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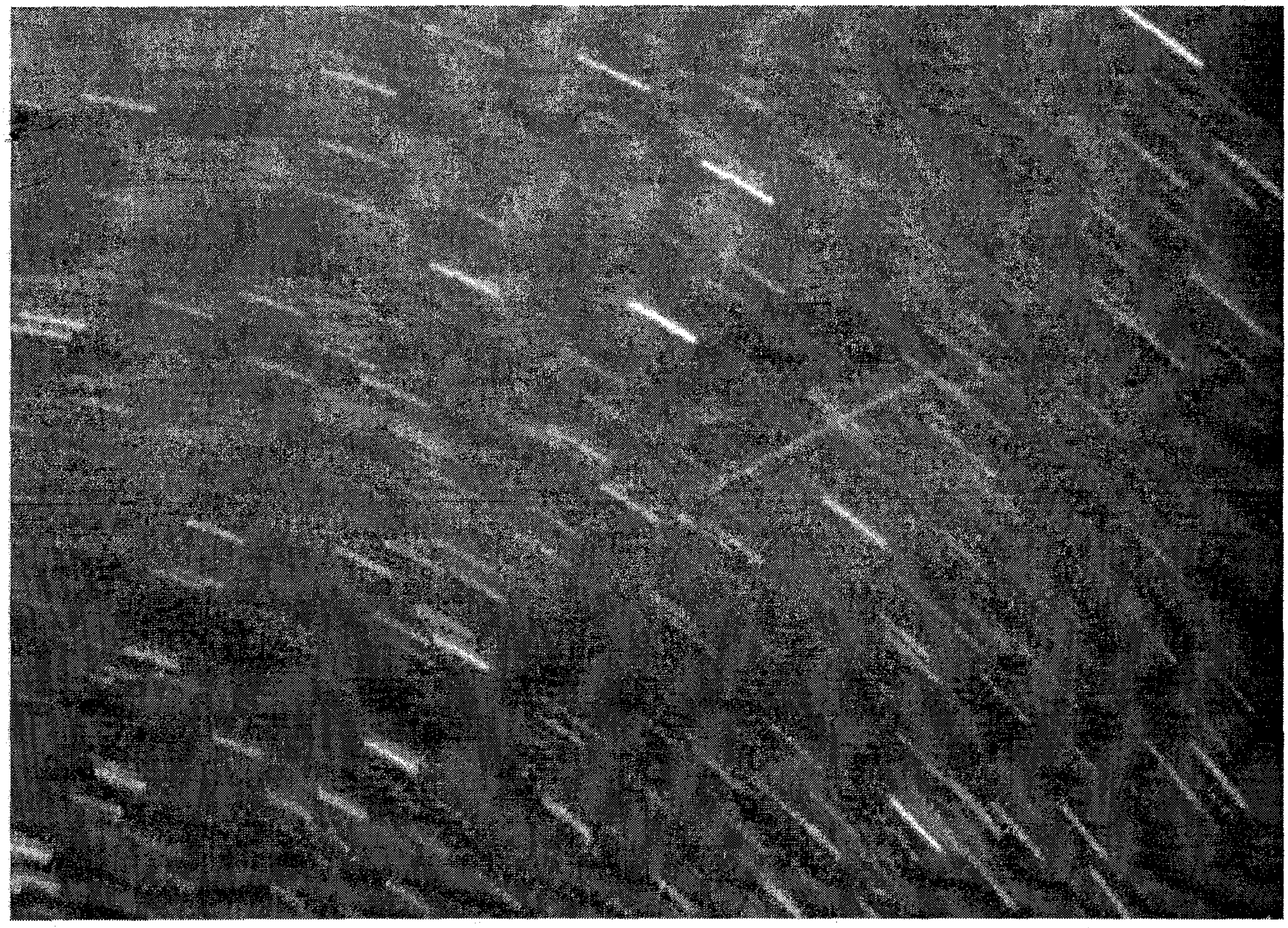

A Perseid of magnitude −1 on August 12, 2001, at $01^h19^m01^s$ UT as photographed by Javor Kac from the *MBK Team* from Maribor, Slovenia. The bright star above the center is 50 Cassiopeiae. The photo was exposed from $01^h15^m24^s$ to $01^h26^m22^s$ UT.

