \frac{Y_0^2 + (W_{\mathrm{t}}/2)^2}{(X - X_0)^2 + Y_0^2 + (W_t/2)^2}, \tag{4}$$

which has a similar form as equation (3). In that case, the width of the dust trailets equals

$$(W_{\mathrm{t}}/2)^2 = (W/2)^2 - Y_0^2, \tag{5}$$

and the peak rate in the trailet is

$$\mathrm{ZHR}^{\mathrm{t}}_{\mathrm{max}} = \mathrm{ZHR}_{\mathrm{max}} \times \frac{(W/2)^2}{(W/2)^2 - Y_0^2}. \tag{6}$$

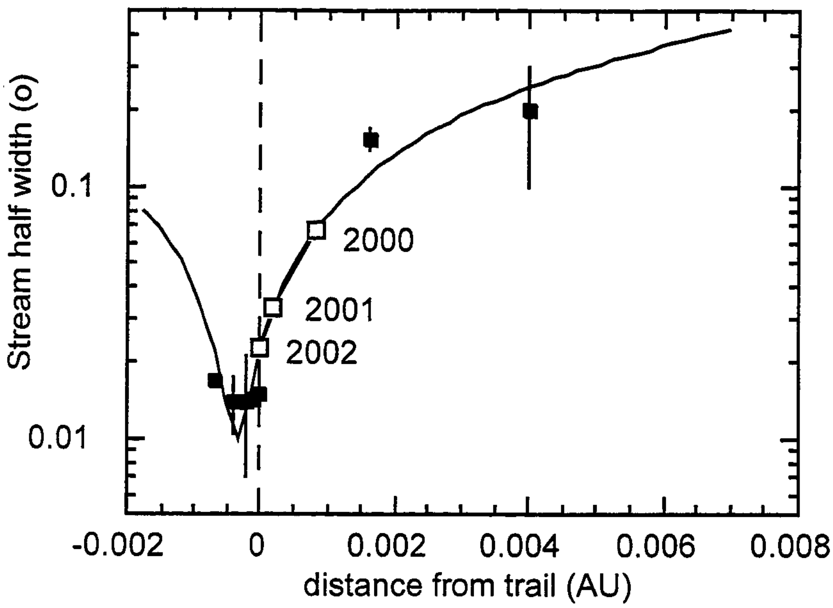

Figure 5 – The width of the profile as a function of the distance from the center of the trailet.

The width of the profile gradually increases if the Earth passes further away from the center of the trailet. Near the center is a core with a steep slope, which has a more shallow tail further out. The core is typical for the 1866, 1867, 1966, 1969, and 1999 profiles, while the profiles of 1998, 1965, and the second peak of 1999 are cases of further out. If we plot the width versus the distance to the trailet center (Y_0), as calculated by McNaught and Asher [5], then we find that (5) (solid line in Figure 5) does indeed fit the result. Note that the fit is not perfect, which suggests that individual trailet positions are uncertain by at least ± 0.0001 AU.

However, the calculated trailet pattern (together making up the comet dust trail) is shifted outward by about +0.0003 AU. The curve in Figure 5 should center on zero. We conclude that the Earth crossed about 0.0003 AU deeper into the debris trail ejected in 1899 than predicted. Unfortunately, that means that Earth will not cross quite as deep into the 1866 epoch trailet in 2001 and 2002, for which McNaught and Asher predicted peak rates of 10 000–35 000 and 25 000, respectively [5].

On top of that are two more factors that influence the peak rate in future years: (*i*) the rate of decrease of dust density away from the comet for a pristine trailet of 1 revolution, and (*ii*) the decay of dust density with each subsequent revolution.

Regarding (*i*), we have only the 1969 observations to base our discussion on (Figure 6). For that encounter, McNaught and Asher [5] calculated a dead-center trailet passage through a mere 1-revolution trailet. If we adopt the shift of +0.0003 AU, then, according to (6), the peak density at the trailet center would correspond to about four times higher a rate than observed, i.e., ZHR = 800. Similarly, we calculated the peak trailet density (in terms of ZHR) from all other storm and outburst profiles.

Furthermore, we assume that the dust density falls off inversely with the number of revolutions (N), as follows:

$$\mathrm{ZHR}^{\mathrm{t}}_{\mathrm{max}}(1\ \mathrm{rev.}) = \mathrm{ZHR}^{\mathrm{t}}_{\mathrm{max}} \times N, \qquad (7)$$

which is expected if the spreading is mainly due to differences in orbital period of the particles in the dust trailet. We also assume that all trailets are equal after 1 revolution. The result is shown in Figure 6, as a function of mean anomaly (time after passage of the comet). Dark points at small mean anomaly are from IRAS observations of the Comet Tempel 2 dust trail [6], scaled to match the Leonid shower data, to show how high the dust density might go up near the comet.

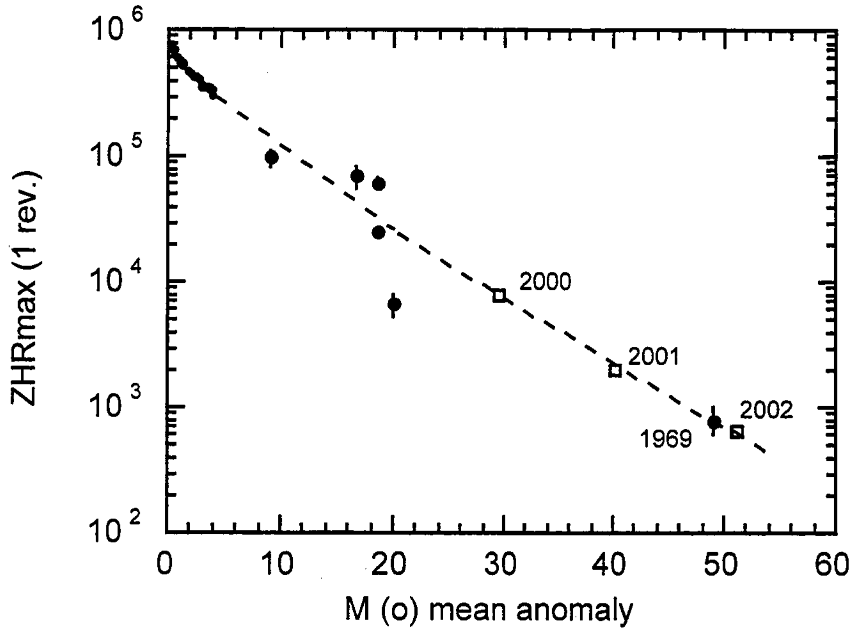

Figure 6 – Peak dust density in the trailet after 1 revolution, as derived from the flux profiles of past meteor storms and outbursts.

It is possible to predict the peak activity in 2000–2002 from the time since perihelion passage. Those moments are marked on the dashed line with an open square. The predicted peak rate follows from this by corrections according to equations (7) and (6). We find ZHR = 50 in 2000, ZHR = 50 in 2001, and ZHR = 40 in 2002 (1866 epoch ejecta only), whereby the width of the profiles should gradually decrease.

These would be Perseid-like showers, no meteor storms, but with all the charm of meteor outbursts: a brief episode of high rates. Observations in November 2000 will test the assumptions that went in the model and the predictions above. The next three years may help to measure how quickly the dust density falls off away from the comet, and each encounter will be a strong test for refining the theoretical model.

The video record is a treasure of information that can be analyzed further. Unlike the hybrid visual-video observation technique, such in-depth analysis is time-consuming, and results are not expected for some time.

Acknowledgments

We thank the visual observers who participated as the "flux team" onboard ARIA and Mike Koop, who operated the intensified cameras onboard FISTA. Visual observers were Dave Holman, Klaas Jobse, Gary Kronk, Michael Schmidhuber, Jane Houston, Kelly Beaty, Chris Crawford, and Peter Jenniskens, while David Nugent took care of real-time data transmission to the ground. Mike Koop, Morris Jones, and Pete Gural assisted in the visual examination of the FISTA tapes. The flux measurements in the Leonid MAC 1999 mission were supported by grants from USAF/XOR and the NASA Planetary Astronomy and Suborbital MITM programs.

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SPA Meteor Section: 1999 Leonids—Radio Results

Alastair McBeath

Details from radio observations submitted to the *SPA Meteor Section* during the 1999 Leonids are presented and discussed. A very strong but brief radio maximum was detected in the one-hour binning interval between 2^h and 3^h UT on November 18, 1999, in nearly all the available radio data. Using shorter time-bins, a remarkable similarity between the radio results and the *IMO* visual results already published [1] was found, even to some of the small-scale submaxima nearest the storm peak. Despite the very high visual and excellent radio activity, no Sporadic-E (Es) events near-coincident with the storm maximum were found. A small-scale experiment using ordinary car radios to detect the Leonid storm from Madeira is also briefly discussed.

1. Introduction

Significant radio observations have been reported for each Leonid return since 1994 in various places, including in previous numbers of this journal under the *SPA Meteor Section* masthead. A particularly detailed examination was possible for the 1996 return [2], for example. Results from 1997 and 1998, although showing a very notable Leonid presence, did not permit such a complete analysis. The Leonid storm of November 18, 1999 generated a much more useful set of radio data, however.

The radio results studied here were published in tabular form with equipment details in *Radio Meteor Observation Bulletins* (*RMOB*s) 76 and 77, dated December 1999 and January 2000, respectively. These were kindly provided by *RMOB* editor Chris Steyaert. R.B. Minton also provided an advance copy of his data with discussion of his observing system separately. The full list of contributing observers is as follows:

> Enric Fraile Algeciras (Spain), Michael Boschat (Canada), Maurice de Meyere (Belgium), Ghent University (Belgium), Werfried Kuneth (Austria), R.B. Minton (New Mexico, USA), Sadao Okamoto (Japan), Ingo Reimann (Germany), Ton Schoenmaker (La Palma, Canary Islands), Kiss Szabolcs (Hungary), Garfield Tsao (China), Ilkka Yrjölä (Finland), and Wim T. Zanstra (the Netherlands).

A series of postings to the *IMO News* e-mailing list by Kazuhiro Suzuki in Japan (various dates from November 10 onwards), which featured annotated radio results from November, were drawn on for comparison as well, but are not reused in this present work.

The usual procedures for examining raw radio results, as outlined in [2], were again followed, by comparing the shapes and characters of graphs based on the numerical data with one another and previous results, taking into consideration the known active radiants and their sky positions for the periods in question, and the locations of the observers. Comparison was also made from day to day of data collected using the same equipment, where such information was available. Since the intention was to concentrate on the period around the Leonid maximum, only results obtained between 12^h UT on November 16 to 12^h UT on November 19, 1999, are considered here.

2. Results and discussion

Figure 1 shows a series of six graphs collected by various observers in Europe (four), the USA and Taiwan (one each). The European observers were ideally-placed to catch the Leonid storm peak, and, for once, virtually all the available data sets coincided on a peak in the hour between 2^h and 3^h UT on November 18. Garfield Tsao's data from Taiwan show a very clear Leonid peak around 1^h–3^h UT, the difference in counts between the two hours being quite marginal. Most observers provided raw counts in hourly bins only, so greater precision was not expected immediately, but the near-perfect timing coincidence in the majority of data sets is a valuable confirmation of just how well the storm was detected by radio, at least from sites where the radiant was clearly visible above the horizon.