In this issue:
- Information on the 2001 Leonids
- Comprehensive study of the Lyrids
- Zenith attraction and radiant position
- Status of the Spanish Meteor Network
- The Meteroids Conference in Sweden

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Contents

Useful Information

The October issue *(WGN 29:5)*

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

Subscriptions and ordering of publications

Volume 29 (2000) of *WGN* is expected to contain at least 240 pages and costs 35 DEM or 17.90 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription/membership fees. 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

We are currently in the process of working away our publication delay; we are not quite there, but we have good hopes that the October issue will appear in time, especially because it is anticipated to contain information of the 2001 Leonids which we want to reach observers in time. Nevertheless, we have already included quite a lot of important Leonid information in this issue!

Another positive note it that the flow of article is increasing again. After the last Leonid event, significantly less articles were submitted, but this tendency seems to have changed again, and I am glad and relieved about that. A lot of people need to get involved in an international effort such as the IMO *in order for it to work and to keep working! In that respect, I am also looking forward to the upcoming* International Meteor Conference *in Cerkno, Slovenia. I hope to meet a lot of enthusiastic meteor workers, and I hope that several are also willing to take a commitment in the organizational aspect of international meteor work!*

Leonids

Leonid Observing Hints for 2001

Rainer Arlt

1. Prospects

Another period of very high activity of the Leonid meteor shower is expected for November this year. A number of models predict strong peaks in the UT late morning as well as for the UT evening of November 18. The two main peaks—according to McNaught and Asher [1,2] fall on November 18, $10^{\rm h}01^{\rm m}$ UT and November 18, $18^{\rm h}19^{\rm m}$ UT with an additional side-maximum before the latter at November 18, $17^{\rm h}31^{\rm m}$ UT. The computations by Lyytinen and van Flandern [3] deliver $9^{\rm h}58^{\rm m}$ UT for the first peak and times between $17^{\rm h}20^{\rm m}$ and $18^{\rm h}22^{\rm m}$ UT for a group of four dust trails as the second maximum.

The first maximum is thus in good position for all American observers with preference to the east-coast North Americans. The second and third peak have geometrically ideal locations in the western Pacific, but locations in eastern Asia will provide prolific radiant heights, even if one goes west, away from the coastal areas with less probability of clear skies. From many locations in Australia, observers will see a good show with radiant elevations of 30°–40°.

The question of how high the ZHRs of these peaks will be is still hard to answer. At least predictions for 1999 and 2000 were correct to the order of magnitude. ZHRs of 10000 or more are favored by the McNaught and Asher model [2] for the Asian peak, but an order of magnitude smaller ZHRs are given for the American maximum. The dust trail computations by Lyytinen and van Flandern [3] give 6100 for the trail at $18^{\rm h}22^{\rm m}$ UT plus roughly 1000–2000 from other trails which may overlap. They predict a ZHR of 2000 for the American maximum. In 2000, the prediction by Lyytinen and van Flandern had turned out to be closest to the actual peak ZHRs.

Recently, these computations were updated as presented at the *Meteoroids 2001* Conference in Kiruna, Sweden, and are given in detail in this issue [4]. Here is a quick-look:

- November 18, $10^{\rm h}28^{\rm m}$, ZHR = 2000, duration 2 hours;
- November 18, $18^{\rm h}03^{\rm m}$, ZHR = 2600, duration 2 hours;
- November 18, $18^{\rm h}20^{\rm m}$, ZHR = 5000, duration 1.5 hours;
- November 18, $19^{\rm h}10^{\rm m}$, ZHR = 200–300, duration 4 hours.

A recent presentation by Jenniskens at the *Meteoroids* Conference indicates the chance to see higher activity from the first peak according to phenomenological considerations. He derives a peak ZHR of 4 200 for the American maximum.