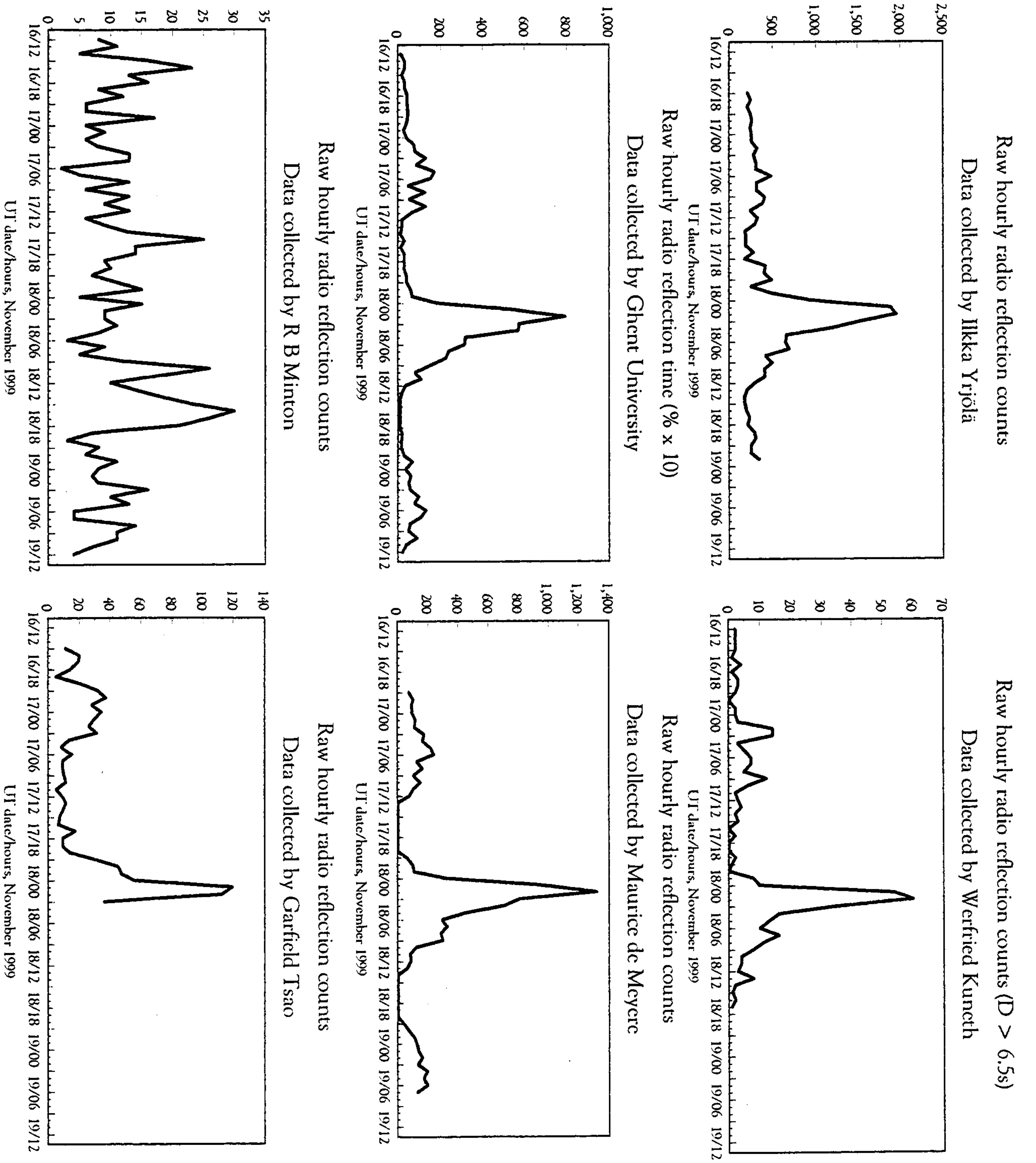


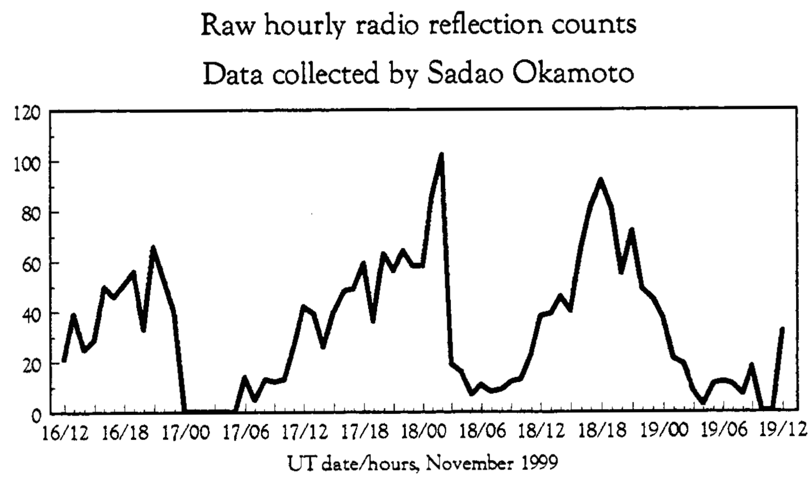
Figure 1 – Graphs of raw hourly radio meteor echo counts collected between 12^h UT on November 16, to 12^h UT on November 19, 1999, by various observers, as captioned. Zero counts (only seen in Werfried Kuneth's and Maurice de Meyere's data) and missing sections of line between the given times above indicate periods when the equipment was not operating. In all the graphs shown here, note the very different y-axes' scales. In Figures 1 and 2 though, the x-axes have all been deliberately scaled identically for easier comparison.

The shape of the graphs in Figure 1 nearest the Leonid storm peak time show different skews because of the varying radiant elevation, which was more favorable for Far-Eastern sites in the hours preceding the storm, while, in Europe, the radiant was well-placed from about the time of the storm maximum onwards. This means that although the general character of the steep rise and fall from the peak is similar to the visual results, the skew of the ZHR graph around the Leonid storm peak (Figure 3 in [1]) cannot be compared directly to these radio graphs.

R.B. Minton's data do not show a clear maximum spike on November 18. He, along with most observers in mid and western North America, was in about the worst place possible, as the Leonid storm was over long before radiant-rise there. However, the secondary peak reported in [1] as occurring around $16^h \pm 1^h$ UT on November 18 was noted as R.B.'s most active spike over the Leonid peak epoch, exactly at 16^h UT. The detected rates then persisted at only somewhat reduced levels between 15^h and 18^h UT at least.

A similar peak at around 16^h–19^h UT on November 18 can be seen in the Japanese data (Figure 2) in both all-echo and longer-duration echo counts. The highest raw counts were found at about 18^h UT in all the available Far-Eastern data, but the counts at 16^h UT are considerably more interesting owing to the much lower radiant elevation over Japan then. The main storm peak around 2^h UT on November 18 is clear in Sadao Okamoto's all-echo results despite a westering radiant by then, but pales rather when we look at the longer-duration counts, where a sharp, strong maximum was recorded at 22^h UT on November 17.

There are no corroborating comparable data available to check then, unfortunately—the Leonid radiant had yet to rise for European observers—and 21^h–22^h UT is when the radiant culminates from Japan in mid-November, so it is advisable to be cautious.



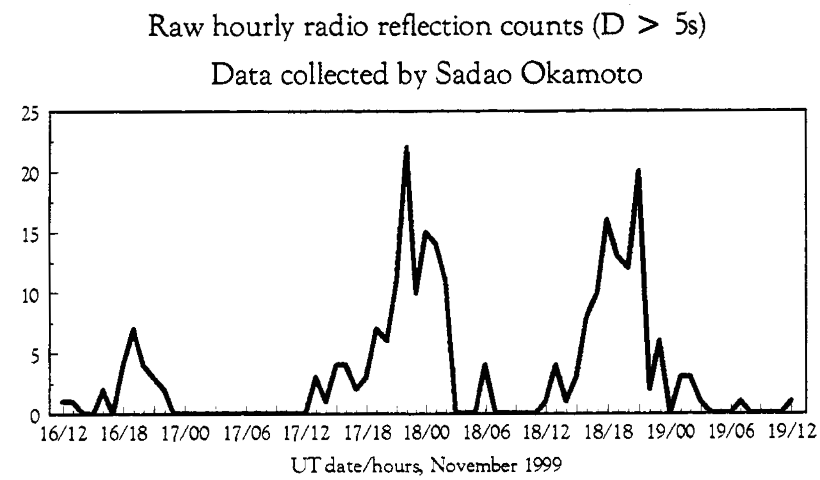


Figure 2 – Raw hourly radio meteor echo count graphs, all-echoes (*top*) and longer-duration echoes ($D > 5$ s; *bottom*), from data collected by Sadao Okamoto between 12^h UT on November 16 to 12^h UT on November 19, 1999. In the all-echoes graph, zero counts indicate periods when data was lost because of interference (the break on November 17) or Es (two hours only on November 19). Zero counts outside these intervals in the longer-duration graph show actual zero echo rates.

A similarly sharp peak spike was seen on November 18 at 21^h UT in Sadao's data, for instance. The fact that the November 17, 22^h UT event does not show up in the all-echo data, while that on November 18, 21^h UT does, may imply an increased flux of larger meteoroids/brighter meteors around 22^h UT on November 17. This would be at $\lambda_\odot = 235\overset{\circ}{.}12$–$235\overset{\circ}{.}16$ (eq. J2000.0) if so, a time not yet investigated in the preliminary 1999 global visual results [1].

Two European observers, Ingo Reimann and Kiss Szabolcs, provided raw echo counts at less than a one-hour binning interval near the expected Leonid peak on November 18. Their data are shown graphically in Figure 3. Ingo's ten-minute counts show some small-scale structure which hints at the forms seen in the visual data, and these become still clearer when we examine Kiss's five-minute counts. Indeed, a direct comparison, choosing a judicious graph scaling, shows a near-perfect coincidence in timing between Kiss's five-minute raw radio counts and the *IMO* visual ZHRs (Figure 4). This coincidence is even to some of the small-scale features identified in [1], including those at $\lambda_\odot = 235\overset{\circ}{.}259$, $\lambda_\odot = 235\overset{\circ}{.}307$, and $\lambda_\odot = 235\overset{\circ}{.}346$, which suggests these visual features are almost certainly genuine shower aspects. An investigation of still shorter time-scale radio data might well confirm an even better series of coincidences.

The maximum period in Kiss's data is not quite as sharp as in the overall visual graph, though this was not unexpected from visual data in southern France and southern Spain, which also showed maximum rates persisting for a similar period at near-comparable levels (see Figure 4 of [1]). The 5-minute radio counts reach their greatest level in the 2^h05^m–2^h10^m UT bin ($\lambda_\odot = 235\overset{\circ}{.}286$–$235\overset{\circ}{.}29$), but, again, this is much as expected, allowing for an approximate topocentric correction of $+5^m$ for a site in Hungary, as outlined by Rob McNaught in [3].

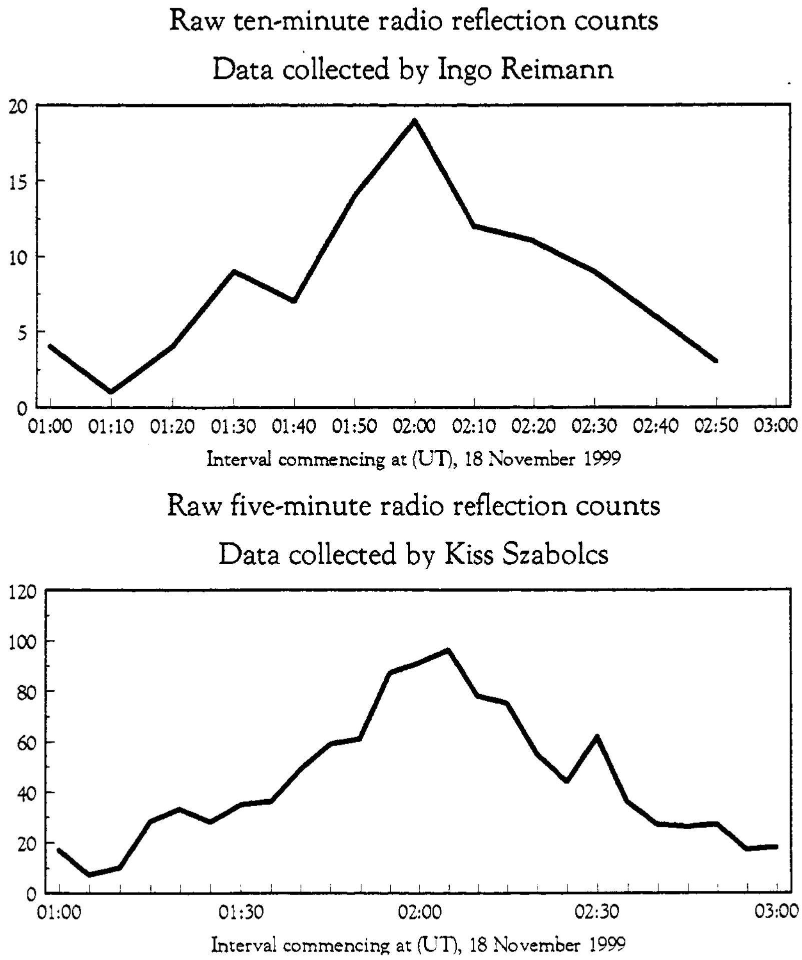


Figure 3 – Graphs of raw radio meteor echo counts collected by the indicated observers during the shown binning intervals, between 1^h and 3^h UT on November 18, 1999. Only the two x-axes scales are identical.

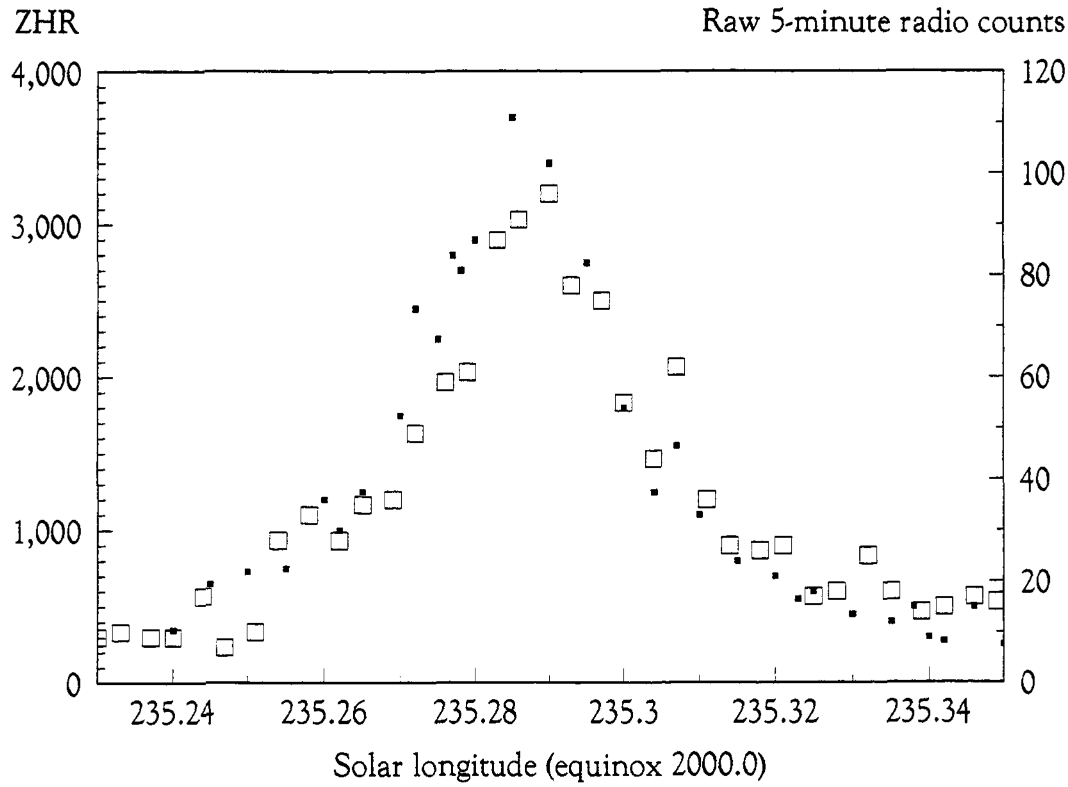


Figure 4 – *IMO* visual ZHRs (small filled squares; simplified to approximate five-minute intervals, and with error bars removed; data from Figure 3 of [1]) scaled using the left-hand y-axis, directly compared with raw five-minute echo count data-points from Kiss Szabolcs's data shown in Figure 3 here (larger open squares), scaled using the right-hand y-axis, for the period between November 18, 0^h43^m to 3^h34^m UT, 1999. Times are given in degrees of solar longitude.

Interestingly, there was no sign of any significant Es activity around the Leonid storm maximum in 1999. In 1996, when visual Leonid ZHRs were of the order of 40–50 at best, it seemed as if the Leonids had created an almost instantaneous Es event for the radio observers [2], as had been observed with other unusual meteoric events previously. In 1997 and 1998, very little evidence of Es was found associated with the Leonid maximum, however, and that trend continued in 1999. Indeed, Werfried Kuneth, one of the radio observers who regularly provides detailed results for Es and other radio interference as well as meteor echo counts, not only found no Es during the 1999 Leonids, but also made the point that good Leonid radio rates were detected for barely two hours, as compared with over eight hours during the Leonid fireball outburst of 1998. Clearly, there is rather more to Es production than simply large numbers of meteors occurring in the atmosphere at about the same time.

Another curiosity is that the peak Leonid raw echo counts have been of similar orders of magnitude for some years, as far as equipment changes allow us to tell. The radio rates in 1999 were not significantly different in strength to those in 1998, for instance, though the best 1999 visual ZHR was roughly ten times higher than in 1998. None of the 1999 radio observers reported any sign that their equipment was saturated by meteor echoes during the Leonids, which, with the lack of Es, gives further support to the unusual visual magnitude distribution during the storm, and probably indicates a real absence of any small meteoroids/faint meteors in the 1999 storm stream component.

3. Observations from Madeira using car radios

After completing the bulk of this analysis, an additional data set from Madeira became available from one of its organizers, Pedro Augusto of Madeira University. Some details of the method and preliminary results were published in [4]. The basic principle was to use an over-the-horizon commercial transmitter on the Canary Islands, about 700 km south of Madeira, as a source, and ordinary car radios as receivers. Madeira was unfortunately clouded-out during the Leonid storm, and although originally intended only as a back-up plan, this radio method allowed Madeiran observers to "see" the storm through the clouds very well. Observations ran from 21^h15^m to 4^h05^m UT on November 17-18, and a clear peak is apparent in the raw counts between 1^h45^m and 2^h15^m UT. The maximum count number occurred in the ten-minute interval centered on 2^h00^m UT. Twenty minutes of data were lost from 2^h15^m to 2^h35^m UT, but the counts immediately after this were well down on the storm level. It is interesting to see that the numbers increased slightly again after 3^h05^m UT until the observation's end, which may reflect the higher Leonid radiant elevation by that time, perhaps coupled with the typically increasing sporadic rates in the hours shortly before dawn. Six echoes longer than 10 s duration were recorded between 0^h35^m and 3^h45^m UT, four of those in the 50 min interval between 2^h55^m–3^h45^m UT. The observers on Madeira hope to repeat their experiment in greater detail, possibly alongside a dedicated radio meteor receiver system, in November 2000.

Acknowledgments

My grateful thanks are extended to all the radio observers active during the 1999 Leonids who provided the data used here, and to other correspondents for their useful comments.

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SPA Meteor Section: 1999 Leonids—Visual and Imaging Results

Alastair McBeath

Details of visual, video, and photographic observations submitted to the *SPA Meteor Section* between November 16-17 and 18-19, 1999, are given. Especial emphasis is made of the results obtained by UK observers in spite of generally poor skies on November 17-18, which included determining a photographic and video radiant position for the Leonids around $\alpha = 150° \pm 3°$ and $\delta = +21° \pm 2°$ for November 18. Some visual magnitude, rate, and train results are given, along with a short discussion of some unusual bright flashes seen on November 16-17, which most likely resulted from over-the-horizon lightning.

1. Introduction

The first *SPA Meteor Section* results paper on the 1999 Leonids dealt with the radio reports received [1]. This second paper discusses the visual and video/photographic imaging data recorded between November 16-17 and 18-19, 1999, inclusive. A third paper will conclude the Section's reports on the 1999 Leonid storm with a compilation of personal recollections on the event.

It would of course be pointless to pretend that any single group could compete with the data collection abilities and detailed analyses possible for the *IMO*. As Table 1 demonstrates, the *SPAMS* Leonid total was less than one-tenth that available for the preliminary *IMO* analysis [2]. However, a discussion article like this may show what smaller groups can achieve, and can discuss items *IMO* visual reports do not routinely include—for example, meteor train details.

Table 1 – Visual, photographic, and video hours and meteor totals recorded between November 16-17 to 18-19, 1999, inclusive, including a partial breakdown of visual meteor types.

Visual	STA	NTA	AMO	LEO	Meteors	Photo	Trails	Video	Trails
$154^h\!.8$	40	79.5	34	24 409	25 350	$6^h\!.4$	53	$36^h\!.2$	1463

The following lists comprise all observers active and reporting to us (directly or occasionally via a third party) during the Leonid epoch discussed, regardless of whether they were successful in seeing anything of the shower or not. The first list is of UK-only observers, the second of overseas ones. In the UK listing, all the people involved were in England unless noted otherwise, and were visual observers only unless accompanied by the abbreviations "Ph" (photographic) or "Vi" (video), indicating those results were also provided. In the overseas listing, the same abbreviations apply, with the addition that "AKM" indicates members of the German *Arbeitskreis Meteore* group, whose data was extracted from their journal *Meteoros* 2:12 (1999), kindly provided by Ina Rendtel.

The UK-only observers are as follows:

Pamela Armstrong (Scotland), Mark Bailey and others (Northern Ireland), Lyndall Barbour, Matthew Barrett, Neil Bone, Tom Crann, Clive Down (Wales), Steve Dunn, Keith Edwards and colleague (Scotland), Guy Fennimore (Wales), Ami Frydman, David Frydman, Dave Gavine and others (Scotland), Shelagh Godwin and others, Peter Grego, Lucy Hague (Scotland), Chris Hall and others, James Hamilton, Eva Hans, Kath Hodges, Mike Holmes and others (Scotland), Martin Ince, John Lambert, Jeff Lashley (Vi), Richard Livingstone (Wales), Tony Markham, Nick Martin, and others (Scotland), Michael Martin-Smith (Ph), Alastair McBeath (Ph), Peter McBeath (Ph), Roy McBeath, Simon McBeath, Tom McEwan (Scotland), John McFarland and others (Northern Ireland), Michele Minett, Jacqueline Mitton, Neil Mortimer, Dave Newton (Ph), Michael Oates, Tom Patton (Scotland), Trevor Pendleton, Ian Ridpath, Ian Rigney, Maurice Robinson, Graham Rule and others (Scotland), Neville Saunders (Wales), Paul Saunders (Ph; Wales), Brian Sidney, George Spalding, Stanley Toyn, and Bill Ward (Scotland).

In addition, media reports were forwarded by various correspondents from two sites in England, one in Norfolk, the other in Kent.

The overseas observers are as follows:

Rainer Arlt (AKM; Spain), Stan Armstrong (Ph; Morocco), David Asher (Jordan), Pierre Bader (AKM; Germany), Godfrey Baldacchino (Malta), Jay Brausch (North Dakota, USA), Tim Cooper (Belgium), John J. Costello (Ph; Philadelphia, USA), Maggie Daly (Ph; Canary Islands), Martin Galea de Giovanni (Malta), Jack Drummond and others (New Mexico, USA), David Dunham (Maryland, USA), Andrew Elliott (Vi; Portugal), Frank Enzlein (AKM; Germany), Steve Evans (Ph, Vi; Portugal), Mildred Formosa (Malta), M. Gerding (AKM; Vi; Germany), Andrei Dorian Gheorghe (Romania), Valentin Grigore (Romania), Marc Gyssens (Belgium), Morton Henderson (Ph; Portugal), Arno Hesse (AKM; Germany), Claudia Hinz (AKM; France), Wolfgang Hinz (AKM; France), Nick James (Israel), Carl Johannink (Spain), Mark Kidger (Spain), André Knöfel (AKM; Spain), Ralf Koschack (AKM; Spain), Detlef Koschny (AKM; Spain), Sylvio Lachmann (AKM; Spain), Marco Langbroek and others (France and Spain), Hartwig Lüthen (AKM; Canary Islands), Michael Maunder (Ph; Bali), Rob McNaught (Ph; Jordan), R.B. Minton (New Mexico, USA), Koen Miskotte (Spain), Sirko Molau (AKM; Vi; Spain), Sven Näther (AKM; Germany), Mirko Nitschke (AKM; Vi; Canary Islands), Guy Ottewell (South Carolina, USA), Alexei Pace (Malta), Gelu-Claudiu Radu (Romania), Ina Rendtel (AKM; Germany), Jürgen Rendtel (AKM; Vi; Spain), Vanya Rodiger (Croatia), Paul Roggemans (Belgium), Marion Rudolph (AKM; Germany), Robin Scagell (Ph; Canary Islands), Ulrich Sperberg (AKM; Vi; Canary Islands), Umberto Mule' Stagno (Malta), Paul Sutherland (Ph; France), Manuela Trenn (AKM; Spain), Mihaela Triglav (Slovenia), Jan Van Elst (Belgium), Elfi Vints-Laridon (Ph; Spain), Mark Vints-Laridon (Spain), Roland Winkler (AKM; Canary Islands), Nikolai Wünsche (AKM; Germany), and Joseph Zammit (Malta).

2. UK observations on November 17-18

Disappointingly for many observers, in the southern half of England especially, the clearer skies promised in all the national TV and radio weather forecasts for at least part of the post-midnight period on November 17-18 failed to materialize. Instead, frontal clouds and rain or drizzle were all that could be seen. As most UK-national media are based in south-east England, this rapidly translated into media reports of "virtually the whole British Isles" being clouded-out for the Leonid storm.

It was obvious to those of us who had seen something of the storm, including myself, that this was incorrect, and as positive reports rapidly began to appear from other places, a more useful appreciation of the night became apparent. Figure 1 shows the distribution of UK observers' sites on November 17-18 (multiple observers or those at very nearby sites are generally indicated by only a single symbol), which gives a very clear indication of where the best weather conditions were: across northern England and south-central Scotland.

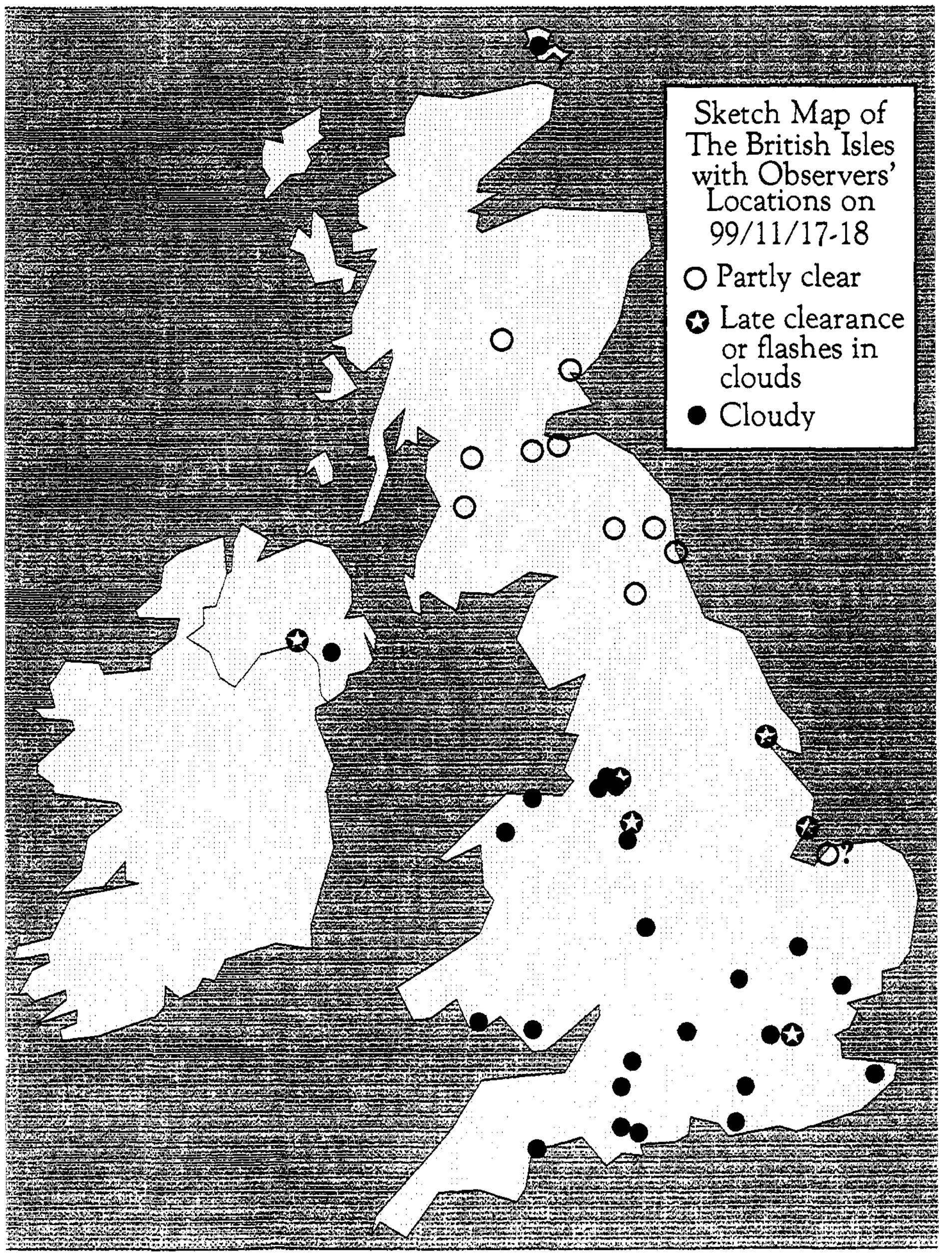

Figure 1 – Site locations for UK observers on the Leonid maximum night. For further details, see text.