Meanwhile, the distance to the parent comet, 55P/Tempel-Tuttle, has become so large (3 years after perihelion passage), that it is likely that the dust trails are less concentrated than close to the Comet. The durations given in [4] are quite short (see items above), but longer durations of the maxima cannot be ruled out for 2001. Even the chance that either of the peaks can extend into the observing periods of European observers are not vanishing. The decreasing branch of the Asian peak in the European night November 18-19 might produce a number of very long meteors before midnight when the Leonid radiant rises. West-European observers might see the activity rising towards the American peak just before dawn in the night of November 17-18.

2. For storm observers

For the case that a real storm materializes, the observer should take some considerations into account, particularly as the peak might be much stronger than the 1999 storm. The essential information is two-fold: high temporal resolution of the activity profile is requested, and magnitudes are needed as long as possible.

If anything more happens than what you know from a Perseid display, please report Leonid/non-Leonid numbers *in one-minute counts*. This might result in some periods with few meteors or none, but remember that it is always possible to combine periods to longer ones, but it is usually not possible from the report to divide long periods into smaller ones.

If a strong storm with more than 20 meteors per minute occurs, please try to report meteor numbers in *half-minute counts*. Note that it is not necessary to distinguish Leonids and non-Leonids anymore.

Meteor magnitudes are very essential to obtain physical parameters of the meteoroid stream. They are in fact needed before any ZHR computation to derive the population index which then goes into the ZHR for correction reasons. Please try to report meteor magnitude even if activity goes really high. If you speak onto a tape, just let the tape run and speak a sequence of numbers "three-four-four-one-three-minus two-four" onto the tape. Again, the distinction between Leonids and non-Leonids is not essential for rates above 5 meteors per minute, since the vast majority of meteors are Leonids, and the contamination with Taurids and sporadics is negligible.

In the case of a storm, if you have to choose whether to omit the shower information or the magnitudes, *omit the shower information first*. You will certainly have the impression that your magnitude estimates are closer to a lottery than to scientific data acquisition. Naturally, the quality of the individual population index will be poor, but remember the huge amount of data which even then allow to filter out meaningful results.

Since you will have little time to determine the limiting magnitude, it would be best to make a short break for the lm-counts. It is understandable, that observers will not like a break amidst highest activity. As a compromise, the *lm-counts before and after the peak should be interpolated* smoothly for the one-minute or half-minute counts.

3. For non-storm observers

Observers not located in America or eastern Asia—in particular observers western Asia, Europe, and northern Africa—are very much encouraged to carry out careful Leonid observations, too.

As it is again most difficult to predict the activity between the peaks, observers should be prepared to see high activity as well. Five-minute counts should be the rule for Leonid reports. For any activity exceeding that of a normal Perseid maximum, one-minute counts are again requested.

4. General instructions

Observations should preferably sent by e-mail to the Visual Commission of the *IMO*; the data are collected by the author. Send data to `visual@imo.net`. If, for some unforeseen reason, the *IMO*-domain is not working, please use `rarlt@aip.de` instead. We would like to ask the observers to send plain ASCII files. These are files created with an "Editor" or "Notepad" and have typically the extension `.TXT`. *Never send files created by MS-Office programs "Word," "Excel," or "Access,"* since these formats are PC-dependent.

If you type in your magnitude distributions, please use "–" or "0" for empty columns to make the table unambiguous. If you type in your report in a mail program on a PC, please choose "Courier" as the character font. This ensures tables being aligned properly.

Observing reports submitted by postal mail should be directed to *Rainer Arlt, Friedenstraße 5, D-14109 Berlin, Germany*. The standard *IMO* form will not be sufficient for all the periods; a similar, hand-made form is well suited instead.

As you will report very short observing periods, use three or even four decimals for the effective observing time. Below six minutes, there should be two significant digits left for accuracy reasons. A period of four minutes duration is thus $0\overset{h}{.}067$, a half-minute period will be $0\overset{h}{.}0083$.