The partly clear site marked with a question mark on the north coast of East Anglia represents a positive report forwarded only from media sources. The observer(s) have not proved otherwise traceable, regrettably, so the sky conditions there remain unknown.

Most of the "late clearance" symbols indicate that skies improved enough for some observing only after the Leonid storm had passed, generally after 3^h–3^h30^m UT, except for that in London, where 9-year old Ami Frydman spotted a lone possible Leonid in a cloud-gap soon after 23^h UT. The latest clearance was that shown in the cluster of four symbols near Manchester, after 5^h30^m UT, caught by the perseverance of observer Ian Rigney. The "late clearance" symbol a little way south of this cluster was from a site in the Pennine Hills where clouds thinned enough to allow several observers with Chris Hall to see some meteors in the post-storm phase, as well as several bright flashes in the clouds from unseen meteors, but proper meteor watching was not practical. The one "late clearance" symbol in Northern Ireland was a group from Armagh Observatory with Mark Bailey, who endured overcast skies and drizzle nearly all night, but reported three distinct flashes in the cloud-sheet at about 2^h10^m UT, 2^h30^m UT, and 2^h45^m UT. The 2^h30^m UT event was bright enough to be seen by the whole group. Similar flashes in clouds were reported by observers at other sites with partly clear skies in northern England and Scotland. Occasionally, some part of the meteor's trail was also seen, as it shot into a patch of clearer sky.

Those who did enjoy better fortune generally found the sky to be overcast for the first half of the night, with what clearer periods there were coming along only just in time for the storm peak, shortly before 2^h UT. Even so, clouds were always a problem. At Morpeth in Northumberland, my average cloud cover percentage (field of view, not the whole sky) was 55% for the night, for instance. Conditions were often very variable only a few kilometers apart as well. There is no consistent pattern in the better observing times between four separate groups watching from different parts of Edinburgh, for example, yet the greatest distance between any was just 7 km. Further north in Dundee, Keith Edwards enjoyed the storm in patchy skies but a colleague living on the opposite side of the city saw only clouds all night!

These conditions hampered attempts to compute ZHRs from UK data, though it was clear to all who could observe then that the very highest Leonid rates were seen between 2^h00^m and 2^h15^m UT, bracketed by a period lasting from about 1^h50^m to 2^h40^m UT when rates were still exceptionally good. Distinctly lower numbers were found beyond these times. Observed rates at best (bearing in mind field-of-view cloud cover percentages never less than 40–70%) were 6–8 Leonids per minute, with several observers reporting 3–5 Leonids appearing almost simultaneously in even small cloud gaps on occasion.

Few people attempted any photography during the storm because of the poor skies, and most of those who did were unsuccessful. At Morpeth, though, my father Peter recorded five Leonid trails on just two 8-minute exposures between 2^h08^m and 2^h25^m UT, a particularly pleasant surprise as we were only using 200 ISO color print film at the time. Most of the trails were faint, but one magnitude $-3/-4$ event was recorded, too.

At Derwent Reservoir, 40 km southwest of Morpeth, Jeff Lashley was observing with a group from *Sunderland Astronomical Society*, using his CCD meteor video system. His camera had a 25° effective field of view, recording stars to magnitude +4 or +5 and meteors to about +3 (note these magnitudes are not corrected for the IR sensitivity of the system, so are not equated precisely with typical visual magnitudes). Tests with this system on non-major shower nights have yielded average video meteor rates of about 2 per hour. In 2 hours 10 minutes effective time on November 18, between 1^h55^m and 4^h17^m UT, Jeff recorded 43 trails; 40 Leonids, 2 Taurids, and 1 sporadic. Twenty of the Leonids occurred between 1^h55^m and 2^h21^m UT at up to 3 per minute (2^h11^m UT). Also Jeff's group had problems because of very variable sky conditions (it is depressing to watch all but two stars in Orion's belt disappearing into the clouds on the tape, for example), but, allowing for these, the drop-off in Leonid rates is very clear, especially after 2^h40^m UT. A spectacular Leonid fireball (of maybe $-6/-8$) was caught fully in the field of view at 3^h49^m UT, leaving a distinct persistent train for around 2 s on the video.

Jeff concentrated on trying to video areas around Auriga-Taurus-Pisces and Orion, while, at Morpeth, our better skies were to the north in Ursa Major and Draco, so by chance we collected sets of trails at almost right-angles to one another.

Using the five photo trails and eleven of the better-sky video trails, it was possible to derive an approximate radiant from the period 2^h01^m–3^h55^m UT on November 18 at $\alpha = 150° \pm 3°$ and $\delta = +21° \pm 2°$. This is pleasingly very close to the video radiant derived from 633 video trails at $\alpha = 153\overset{\circ}{.}6 \pm 0\overset{\circ}{.}1$ and $\delta = +21\overset{\circ}{.}9 \pm 0\overset{\circ}{.}1$ around the same time in *AKM* data [3], and is especially impressive considering the very poor sky conditions the British observations were made under.

3. Observations from around and across the storm

One frustrating aspect of the 1999 Leonids for southern-UK observers, which was also found in some other parts of Europe, was that skies were significantly better on both November 16-17 and 18-19 than on 17-18.

Godfrey Baldacchino commented that, on Malta, November 17-18 was probably the only night in November nothing astronomical could be seen!

As usual, the early winter weather in Europe produced problems for everyone. In the north, Belgian skies were patchy, though everyone reporting from there (Tim Cooper, Marc Gyssens, Paul Roggemans, and Jan Van Elst) saw something during the storm. In Germany, Ina Rendtel and Marion Rudolph drove 200 km west out of Potsdam seeking better skies, but managed barely 35 minutes observing between them all night. South and east in Romania, Gelu-Claudiu Radu drove over 400 km in total overnight, being rewarded with one brief gap only soon after 2^h UT, but even then seeing 10 Leonids in 4 seconds! Elsewhere in Romania, conditions were worse, though Andrei Dorian Gheorghe in Bucharest managed to spot a few flashes probably due to bright meteors in a generally overcast sky. Much of the Balkans fared no better. Both Vanya Rodiger in Croatia and Mihaela Triglav in Slovenia were stuck with heavy snowfalls blocking the roads, preventing them even leaving home to hunt for better skies.

Those North-Europeans who decided they wanted the chance to see the Leonid storm under good skies never planned on staying at home anyway, and most had sensibly opted for sites in the Near East, North Africa or the Canary Islands well ahead of time, with the southern parts of Portugal, Spain, and France often chosen as good compromise alternatives. Those who were able to take advantage of late weather news were often able to get cheap flights to southern Spain especially, where the forecast better skies did appear. From such places, the storm was a wondrous sight, with single-minute visual counts reported to us in the range of 40–75 Leonids nearest the storm's height.

Drawing on all the available *SPAMS* results, Figure 2 shows the average Leonid ZHRs derived across the storm peak. The ZHR bins on November 17-18 are in variable-length intervals (15–95 minutes long) intended to emphasize both the storm's height, timing, and sharpness. The highest mean ZHR was 3370 ± 140 in the interval 2^h00^m–2^h15^m UT.

Leonid ZHRs were clearly much lower away from the storm maximum, but it is interesting that, even so, at 15–30 they were still around or up to twice the value seen at the shower's very best in years well away from the storm returns. North-American observers were generally unimpressed by this, however. Indeed, some comments made it clear that many had hoped storm rates would manifest over the USA again, which led to some disappointment, although no serious predictions suggested a Leonid storm was likely in time to the radiant's nighttime visibility over America. Despite this, observations made away from the storm do suggest rates were occasionally quite variable on short time scales. Two observers in south Wales on November 18-19, Paul and Neville Saunders, noted casual Leonid rates of almost one per minute between about 4^h15^m and 4^h30^m UT, for instance, and some other observers earlier that night found similar, lesser, variations. Looking at short time bins (5–15 minutes), these variations could carry ZHRs up into the 50–100 range, but the hourly average for the night as a whole was around 30 ± 10.

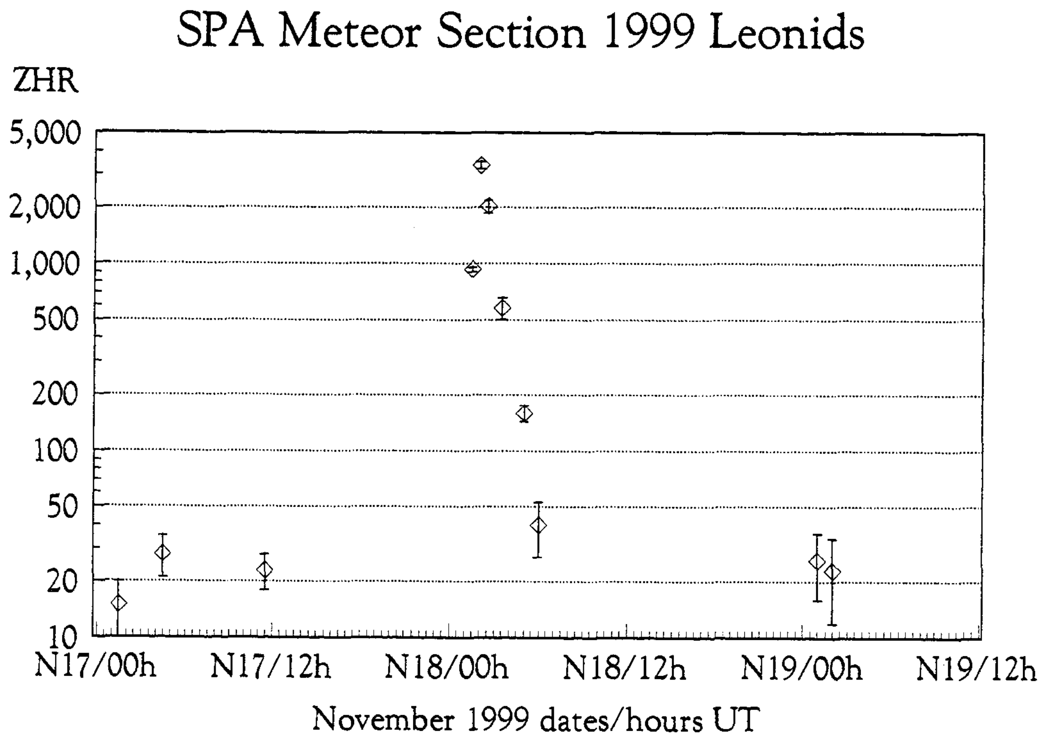

Figure 2 – Mean Leonid ZHRs from November 16-17 to 18-19, 1999, extracted from *SPAMS* data, with standard error bars appended. Note the y-axis scale is logarithmic in order not to lose the low-end ZHRs away from the storm peak. An r-value of 2.3 was used for the calculations, after the value assumed in [2].

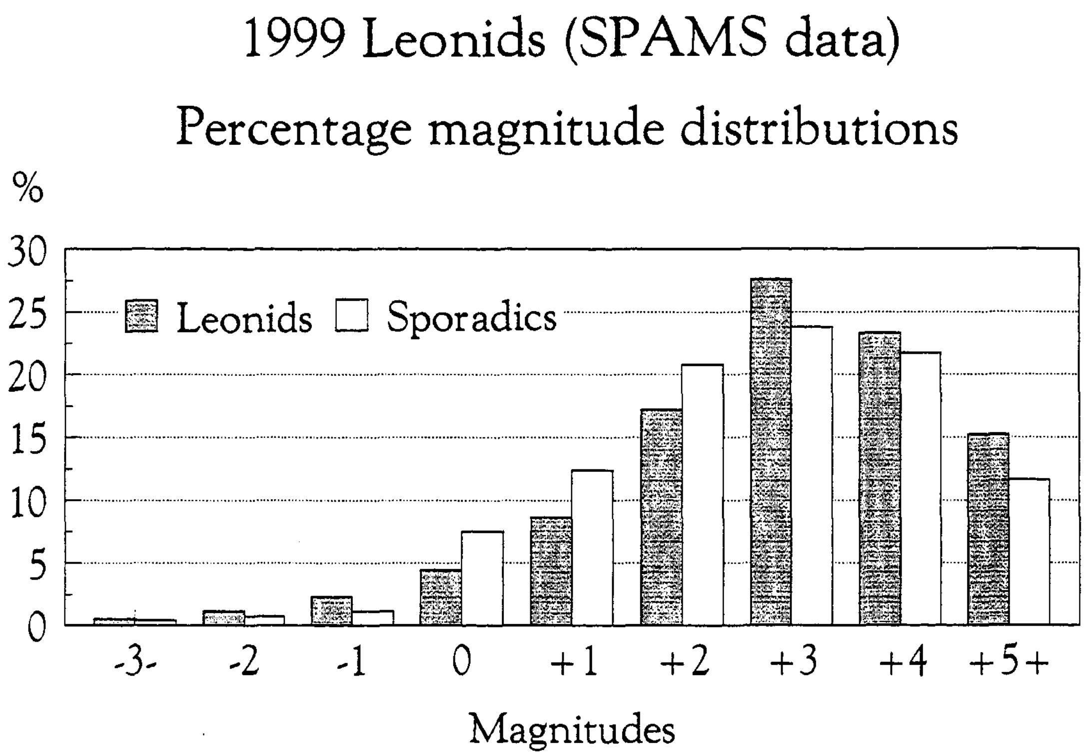

Figure 3 – Percentage magnitude distributions for 838 Leonids seen between November 16-17 and 18-19 (the majority on November 17-18) and 267 November sporadics (mostly seen contemporaneously with the Leonids). The mean limiting magnitudes for these observations was +5.94, and corrected mean magnitudes for the Leonids and sporadics respectively were +3.47 and +3.24.

As already noted in [2,3], the Leonid magnitude distribution during the near-storm phase especially was rather unusual in 1999. Looking at the Leonid percentage magnitude distributions in Figure 3, based on better-sky *SPAMS* data (limiting magnitude of +5.5 or better, cloud cover less than 30%, the latter a minor increase from normal because of the very variable UK conditions) shows a surprising similarity to the sporadics. The sporadic distribution looks quite normal, but we would typically expect to see the Leonid magnitudes peaking in the +2 to +3 bins, not the +3 to +4 ones. A very marked cut-off was seen between the +5 to +6 bins not demonstrated here, which again was as found in other 1999 observations.

Poor conditions and the fact that very few people routinely reported trains during the storm thanks to the very high Leonid activity means the details in Table 2 need to be treated with caution, but give an indication of a possibly weaker showing of Leonid trains consistent with their overall fainter magnitudes in 1999.

Table 2 – Global train percentages and mean durations in seconds per magnitude class for the Leonids on November 16-17 to 18-19, 1999, and the November sporadics. Train details were available for only 121 Leonids from the magnitude distributions and 167 sporadics. Blanc entries indicate that either the field is not applicable or that the information was not available.

Magnitude	-3^-	-2	-1	0	+1	+2	+3	Tot	%
LEO train %	67	100	50	64	45	35	17	40	33%
LEO duration		$4\overset{s}{.}7$	$2\overset{s}{.}8$	$1\overset{s}{.}9$	$1\overset{s}{.}9$	$1\overset{s}{.}5$			
SPO train %	0	100	50	17	18	8	3	11	7%
SPO duration		$4\overset{s}{.}0$	$4\overset{s}{.}0$	$1\overset{s}{.}8$	$1\overset{s}{.}5$	$1\overset{s}{.}0$	$0\overset{s}{.}8$		

4. Fireballs, flashes in clouds, and lightning flashes

One thing was immediately apparent to everyone who saw something of the wonderful Leonid fireball night of November 16-17, 1998, who also saw some part of the Leonid storm in 1999—the relative paucity of fireballs in 1999. Some initial reports suggested no fireballs at all had happened during the storm, though this was clearly incorrect as demonstrated by photographic, video, and visual reports from the storm made elsewhere, but it seems this impression was simply a matter of luck.

On the Canary Islands, in some parts of Spain and Morocco, virtually no fireballs were seen at all. Mark Kidger in Spain reported no meteor brighter than magnitude -1 from almost 800 Leonids, something that is borne out by other visual reports and photographic data. For instance, Robin Scagell on Tenerife recorded just 19 faint to very faint Leonid trails in 1 hour and 51 minutes of exposures using 1600 ISO color film and a 20 mm $f/2$ lens. He felt this was comparatively poor by contrast to our efforts at Morpeth using a much slower film. Stan Armstrong in Morocco ran off three hours of fish-eye and 28 mm $f/2.8$ lens exposures during the storm peak, but recorded no trails at all.

In southern France, however, Paul Sutherland caught a superb magnitude -14 Leonid bolide at $1^{h}56^{m}$ UT (which was also photographed from other sites in southern France and northern Italy), a second Leonid fireball of perhaps $-6/-8$, a magnitude 0 Leonid and a couple of fainter Leonid trails on a single fish-eye exposure lasting only three minutes! UK reports mention several fireballs up to about $-8/-9$, but clearly nowhere near as abundantly as in 1998, some partly or wholly in clouds.

Mark Kidger raised the very valid point in his correspondence that some of the cloud-flashes may have been the result of lightning, rather than meteors. Some Spanish reports, especially from the north-eastern region of Catalonia had reported flashes too, which after much discussion were largely demonstrated to have been the result of lightning flashes from thunderstorms.

The Romanian reports of cloud-flashes during the Leonid storm may have been lightning, but it is curious that none of the nocturnal lightning photographers there (most of whom are also meteor observers) reported any lightning flashes at that time.

The flashes seen in Northern Ireland might have been lightning as well, but there were no reports of thunder there or indeed at any of the UK sites from November 17-18. The frontal system over the central and western UK seems to have been only moderately active (reports are of drizzle or steady rain, not torrential downpours or hail that might be linked with thunderstorms, for example), and, although there were shower clouds over the North Sea and near the eastern coasts of Scotland and England for much of the night, the sites here tended to report definite Leonid fireball or bright meteor sightings, sometimes partly in clouds, as well as localized flashes in the clouds from unseen meteors.

Some observers were able to contrast these with flash events witnessed from various UK sites in clear skies from north-east England south to Essex in East Anglia and inland as far as Sheffield on November 16-17 between about 23^h and 3^h UT. These suggested over-the-horizon lightning was occurring from a thunderstorm cell some way out in the North Sea probably east of Norfolk in northern East Anglia. A few occurred near-simultaneously with definite meteor sightings, and some flashes lit up distant cloud-tops, but most were simply sudden, brief brightenings of the sky, usually in one direction, out to sea. It seems improbable these flashes could have all been unseen meteors, persisting for several hours as they did without a single fireball sighting, and a lightning source is far more plausible.

It should be noted though that several fireballs were seen in the local evening sky of November 16-17 from sites across the north-eastern to northern-midwestern USA. The brightest of these was seen from at least eight states between New York and Maryland on the east coast inland to Wisconsin and Illinois and occurred around 0^h05^m UT. It was a spectacularly brilliant, fragmenting bolide.

David Dunham (lucky enough to see the bolide while with all his meteor video equipment to hand, but unlucky enough to have it neatly stored in his van while he was driving along at the time!) reported a fainter magnitude -3 event around 0^h21^m UT, and there are reports that other lesser fireballs were apparent near this time too (which often happens after a bright meteor sighting commonly due to mistakes in giving timings for the main meteor), so it is not clear how many events were represented here in total.

The timing coincidence with the UK flashes is probably nothing more than by-chance, but one or more possible distant, unseen fireballs cannot be absolutely ruled out in the UK instance because of this.

Acknowledgments

I am as always delighted to thank all the observers and correspondents who reported results from the 1999 Leonid epoch.

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Daytime Leonids Observed from Japan

Masayuki Toda, Masayuki Oka, Takema Hashimoto, Hirotaka Serizawa, Kazuhiro Osada, Kouji Maeda, Takashi Sekiguchi, Ryosuke Morita, Masaaki Takanashi, and Yoshihiko Shigeno

A Leonid outburst was observed around 2^h UT on November 18, 1999, in Europe [1]. At the same time, around 11^h a.m. Japan Standard Time (JST), several observers recorded Leonids in Japan, though it was daylight.

1. Observation report

Kouji Maeda recorded an increase of meteoric radio echoes and attributed it essentially to daytime meteors. In response to the request of Maeda, four observers in the Shizuoka Prefecture started observing. They shaded the direct sunlight, and then noted the times of observed meteors accurately.

Table 1 shows the results of the observations conducted by eight experienced meteor observers. Their locations range over about 700 km from east to west in Japan. The positions of the estimated radiants prove that the meteors are indeed Leonids. However, it was impossible to estimate meteor magnitudes because there was no object for comparison.

Table 1 – Hourly Rates of the Leonids during Japanese daytime of November 18, 1999.

Observer	Location	0^h– 1^h UT 9^h–10^h JST	1^h– 2^h UT 10^h–11^h JST	2^h– 3^h UT 11^h–12^h JST	3^h– 4^h UT 12^h–13^h JST
K. Osada	Shizuoka	1			
T. Sekiguchi	Saitama	2			
K. Maeda	Miyazaki		5	9	
R. Morita	Yamanashi			1	1
M. Oka	Shizuoka		1	10	
T. Hashimoto	Shizuoka			9	1
M. Toda	Shizuoka			3	2
H. Serizawa	Shizuoka			1	
Radiant elevation	Shizuoka	45°	32°	20°	8°

2. Conclusion

Venus has an apparent magnitude of −4, but is not easily observable in the daytime. Therefore, meteors which are visible under these conditions should have a magnitude of at least −6. Ten meteors were reported within one hour from 11^h a.m. (JST). On the other hand, only one magnitude −6 meteor was observed in Spain during the Leonid storm over Europe [2], and only one meteor per hour of magnitude −6 or brighter was observed from Egypt [3].

This indicates that the emission of light of the daytime meteors differs from the meteors observed at night. For example, the gas and dust from the meteors may reflect the sunlight. It was also reported that the meteors appeared visually like a short beam rather than a moving light spot.

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Editor's comment

While the observations reported above are intriguing, due caution is always required when interpreting visual phenomena at the edge of what is discernable.

Leonid Radiants Determined by Double-station TV Meteor Observations

Yoshihiko Shigeno, Hiroyuki Shioi, and Shoichi Tanaka

The radiant of a meteor shower is concentrated within a narrow area when the parent comet recurs. Double-station observations of the Leonids by TV proved that the radiant varies little over several years and that there is a number of radiants spread over a larger area.

1. Introduction

Our double-station TV meteor observations proved that the spread of radiants of the Perseids and Geminids ranges from $\pm 0\overset{\circ}{.}4$ to $\pm 0\overset{\circ}{.}6$ in standard deviation, as shown in Table 1.

However, it was reported that the spread of meteor shower radiants during an outburst or storm was very narrow when the parent comet recurs. For example, it was found that the spread of radiants was within $\pm 0\overset{\circ}{.}1$ in standard deviation for the outburst of the Perseids in 1991 [1].

Furthermore, it was reported that the spread of radiants of the 1995 Leonids was within $\pm 0\overset{\circ}{.}12$ in right ascension and $\pm 0\overset{\circ}{.}07$ in declination in standard deviation [2]. There has been one major radiant concentration and little spread of radiants.

The above-mentioned results are for double-station photographic observations. We have also conducted double-station TV observations of the Leonids using an image intensifier and a CCD camera in succession and obtained some interesting results as outlined below.

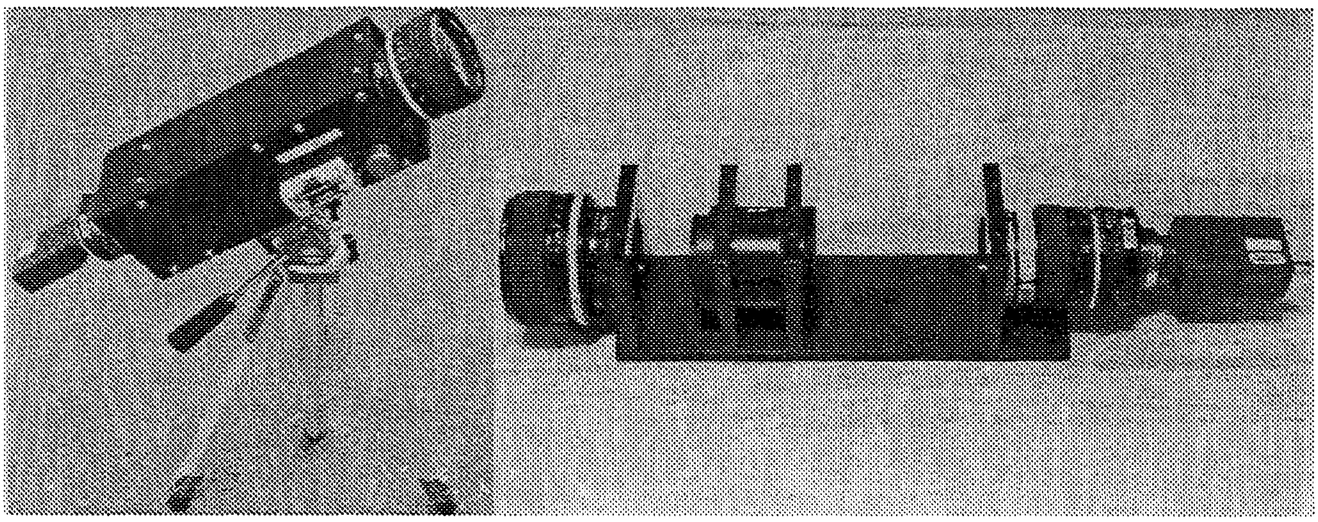

Figure 1 – TV observing device.

Table 1 – Averages and standard deviations of parameters determined for the Perseids and Geminids. The upper line gives the averages, the lower line gives the scatter in the data in standard deviation and does not indicate the errors in the averages. All data refer to eq. 2000.0.

Date (UT) (YMD)	$\lambda_\odot$	Radiant α	Radiant δ	SD	v_G (km/s)	SD (km/s)	a (AU)	e	q (AU)
19960812.689	140°276	47°97	+57°87	0°29	58.9	1.4	13.7	0.930	0.952
SD	0°059	0°06	1°13	0°63	0.3	1.1	0.7	–	0.063
19981211.678	259°435	110°23	+32°98	0°25	33.5	1.0	1.30	0.883	0.152
SD	0°032	0°03	0°36	0°42	0.2	0.9	0.50	–	0.010