An error often occurring regards the period boundaries. If you report five-minute periods, these are for example: 01^h00^m–01^h05^m, 01^h05^m–01^h10^m, 01^h10^m–01^h15^m, and so forth. These periods have a duration of five minutes each. Reporting 01^h00^m–01^h05^m, 01^h06^m–01^h11^m, 01^h12^m–01^h17^m *is not correct*. It is obvious that, in this case, you observed for 17 minutes, but your total $T_{\rm eff}$ is only $0\overset{h}{.}250$ instead of $0\overset{h}{.}283$. In general, if you could not match the begins of the minutes with your periods, please also report times with seconds: e.g. $01^h00^m40^s$–$01^h01^m30^s$ (giving $0\overset{h}{.}0139$ duration).

5. Summary

Here are the main issues of Leonids storm watching again:

- *Activity of more than 20 meteors per minute*: Report half-minute periods, distinction Leonids/non-Leonids not necessary.
- *Activity of at most 20 meteors per minute*: Report one-minute periods, distinction Leonids/non-Leonids if possible, but not essential.
- *Report meteor magnitudes as long as possible.* As rates increase, drop shower information first, then magnitudes.
- For $T_{\rm eff}$, give three decimals for periods with 1–6 minutes duration, give four decimals for periods shorter than one minute.

We are looking forward to your reports and wish clear skies at your observing location!

References

[1] R.H. McNaught, D.J. Asher, "Leonid dust trails and meteor storms", *WGN* 27, 1999, pp. 85–102.

[2] D.J. Asher, "Leonid Dust Trail Theories", *Proc. Int. Meteor Conf. Frasso Sabino 1999,* Potsdam, 2000, pp. 5–21.

[3] E. Lyytinen, T. van Flandern, *Meta Res. Bull.* 8, 1999, pp. 33–40.

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

Leonids—Weather Prospects in Asia and Australia

Hartwig Lüthen

1. Introduction

According to the dust trail model [1] the Leonids will display three peaks in 2001, all of which have been suggested to rise to storm levels. On November 18, 10^h01^m, an encounter with the 1767 trail will favor observers in North and Central America. A double peak at 17^h30^m and

18^h20^m UT is expected to occur due to the passage of the 1699 and 1866 trails and will be observable from eastern and central Asia and from Australia. Although there is still a lot of confusion concerning the expected rates, a number of observers will travel to remote areas to witness the event. American weather prospects have already been outlined in [2]. This paper will therefore focus on the prospects for Asia and Australia.

Generally, a fine site for observing the Leonids is expected to promise a radiant high in a dark sky during the predicted maximum times and an excellent weather statistics. But in real life, such a site is difficult to find. November marks a worldwide time of transition with unstable weather conditions. It appears there is no place with the radiant high in the sky and guaranteed weather prospects, but there are again regions which offer an acceptable compromise.

2. Asia

Around mid-November, high pressure tends to build up over continental northeastern Asia. However frontal systems sometimes cross this area from NW to SE. Weather statistics in Mongolia are quite promising. Therefore, this country was the target of the *AKM* Leonid expedition in 1998. This year, the radiant will be a little low (Table 1). Local infrastructure is sparse, and temperatures tend to be extremely low. In the night of the maximum of 1998, we struggled with temperatures of $-30°$ C. A bit more to the east, in northeastern China, the weather statistics are also excellent, with similar extremely low temperatures. The difference is that the radiant climbs to significantly higher altitudes at the predicted maximum times. A problem in both regions is the restricted mobility. It will be difficult to escape unexpected clouds.