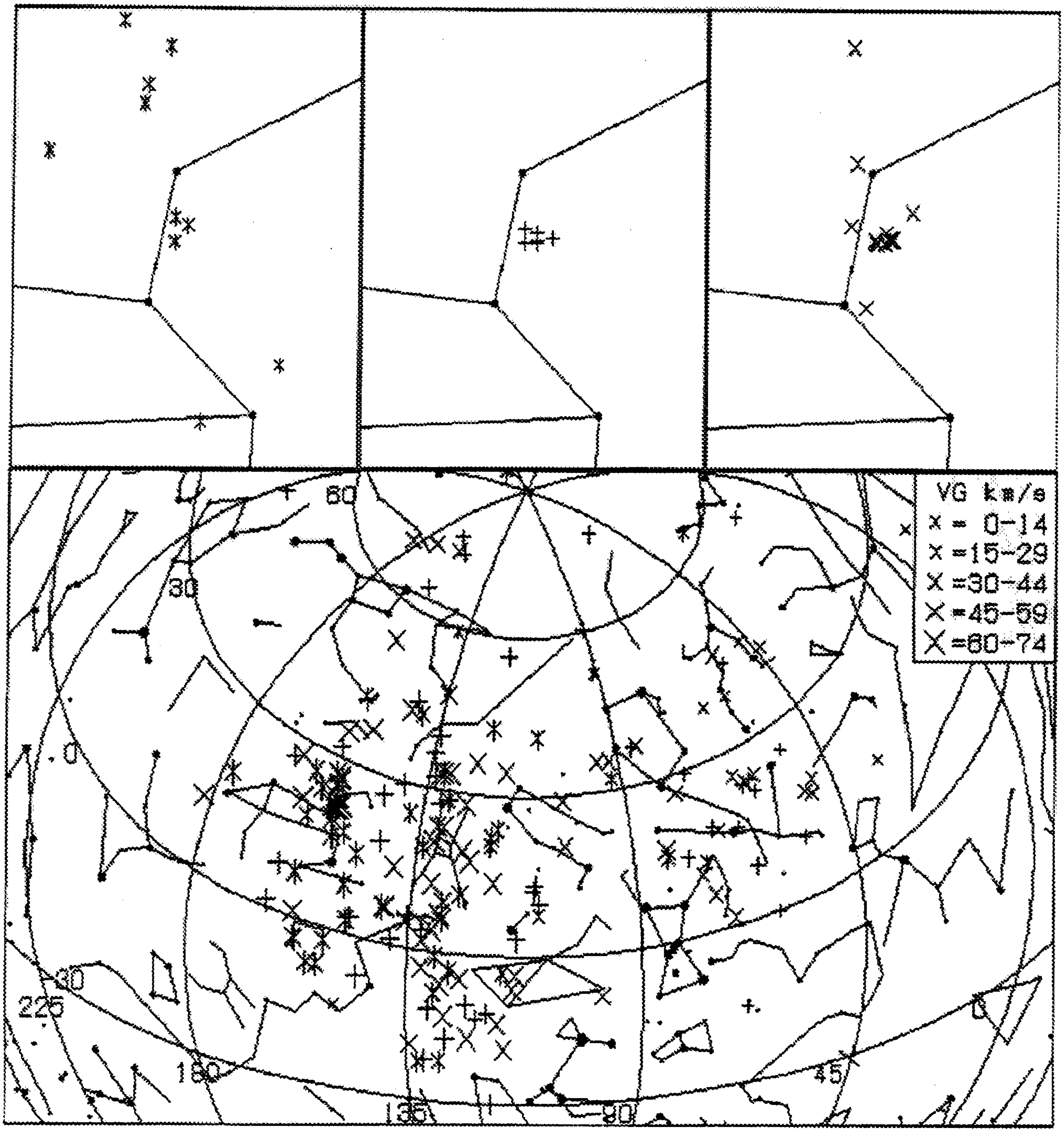

Figure 2 – Charts showing the corrected radiants. Stars refer to November 18, 1995, plusses to November 17, 1998, and crosses to November 18, 1999.

Table 1 – Continued.

Date (UT) (YMD)	ω	Ω	i	Abs. mag.	H_b (km)	H_e (km)	Met.
19960812.689	151°0	140°3	113°3	2.8	114	98	19
SD	0°0	2°1	0°1	1.0	2	5	4
19981211.678	323°3	259°4	22°6	3.7	101	85	7
SD	0°0	0°5	0°0	1.1	1	2	4

Table 2 – Averages and standard deviations of the Leonid data.

Date (UT)	$\lambda_\odot$	Radiant		SD	v_G	SD	a	e	q
(YMD)		α	δ		(km/s)	(km/s)	(AU)		(AU)
19951118.750	235°979	154°08	+21°88	0°38	71.0	1.9	14.9	0.934	0.985
SD	0°020	0°021	0°23	0°36	0.0	1.4	1.0	–	0.131
19981117.782	235°236	153°72	+21°65	0°26	70.8	1.3	11.9	0.917	0.984
SD	0°020	0°021	0°28	0°16	0.1	0.8	0.4	–	0.064
19991118.787	235°994	153°88	+21°58	0°26	71.1	1.3	15.8	0.938	0.986
SD	0°062	0°062	0°19	0°07	0.12	0.5	1.0	–	0.046

2. TV observation equipment

Figure 1 shows the observing equipment. The image of an objective lens is intensified. The intensified image is recorded through a close-up lens to the CCD, then recorded on a Hi-8 video tape recorder. About 50 sets of this equipment have been released and are used by many observers.

The performance of this observing equipment depends on the focal length of the objective lens or setting of the device. Table 3 shows its standard performance. We observed 1404 meteors simultaneously using this camera setup; our website announces all the results of the observations and related data such as the orbits [3].

Table 3 – Performance of the TV cameras.

Year	Lens	Field of View	Accuracy	Stellar Lm
1992–1995	50 mm $f/1.2$	17° × 13°	130″	9–10
1996–1998	85 mm $f/1.4$	9°5 × 7°5	90″	10–11
1999–	85 mm $f/1.2$	10°5 × 8°5	100″	10–11

3. Spread of Leonid radiants

Double-station TV observations of the Leonids have been conducted continuously since 1993 and some radiants were observed at three occasions, as shown in Table 2. Only a few meteors were observed in other years due to bad weather. Figure 2 shows the observed distribution of corrected radiants.

As shown in Table 2, the radiant positions and their scatter observed in 1995, 1998, and 1999 was very small. The spread of radiants and radiant calculation errors are almost same during all three returns of the Leonids. This suggests that the actual spread of radiants may have been even narrower.

4. Conclusion

A series of double-station TV observations of the Leonids proved that their radiant appears concentrated with only little spread (about 3°) over several years (see the upper part of Figure 2, especially for 1999). Apart from the Leonid radiant, we find a large number of radiants which were scattered about 7° around the region of Leo's head, particularly in the 1995 and 1999 data. We are planning to observe the radiant distribution during future activity outbursts and to follow the change of radiant positions and scatter during the next Leonid returns.

Table 2 – Continued.

Date (UT) (YMD)	ω	Ω	i	Abs. mag.	H_b (km)	H_e (km)	Met.
19951118.750	173°3	236°0	162°3	2.2	111	92	3
SD	0°0	1°3	0°0	0.4	2	11	1
19981117.782	171°9	235°2	162°5	4.0	118	100	6
SD	0°0	1°0	0°0	0.5	1	4	2
19991118.787	174°1	236°0	162°7	1.7	128	93	9
SD	0°.0	0°5	0°1	0.1	3	13	3

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Observational Results

SPA Meteor Section Results: May–June 1999

Alastair McBeath

Details from results submitted to the *SPA Meteor Section* from May and June 1999 not already published in [1] are given. Observing conditions were generally unhelpful, but an unusually extended η-Aquarid peak, perhaps with several submaxima, between roughly May 3 and 12, was suggested by both visual and radio results. No significant June Lyrid activity was found around June 16, and visual observers braving the late June moonlight found a complete absence of June Bootids this year. The lack of June Bootids is confirmed by the radio results.

1. Introduction

A significant part of the results from this period, particularly the radio data, have already been examined in some detail [1], so this report concentrates on the observations made at other times. Totals for all data received in May and June, 1999, are given in Table 1. Extended twilight caused its regular difficulties for northern hemisphere visual observers at this time of year, while the radio observers struggled particularly with Sporadic-E (Es) notably after mid-May.

Photographic reports were received from *Arbeitskreis Meteore* (*AKM*) members Ina Rendtel (who kindly provided all the *AKM* details, extracted from the journal *Meteoros*, issues 2:6, 2:7-8 (both 1999), and 3:2 (2000)), Jürgen Rendtel, Roland Winkler, and Jörg Strunk, all in Germany. A single trail was found among their all-sky fireball patrol negatives from June. All the video data were collected by *AKM* member Sirko Molau, again in Germany.

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

Month	Visual	ETA	Meteors	Photo	Radio	Video	Trails
May	$49^h\!.9$	58	373	130^h	3614^h	$17^h\!.9$	38
June	$31^h\!.6$	–	181	$91^h\!.3$	4152^h	$23^h\!.2$	62

Radio observations were forwarded to us by Chris Steyaert in the form of *Radio Meteor Observation Bulletins* 70–72 inclusive, June to August 1999. The radio observers included:

> Enric Fraile Algeciras (Spain), Michael Boschat (Canada), Maurice de Meyere (Belgium), Ghent University (Belgium), Ou Yang Tian Jing (China), Will Kelsey (California, USA), Werfried Kuneth (Austria), R.B. Minton (New Mexico, USA), Sadao Okamoto (Japan), Chikara Shimoda (Japan), Garfield Tsao (Taiwan), and Ilkka Yrjölä (Finland).

The raw data was analyzed as usual in the *SPAMS* results, and a graph showing some representative early May details is given here as Figure 1. A graph of radio activity during the remainder of May and all of June can be found in Figure 1 of [1].

Visual reports came from

> *AKM* members Rainer Arlt, Frank Enzlein, Christoph Gerber, Matthias Growe, Sven Näther, Jürgen Rendtel, and Oliver Wusk (all in Germany); Tim Cooper (South Africa), Steve Foggo (England), and Chris Hall (England).

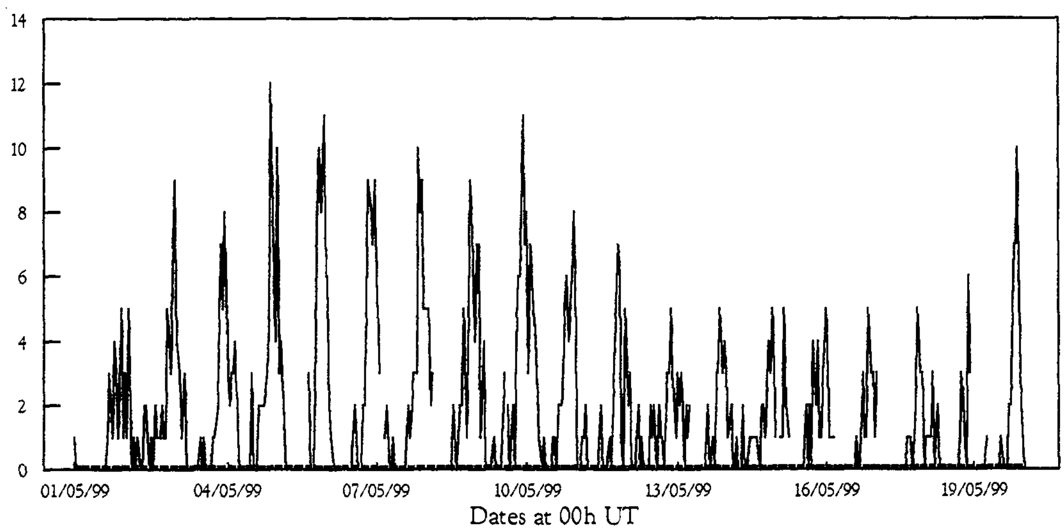

Figure 1 – Raw hourly radio meteor echo counts (echo durations of more than 5 s) from May 1–20, 1999, as reported by Sadao Okamoto. The unusually extended η-Aquarid peak in early May is very obvious. Breaks are due chiefly to atmospheric interference, as recording was otherwise generally continuous.

2. May

The difficulties in observing the η-Aquarids in early May, whose pre-dawn observing window is very short even from the better-placed southern hemisphere sites, was compounded in 1999 by a waning gibbous Moon. Despite these problems, Tim Cooper managed to secure some data on them on May 2-3, 3-4, and 9-10, and, although some inflation of the ZHR numbers is possible because of poor sky conditions (limiting magnitudes between +4.8 and +5.3), the rates did seem unusually consistently high on these three mornings, at around 65 ± 15, 45 ± 10, and 70 ± 15, respectively.

There are regrettably few other visual η-Aquarid reports for comparison. The radio data, however, do support a generally more extended and relatively consistent level of activity as Figure 1 shows, running between roughly May 3 and 12 ($\lambda_\odot = 42°$–$51°$). The start of this spell especially is not sharply defined, with some radio data suggesting enhanced echo numbers not far short of those during the peak beginning as early as $\lambda_\odot \approx 40°$. No consistency is seen between when the best count-numbers occurred either. A marginally stronger peak was found in 75% of the available data around $\lambda_\odot = 43°$–$44°$ (May 4–5), but in half the data sets, $\lambda_\odot \approx 47°$ (May 8) was at least as strong, and in the Ghent University results (not shown here), this $\lambda_\odot \approx 47°$ peak completely dominated the remainder of May, though this was not found in any of the other radio results. Long-duration echoes suggested a third spike around May 10 ($\lambda_\odot \approx 49°$). The available evidence supports the idea that the 1999 η-Aquarids produced a significantly longer-lasting maximum than normal, possibly with two or three submaxima, which is not inconsistent with the findings of [2], where variations between returns of this shower in different years were noted between 1986 and 1995. The report by Rendtel [3] on the 1997 η-Aquarids also drew attention to the radar profile showing a double maximum at $\lambda_\odot \approx 45.^\circ5$ and $\lambda_\odot \approx 48°$, quite similar times to the stronger maxima found in the 1999 radio data. Radio results in recent years have tended to support η-Aquarid maxima around $\lambda_\odot = 46°$ and less strongly in the interval $\lambda_\odot = 47°$–$50°$, perhaps with an enhancement beginning as early as $\lambda_\odot = 39°$–$40°$ [4].

The remainder of May's radio results, and those from all of June, have already been discussed elsewhere [1], while the visual observers recorded only sporadic and weak Sagittarid rates throughout the latter part of the month.

3. June

Visually, low Sagittarid activity persisted until late June in the available data, but was never better than extremely weak. No obvious Sagittarid maxima were noted during May and June.

Observers had been alerted in case any June Lyrid activity recurred in 1999, the shower having seemingly produced weak but detectable rates in 1996 for the first time since the 1970s. Any potential rates were likely to peak in moonless skies around June 16 [5]. Data were reported to us by European observers from June 13-14, 15-16, 18-19, and 19-20, around the shower's expected active interval, as well as beyond this time too, but only weak to nonexistent rates were seen. The observed rates averaged 1.3 June Lyrids per hour in the data available (9 shower meteors from four observers in $6.^h97$), and, although the meteor numbers were small because of the short twilight-free observing interval, there is an indication of lower sporadic rates coinciding with the relatively stronger possible June Lyrid times. Consequently, many "June Lyrids" may just have been sporadics lining up with the radiant by chance. No unexpected radio peak was found in time to the shower's proposed active period, but a slightly stronger peak than in 1994–1998 was noted around June 13–17 ($\lambda_\odot = 82°$–$85°$). This is highly inconclusive, however. With no unusual June Lyrid reports posted to the *IMO News* or *Meteorobs* e-mailing lists, it seems likely nothing of them occurred in 1999. Certainly a potential shower worth watching out for in future years, though.