Table 1 – Some statistics for a few locations in Asia and Australia

Location	Probability for clear skies	Radiant elevation ($17^h30^m/18^h20^m$ UT)	Begin of twilight (UT)
Ulan-Bator, Mongolia	82%	20°/28°	22^h14^m
Harbin, NE China	86%	32°/42°	20^h52^m
Taegu, Korea	75%	36°/46°	20^h52^m
Taiwan	70%–83%	27°/38°	20^h53^m
Cairns, Australia	76%	32°/40°	18^h16^m
Mount Isa, Australia	63%	24°/33°	18^h32^m
Alice Springs, Australia	63%	19°/28°	18^h48^m

South Korea (North Korea does not permit the import of optical instruments with a power of 6× or more) offers the highest radiant altitude in continental Asia. Due to the proximity of the ocean, the climate is milder, but weather changes more frequently than in central Asia. The probability of cloudiness is higher, but the traffic system is well developed. It should be much easier to travel around. If, for instance, clouds move into the eastern coastal regions it should be easily possible to reach the other side of the peninsula. Taiwan offers similar conditions. Japan's higher price level and its inferior cloud statistics makes this country a less favorable target for a Leonid expedition from America or Europe.

3. Australia: Meteors down under

At the very northeastern coast of the continent, the radiant will rise to similar altitudes as in Korea. However, morning twilight will begin during the maximum. The declining slope of the double peak will thus fall into bright twilight or daylight. Moving a bit to the southwest will increase the time between the maximum and the beginning of the twilight, but every mile will decrease the altitude of the radiant at the predicted maximum times. Generally, the cloud statistics are quite fair. However weather during the early Australian summer changes from year to year, but also from hour to hour which may make even last-minute predictions difficult. The well-developed traffic system should permit to escape upcoming clouds. However, it appears that driving at night in the outback can end in dangerous collisions with kangaroos.

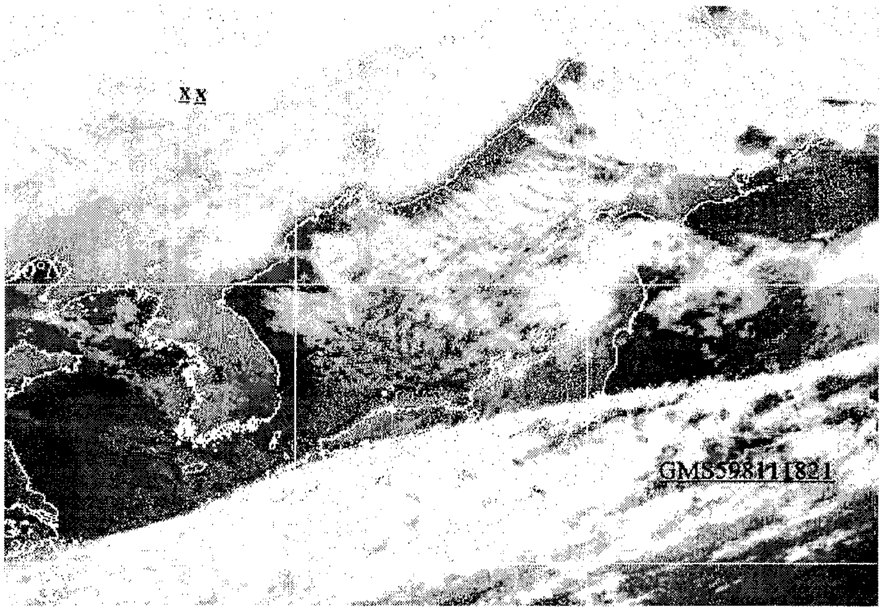

Figure 1 – Typical satellite image (GMS 5), taken on November 18, 1998, 21^h00^m UT. Northeastern China and Korea are free of clouds, whereas parts of Japan and the South-Chinese Sea are partly clouded out. Crosses mark prospective observing sites near Harbin (northeastern China) and in South Korea.

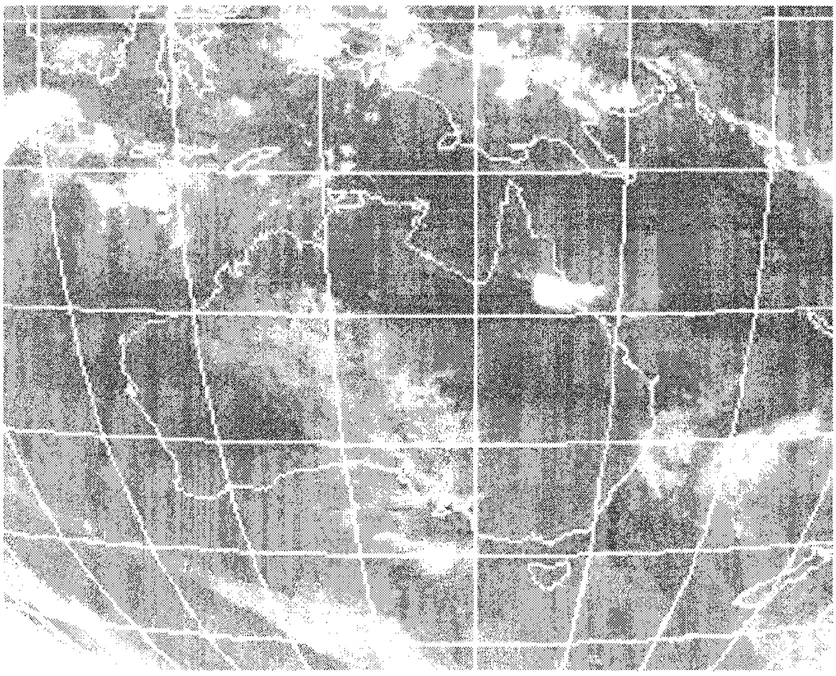

Figure 2 – Satellite image of Australia and Oceania taken at the same time as Figure 1. Large parts of the continent are free of clouds, promising fine conditions for Leonid observations. However, both the region of Cairns and Alice Springs are overcast.

References

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

[2] H. Lüthen, P. Rendtel, "Clear Skies for the Leonids", *WGN* 28, 2000, pp. 143–149.

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Improved 2001 Leonid Storm Predictions from a Refined Model

Esko Lyytinen, Markku Nissinen and Tom Van Flandern

It is expected that the cumulative non-gravitational effect on the semi-major axis in the dust trails that produce meteor outbursts is an important factor affecting the particle spread along the orbit and therefore the apparent ZHR behavior. In this work, we determine a numerical value estimate of this effect from earlier observations, mainly those from the year 2000. Besides getting a better post-prediction of the course of the ZHR curve, we also find that the observed maximum ZHR value of the 8-revolution outburst (1733) is better explained with the new model when the derived non-gravitational A2 distribution is taken into account. The model and newly derived parameter values are used to improve the predictions for the year 2001. The predicted outbursts for the year 2002 have not yet been treated in this way.

1. Introduction

This work is a logical continuation of earlier work on Leonid outburst modeling [1]. Similar methods used by two other, independent groups [2,3] are now well-verified by the generally good fit of their predictions for time and peak activity of the meteor outbursts in 1999. The method calculates the position of particles released on different revolutions near the Sun, which form several narrow dust trails or trailets on subsequent return. Our most recent predictions for 2000 [1] again validate the technique, but leave some room for improvement.

The basis of our work is to assume that the ejection speeds are very small, which results from the satellite model of comets (e.g., [4]). Dust trails form as a result of particles having originally different orbital periods. In our model, the ejected particles will have different orbital periods mainly because the solar radiation pressure per particle mass differs from particle to particle.

Non-isotropic scattering and emission of absorbed light can cause spreading of the grains away from the trail center, which will determine the shape of the ZHR profile [1]. In principle, the spread can be considered consisting of two factors, the direct spread and the A2-effect. The direct spread consists of effects that directly perturb the particles in a way that cause spread at each revolution. We assume this proportional to revolution number. This proportionality is not a result of Newtonian inertia, but requires non-gravitational perturbations at each revolution. The most important cause of the direct spread is thought to be non-isotropic reflection of solar radiation [1; *Earth, Moon and Planets*].