Late June 1998 brought the unexpected June Bootid outburst (as detailed in several papers in the August 1998 and later issues of this journal, for instance). Observers were again alert in 1999 in spite of the Full Moon, in case another return took place. Unfortunately, no trace of any Bootid activity was found either in the visual or the radio data submitted to us, as also noted in [6]. A moderate radio peak on June 27-28 was almost certainly not due to this source, as it happened at a time when the June Bootid radiant would be low or below the horizon. Again, a time to watch in future years, however.

Acknowledgments

My thanks go to all *Section* observers and correspondents as always during this interesting time, even if perhaps a less productive one than might have been hoped for.

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SPA Meteor Section Results: July–August 1999

Alastair McBeath

News and details extracted from reports sent to the SPA Meteor Section from July and August 1999, and not already detailed in [1], are presented. Two bright fireballs were widely seen, one around 4^h14^m UT on July 7 over New Zealand (dealt with in [1]), the other from the Low Countries in Europe at 20^h57^m UT on July 31. The moonlit late July Aquarid and Capricornid shower peaks were recorded primarily by the radio observers. The Perseid primary maximum on August 12 was less active than for some years (ZHRs of 98 ± 9 at best on August 12-13 in these results), and was not well-defined in the radio reports.

1. Introduction

Part of the data, notably the radio results, from the first half of July have already been discussed in [1], and are not repeated here. Visual observations were affected by poor weather at times in both months, and bright moonlight concealed the late July southern-sky shower maxima. August's New Moon eclipse created ideal dark-sky conditions for the Perseid maxima, but, as many people had traveled considerable distances to view the eclipse, fatigue from that or the return trip before the Perseid peaks meant fewer reports were received from the maxima themselves than might have been hoped for. Sporadic-E again produced occasionally severe problems for the radio operators. Our overall observing totals are in Table 1.

All of the photographic work in July, and much of that in August came from *Arbeitskreis Meteore* (*AKM*) members S. Fritsche, Ina Rendtel, Jürgen Rendtel, Jörg Strunk, and Roland Winkler in Germany. The August all-sky fireball data contained 17 trails from 9 events, 5 fireballs caught from two or more sites, with most of these concentrated around the Perseid maximum. Along with all the other *AKM* data used here, these details came from their journal *Meteoros* 2:7-8, 2:9 (both 1999), and 3:2 (2000), provided by Ina Rendtel. Other photographers in August were Bev Ewen-Smith in Portugal (who caught the remaining 8 Perseid trails) and Alan Heath in Turkey. *AKM* members Sirko Molau (Germany and Bulgaria), Jürgen Rendtel (Germany), and Ulrich Sperberg (Germany) provided the bulk of the video reports, along with Bev Ewen-Smith. In the identifiable video trails, 486 were Perseids.

Most of the radio data were taken from *Radio Meteor Observation Bulletins* (*RMOB*s) 72–74 (August to October 1999 inclusive), submitted by Chris Steyaert. Additional reports came from Bev Ewen-Smith. The *RMOB* observers included

> Enric Fraile Algeciras (Spain), Mike Boschat (Canada), Eisse Pieter Bus (Czech Republic), Maurice de Meyere (Belgium), Ghent University (Belgium), Werfried Kuneth (Austria), R.B. Minton (New Mexico, USA), Sadao Okamoto (Japan), Chikara Shimoda (Japan), Garfield Tsao (Taiwan), and Ilkka Yrjölä (Finland).

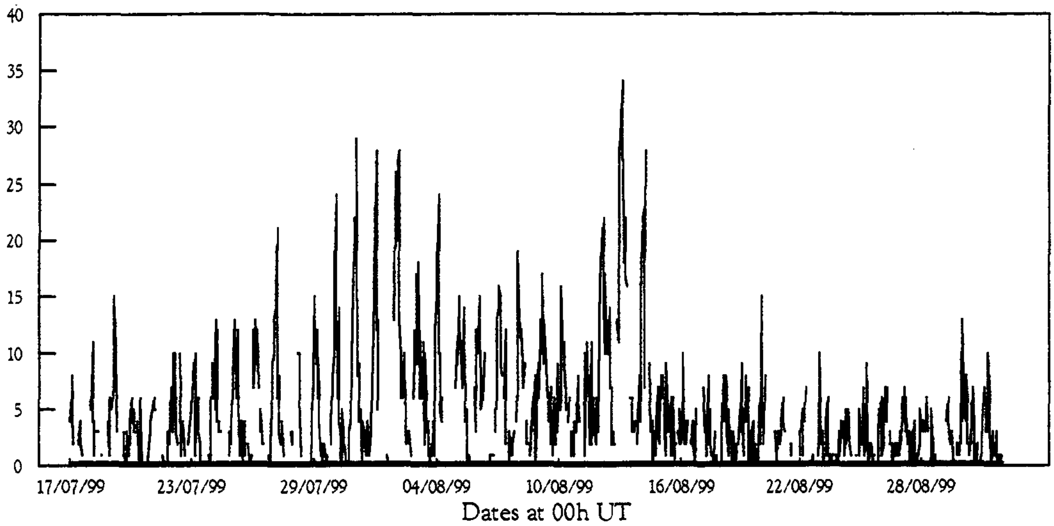

Figure 1 – Raw hourly radio meteor echo counts (echo durations of more than 6.5 s) from July 17 to August 31, 1999, in data collected by Werfried Kuneth. Most of the breaks in the otherwise continuous data collection were due to Sporadic-E. The late-July to early-August southern-sky shower maximal "bulge" and the Perseids are very obvious.

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

Month	Visual	JPE	CAP	KCG	PER	Meteors	Photo	Trails	Radio	Video	Trails
July	$97^{h}.7$	22	47	–	76	833	$130^{h}.4$	0	3538^{h}	$95^{h}.7$	503
August	$356^{h}.5$	–	160	266	4955	8251	$154^{h}.7$	25	3530^{h}	$155^{h}.1$	1549

Our standard procedures for analyzing raw forward-scatter data were followed as usual. Figure 1 shows a representative graph covering late July and all of August. A graph showing the radio data up to July 17 was given as Figure 1 of [1].

The visual observers included

AKM members Rainer Arlt (Germany and Bulgaria), Stefan Berkmüller, Lukas Bolz, Benedikt Dietrich, Philipp Drews, Frank Enzlein, Christoph Gerber (Germany and Turkey), Matthias Growe, Johannes Hopf, André Knöfel (Bulgaria only), Ralf Kuschnik (Germany and Bulgaria), Hartwig Lüthen (France only), Sirko Molau (Bulgaria only), Sven Näther, Ina Rendtel (Bulgaria only), Jürgen Rendtel (Germany and Bulgaria), Janko Richter, Marion Rudolph (Bulgaria only), Mario Scheel, Harald Seifert, Thomas Snoeks (the Netherlands), Nikolai Wünsche, Oliver Wusk (Germany, Greece, and Bulgaria), all in Germany only except where noted; Stan Armstrong (England), Jay Brausch (North Dakota, USA), Michael Ching (Portugal), Paul Coleman (Turkey), Shelagh Godwin (England and France), Alan Heath (Turkey), Marco Langbroek (the Netherlands), Tony Markham (England), Alastair McBeath (England), and Graham Pointer (Scotland).

2. July

Part of the month's results up to July 17 were discussed in [1], including the superbolide of July 7 over New Zealand, and all the radio activity. Most of the visual results were concentrated in mid-July, the majority between July 7 and 20.

For once, we had several data sets featuring the Pegasids, which generally confirmed their maximum on July 10-11, though ZHRs even then were only 2–4 ± 1–3 at best in our data, much as expected. Some confusion occurred when reports of possibly heightened Pegasid rates on July 10-11 seen from Spain were posted to the *IMO News* e-mail list, as for some unaccountable reason, these were suggested as possibly being coincidental with Bev Ewen-Smith's report of unusual radio meteor activity (discussed in detail in [1]) detected 12 hours later from a probable radiant almost on the opposite side of the sky! As the Pegasid radiant had set for Bev's site several hours before he recorded any enhanced radio activity at 13^h–13^h45^m UT on July 11, it is difficult to see how such confusion could have arisen. The Spanish reports suggested Pegasid ZHRs of 5–10 around 1^h45^m–3^h UT on July 10-11, but we have no data from our visual observers active beyond 2^h UT then to confirm this, unfortunately.

On July 22, a curious metallic object apparently crashed through a roof into an iron smelting works at Weert in the Netherlands. Initially, this was thought to be a possible iron meteorite, but later investigation suggested it was not. A more meteorically interesting event, a brilliant fragmenting fireball, was widely seen from the Netherlands and Belgium around 20^h57^m UT on July 31, in evening twilight. Marco Langbroek and Casper ter Kuile sent in details indicating the object's probable surface track as running from a point about 75 km northwest of Amsterdam, out over the North Sea around $\varphi = 52°20'$ N and $\lambda = 3°50'$ E, and ending near the Dutch-Belgian border some 15 km south of Eindhoven, near $\varphi = 51°20'$ N and $\lambda = 5°25'$ E. The trajectory was probably around 180 km long in the atmosphere, indicating an atmospheric velocity between 15 and 35 km/s. An end height of perhaps 60–70 km was suggested, which, with the long trajectory, implied an atmosphere-grazing event. The details are not particularly certain, as many of the witnesses were casual or inexperienced observers, as so often happens.

In the late July radio data, the unusual spike seen at $\lambda_\odot = 115\overset{\circ}{.}25$–$115\overset{\circ}{.}29$ on July 18, 1998 [2] did not seem to recur in 1999. Only the two active Japanese observers recorded even a minor increase in rates on that date, but not coincidentally nor at the same equivalent time as in 1998 (in 1999, July 18, 7^h–8^h UT). All of the other previously detected echo count enhancements in [3] were again found, and nothing unexpected occurred. The Aquarid and Capricornid maxima just before and after the July-August border were detected clearly in the radio results, with especially prominent spikes at $\lambda_\odot = 124°$–$126°$ (July 27–30), all much as usual. No visual observations were possible to confirm these, however.

3. August

With bright moonlight preventing much observing in the opening week, most of the visual data were concentrated between August 7 and 16. The radio observers recorded the normal minor echo count spikes in the pre-Perseid maximum part of the month, though the very weak $\lambda_\odot = 130°$ peak (August 3) seemed to have shifted to $\lambda_\odot \approx 129°$ (August 2) in 1999, while the slight $\lambda_\odot = 135°$ peak (August 8) was only noted in half the available data sets. There was also a marginally unusual, if weak, radio count spike around $\lambda_\odot = 131°$–$133°$ (August 4–6), which was more prominent in long-duration echoes ($D > 5$ s) at $\lambda_\odot = 131°$ as Figure 1 demonstrates, though most observers recorded something from $\lambda_\odot = 131°$–$132°$ at least. The extended late July $\lambda_\odot = 122°$–$126°$ peak has been seen to extend to $\lambda_\odot \approx 131°$ before, but not beyond. Although the small enhancement this year is not conclusively different to such an extension, no peak quite like this has been noted in recent years.

The Perseid radio maximum was very clear near $\lambda_\odot = 140°$ (August 12-13) for all the active observers, but a closer inspection of the data shows no obvious peak time, as the best rates fall fairly uniformly about the time of the radiant's best visibility for all the given sites. It has thus not been possible to independently confirm the preliminary visual findings of [4].

Those visual observers not exhausted by their eclipse-chasing exertions who had clearer skies certainly enjoyed a typically good, if unspectacular, Perseid return. Our highest mean shower ZHR was 98 ± 9 for the period in the order of an hour around August 13, 0^h30^m UT ($\lambda_\odot = 139\overset{\circ}{.}86 \pm 0\overset{\circ}{.}04$). There was some evidence for rates decreasing after midnight UT on August 13, with data from the USA suggesting a ZHR drop to around 50 ± 5 by approximately 8^h UT ($\lambda_\odot = 140\overset{\circ}{.}16$). Mean ZHR values for every night between August 6-7 and 16-17 inclusive are given in Table 2.

Table 2 – Mean Perseid ZHRs computed using $r = 2.3$, except for August 12-13, when $r = 2.1$ was used instead based on data in [4]. Most single data points were centered around 0^h–1^h UT each night.

Date	ZHR	Date	ZHR
August 6- 7	10 ± 3	August 12-13	98 ± 9
August 7- 8	12 ± 2	August 13-14	36 ± 5
August 8- 9	18 ± 4	August 14-15	31 ± 4
August 9-10	17 ± 3	August 15-16	21 ± 3
August 10-11	22 ± 3	August 16-17	12 ± 3

Table 3 – Global magnitude distributions for the Perseids and August sporadics seen in good sky conditions (limiting magnitude of +5.5 or better, average cloud cover less than 20%), including mean limiting magnitudes and corrected mean magnitudes.

Shower	-3^-	-2	-1	0	+1	+2	+3	+4	$+5^+$	Tot	Lm	$\overline{m}_{6.5}$
Perseids	8	8	12.5	41	51	72	94	54	18	358.5	6.06	2.49
Sporadics	1	0	2.5	7	7	33	39.5	45	21	156	6.06	3.48

Table 3 gives magnitude details for the Perseids and August sporadics. Surprisingly few Perseid fireballs were spotted this year, although, as normal, the majority of photographed meteors were concentrated within a day or two of August 12-13. Too few train reports were received to make a full analysis of them practical, but the overall percentages were 36% for the Perseids (38 of 106 meteors) and 2% of sporadics (2 of 113 meteors). As well as Perseids, a steady trickle of κ-Cygnids were detected throughout August. Their ZHRs frequently reached the unimpressive level of about 3, but never significantly more. There was no clear indication of a maximum, although the predicted peak date of August 18 saw virtually no observing at all.