The A2 effect includes all non-gravitational processes that change the meteoroid orbital period at each orbital revolution. According to our earlier study [1; *Earth, Moon and Planets*], the principal cause of the A2 effect is thought to be the seasonal Yarkovsky effect. In principle, the amount of change may be different in each orbital revolution but, without better knowledge, is considered constant (within each particle) in this model. The change of orbital period itself does not change the path of the particles (near perihelion), only the timing. Without planetary perturbations, this effect would not cause particle spread away from the trail center. However, the encountered planetary perturbations are slightly different as compared to the basic solution where $A2 = 0$, thus causing the spread. Typically, the effect is minor in young trails, but appears to be important with older trails. In first order, the additional spread will make the observed ZHRs smaller, as is typical with very old central encounters of dust trails. However, for non-central encounters, this effect can also bring particles closer to Earth orbit and even increase the ZHR.

Here, we study the effect on the peak activity and the ZHR profile of various degrees of the A2 effect. We go a step further than previous work, by not only fitting the time of the peak, but also the shape of the ZHR curve. The next section describes the model in detail. Results are in Section 3.

2. Modeling

We assumed the basic model presented in [1]. Analysis of the 1999 Leonid MAC flux measurements showed the ZHR curve to have a Lorentz profile [5]. In the basic model, the formula of direct spread in the orbital plane (in the direction of the Sun) resembles that of the Lorentz distribution but has an additional power over the denominator (1.35). With a value of 1 the distribution would reduce to the Lorentz distribution. Although we originally assumed this constant to be the same as in the distribution normal to the orbital plane (that corresponds to the observed shape of ZHR curve), it now appears that, in the direction-normal-to-the-plane case, the value 1 is probably a better one [5]. So we adopted the value "1" in the normal direction.

The distribution perpendicular to the Earth's path in the direction of the Sun is wider than in the direction normal to the parent comet orbit. This conclusion is true for the inner core of trails, but less so for the outer edges of trails, because of the adopted different power laws. The trail density can be traced in the direction normal to the normal while the Earth passes trough the trail, but not in the direction of Sun. In this direction, conclusions can be drawn only form observations of different encounters. Especially important was the encounter with the 2000 2-revolution trail of 1932 on November 16-17. This was a fairly distant encounter and thus sensitive to how quickly the dust falls off away from the trail center perpendicular to the Earth's path. We found that, in this direction, the exponent value of 1.35 found earlier would fit the data [6] well.

For each encounter, the basic model gives a "characteristic width." In the Lorentz distribution, this parameter is the half-strength half-width, but, in the more general case, it does not match the half-strength. With the exponent value of 1.35, the parameter corresponds to the 39% strength level.

The basic model gives the direct spread parameters that vary in different encounters. This is a consequence of the basic ZHR model. In this model, the trail width (without the A2 effect) is proportional to the original Δa multiplied by the orbit number. This requires two parameters, one corresponding to the spread in the orbit plane (to the direction of the Sun) and the other orthogonal to it. These are proportional to each other. The latter parameter needed a calibration based on observations (as derived from Lorentzian half-widths for young trails). The 1999 storm data (see [5]) was used because the calibration requires a reliably observed encounter of young trail. The value arrived at is also consistent with the values derived from the storm 1966 [5] and the 2-revolution trail encounter in 2000 [6]. The consistency with the 1966 data in [5] however gives a smaller maximum ZHR than most other sources and the derivation of width is not independent of the reached maximum value.

The A2 effect is modeled in the trail calculation program with a speed change at each perihelion. The speed change is expressed relative to the speed itself. A speed change of 10^{-6} changes the orbital period by about 3/4 of a day each revolution. It is assumed that this speed change has a Lorentzian distribution. The A2 Lorentzian width parameter (half-strength half-width of the distribution) is given as millionths of the actual speed.

For each studied encounter, we ran a number of computer simulations varying the A2 value. The results were gathered in a spreadsheet model. This spreadsheet model then calculated the ZHR values for different solar longitudes by weighing the data according to the A2 value and distribution parameter and added the direct spread effect according to principles in [1] and Section 2 of this paper. Calculated ZHR values were then fitted to observed curves by adjusting two variables: a factor directly affecting all the values, and the A2 spread half strength parameter. In this, the position in solar longitude was not a free adjustable variable.