August 19-20 brought a fireball over Germany bright and well-placed enough to be caught by four of the *AKM* all-sky fireball patrol cameras, part of the *European Fireball Network* (*EFN*). The lucky stations were all in central-southern Germany, and this was one of only two such fireballs to be photographed at four or more *AKM* sites during the year. More information on the *AKM* EFN stations and the fireballs recorded by them in 1999 can be found in two articles by Dieter Heinlein in *Meteoros* 3:2 (2000, pp. 23–27).

The post-Perseid radio echo count peaks previously recorded in [3] were all found again, with the extended $\lambda_\odot = 155°$ period, sometimes running from $\lambda_\odot = 150°$–$156°$ (equivalent to August 24–30, 1999) being detected especially well between $\lambda_\odot = 154°$ and $\lambda_\odot = 156°$ this year (August 28–30), exactly as was found in 1998 [2]. In addition, the new enhancement first noted in 1998 during $\lambda_\odot = 148°$–$149°$ [2] did repeat at the appropriate time (August 22–23, 1999), albeit not as strongly as in 1998. There are very few late August visual results to check for comparison regrettably, thanks to Full Moon on August 26. Consequently, virtually no α-Aurigids were reported in August at all.

Acknowledgments

As ever, my thanks are extended to all observers and correspondents.

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The 1999 Perseid Meteor Shower in Poland

Arkadiusz Olech

We present the analysis of the 1999 Perseid shower based on 6731 meteors seen during 988 hours of effective time by 29 members of the *Comets and Meteors Workshop*. A clear maximum of activity was observed on August 12 at $23^{\rm h}$ UT ($\lambda_\odot = 139\overset{\circ}{.}80$) with ZHR $= 115 \pm 18$. Both activity and the time are in agreement with predictions for the new peak of Perseids activity caused by fresh material ejected from the Comet 109P/Swift-Tuttle. The traditional maximum expected around $\lambda_\odot = 140\overset{\circ}{.}0$ occurred during the daytime in Poland and was not observed. We detect two distinct minima of the population index, the first one at $\lambda_\odot =$ 134–135° with r around 1.95, and the second one at the activity maximum with r around 2.0.

1. Introduction

August 1999 was a very good time for amateur astronomers in Europe. The total solar eclipse with totality area passing through many European countries encouraged a lot of people to watch the sky. Fortunately, the solar eclipse (always connected with the New Moon) occurred on August 11, i.e., one day before the maximum of the Perseid shower. Taking into account that the new maximum of the Perseids connected with the recent return of Comet 109P/Swift-Tuttle was expected at $23^{\rm h}$ UT on August 12, central Europe was the perfect time for spending the holidays. Especially attractive were Romania and Bulgaria, where the probability of a clear sky at that time was around 60%. The Polish *Comets and Meteors Workshop* (*CMW*) decided to send a group of nine observers to Kamen Byrag (Bulgaria). Of course, the rest of our members followed both the eclipse and the Perseids from their ordinary locations.

2. Observations

The most successful observational action of the *CMW* was the 1997 Perseid campaign. That year, 28 of our observers watched the sky during $937^{\rm h}23^{\rm m}$ and detected 8273 Perseids [1]. The next year, a group of 35 of our observers obtained $896^{\rm h}57^{\rm m}$ of effective time with 3342 Perseids observed [2]. The good conditions in 1999 allowed us to set up a new record. From July 15 to August 25, a group of 29 Polish observers obtained 988 hours of observing time with 6731 Perseids. The full list of our observers with the corresponding times (in hours) is as follows:

Tomasz Fajfer ($117\overset{\rm h}{.}00$), Jarosław Dygos ($105\overset{\rm h}{.}41$), Konrad Szaruga ($81\overset{\rm h}{.}62$), Karolina Pyrek ($66\overset{\rm h}{.}56$), Andrzej Skoczewski ($63\overset{\rm h}{.}33$), Ewa Dygos ($61\overset{\rm h}{.}57$), Krzysztof Mularczyk ($54\overset{\rm h}{.}17$), Dariusz Dorosz ($52\overset{\rm h}{.}37$), Marcin Konopka ($50\overset{\rm h}{.}17$), Marcin Gajos ($41\overset{\rm h}{.}85$), Maciej Kwinta ($38\overset{\rm h}{.}42$), Luiza Wojciechowska ($29\overset{\rm h}{.}18$), Mariusz Wiśniewski ($28\overset{\rm h}{.}56$), Dominik Stelmach ($26\overset{\rm h}{.}94$), Izabela Fitoł ($22\overset{\rm h}{.}00$), Arkadiusz Olech ($21\overset{\rm h}{.}85$), Mariola Czubaszek ($18\overset{\rm h}{.}78$), Tomasz Żywczak ($18\overset{\rm h}{.}50$), Piotr Szakacz ($18\overset{\rm h}{.}33$), Łukasz Mikuć ($11\overset{\rm h}{.}95$), Gracjan Maciejewski ($11\overset{\rm h}{.}03$), Piotr Nawalkowski ($10\overset{\rm h}{.}95$), Jarosław Nocoń ($8\overset{\rm h}{.}17$), Krzysztof Socha ($8\overset{\rm h}{.}00$), Aleksander Trofimowicz ($7\overset{\rm h}{.}50$), Cezary Gałan ($4\overset{\rm h}{.}27$), Maciej Reszelski ($3\overset{\rm h}{.}93$), Michał Jurek ($3\overset{\rm h}{.}00$), and Karol Fietkiewicz ($2\overset{\rm h}{.}62$).

3. Results

Population index

The magnitude was estimated for 6730 events grouped in 294 magnitude distributions. These distributions were used for the calculation of the population indices. First, we only used distributions satisfying the following conditions:

- at least four consecutive magnitude classes should be filled with at least 0.5 of a meteor;
- the magnitude distribution should contain at least 15 meteors; and
- the distance between the limiting magnitude and the faintest magnitude class should be at least 1.5.

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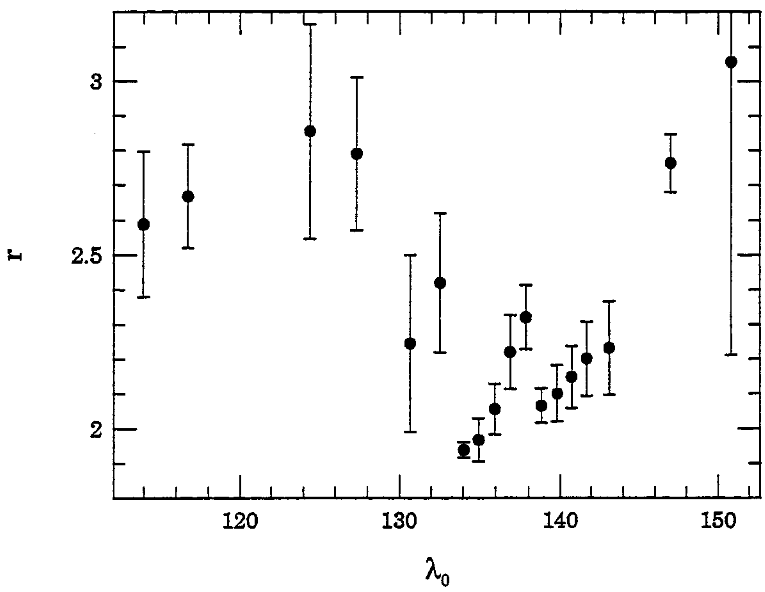

Figure 1 – Population index profile.

After applying these criteria, the number of magnitude distributions which were left was only 114. These and the remaining distributions were corrected for the perception probabilities given by

$$p(\mathrm{Lm} - m) = 1 - 10^{-0.01072(\mathrm{Lm}-m)^2 - 0.00044(\mathrm{Lm}-m)^4},$$

where m is the magnitude class and Lm the limiting magnitude. Next we added each five "bad" distributions with similar limiting magnitudes. If the distribution constructed this way satisfied the above mentioned three conditions, we used it for the calculation of the population index. The final number of magnitude distributions was 142. Figure 1 shows the profile of the average population indices.

The clear feature shown in Figure 1 is the presence of two distinct minima of the population index. One minimum observed around $\lambda_\odot = 139°$ is connected with the maximum of the activity. More surprising is the second minimum with $r = 1.94 \pm 0.02$ at $\lambda_\odot = 134°$ and $r = 1.98 \pm 0.06$ at $\lambda_\odot = 135°$.

Recently, Rendtel and Arlt [3] presented the preliminary results of the 1999 Perseids based on 1297 hours of observations. Their population index profile also shows a dip at $\lambda_\odot = 136°$ with r fading below 2.0.

Activity profile

Knowing the values of population indices we are able to compute the Zenithal Hourly Rates (ZHRs) of the 1999 Perseids. These are shown in Figure 2. The clear maximum of the activity was noted on August 12-13 ($\lambda_\odot = 139\overset{\circ}{.}8$) with ZHR $= 77 \pm 5$. One should remember that this point is the average value of 67 hourly rate estimates. We decided to compute the ZHRs from hourly rates grouped into shorter bins. The result is presented in Figure 3. In the evening hours the ZHR was around 60 and after that it quickly rose to ZHR $= 115 \pm 18$ at $\lambda_\odot = 139\overset{\circ}{.}80$, which corresponds to 23^h UT on August 12. This result is in excellent agreement with work of Rendtel and Arlt [3] who obtained maximum ZHR $= 104 \pm 4$ at $\lambda_\odot = 139\overset{\circ}{.}80 \pm 0\overset{\circ}{.}01$. It is also in very good agreement with the predictions [4].

An interesting feature is the presence of the second maximum at $\lambda_\odot = 139\overset{\circ}{.}87$ (August 13, $0^\mathrm{h}45^\mathrm{m}$ UT) with ZHR $= 101 \pm 23$. At the present time it is hard to interpret this peak due to the large uncertainty of the ZHR estimate. The activity profile of Rendtel and Arlt [3] shows rather chaotic changes of activity with a ZHR between 85 and 90 around that time, but it agrees within the error bar with our value. A more detailed analysis based on a larger sample will certainly clarify this situation.

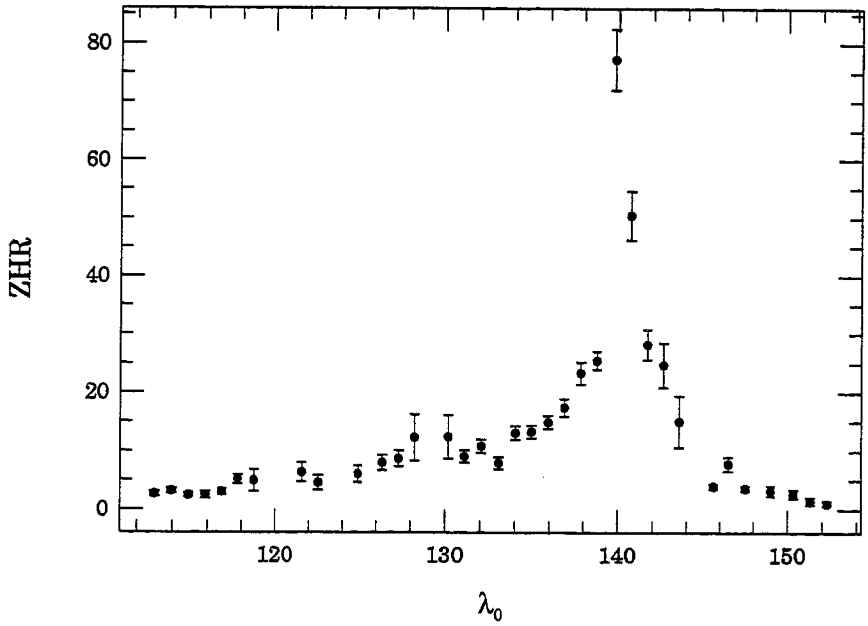

Figure 2 – ZHR profile.

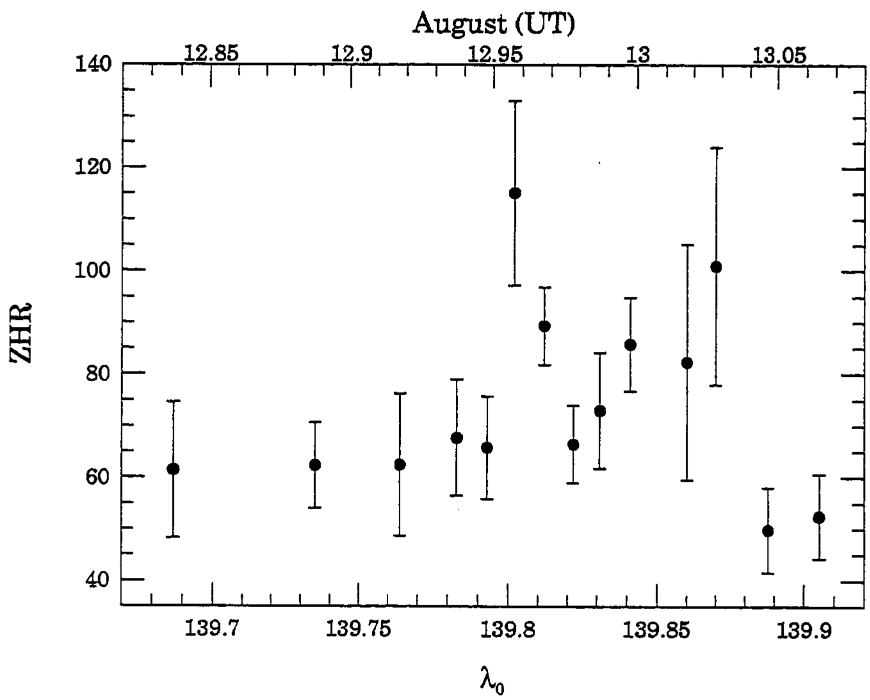

Figure 3 – Detail of the ZHR profile, obtained using shorter bins.

Acknowledgments

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