From each of the program runs, the particles that crossed the ecliptic plane in a specified time window were accepted into the model. In most cases, the window was from ten days before to ten days after the outburst. In the spreadsheet model, the solar longitude interval is $0\overset{\circ}{.}005$. In order to arrive at the distribution (by solar longitude), the model calculates the contribution from each accepted particle. The contributions are calculated according to the direct spread functions and further weighed according to the A2 value in question and the A2 spread half-strength parameter.

Even though each selected particle in the spreadsheet model contributes to the model's ZHR curve, the calculations may be best understood according to the following explanation that is in principle equivalent to the true calculations: the trails from different A2-value modeling can be treated as separate, and the ZHR-curves from each one can be calculated as in the base model. Then the results are summed, each different A2 result weighed according to the A2-width parameter and the assumed Lorentz shape of the A2 distribution.

3. Results

The 2000 encounters

On November 17-18, 2000, Earth passed at some distance from the dust trailets ejected in 1932, 1733, and 1866. The second (1733) trail encounter was observed from Europe, the first and third from the United States. The Last-Quarter Moon disturbed the observations, which are not as reliable as at other times. The A2 modeling is done for the older trails (8 and 4 revolutions) only. Arlt et al. [7] gathered the data submitted to the *IMO* and found peak ZHRs of 270 and 450, respectively, shown in Figure 1. The *IMO* data are approximated at 0°01 spacing. This is also true for the comparison graph.

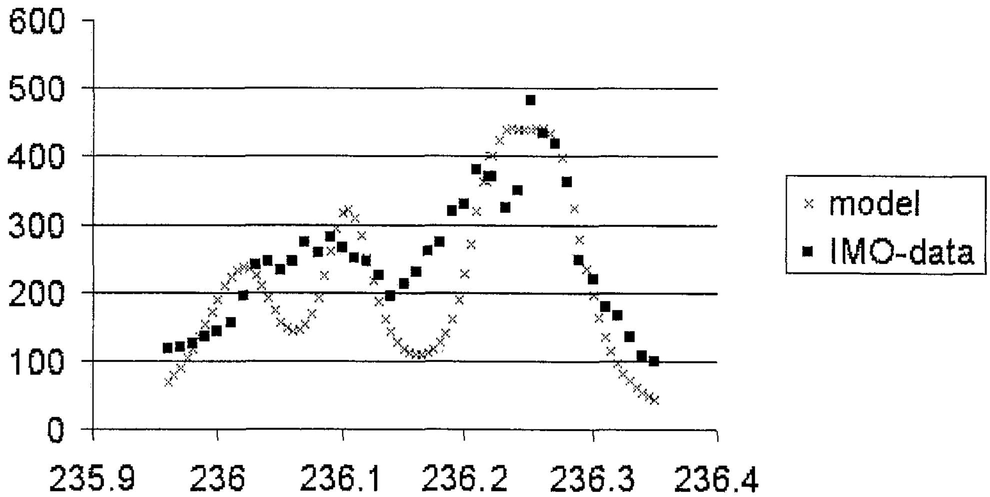

Figure 1 – Model fits for the 4-revolution (1866) and 8-revolution (1733) trails added and compared with the *IMO* compilation of Leonid Zenithal Hourly Rates.

Table 1 – Results from curve fits (those with derived A2 half-width parameters are with the fits by means of model parameters: the others are "free" Lorentz fits)

Year	Trail	$r_E - r_D$	Δa	(derived) A2 h.-w.	ZHR	$\lambda_\odot$	Source
1999	1899 (3-rev)	−0.0007	0.139		3300	235°285 ± 0°001	[5]
1999	1866 (4-rev)	+0.0016	0.081		180	235°87	[9]
2000	1733 (8-rev)	+0.008	0.065	3.2 ± 1.0	305	236°103	[7]
				double-peaked	231	236°020	
2000	1866 (4-rev)	+0.008	0.116	7.1 ± 1.5	432	236°257	[7]
2000	1866 (4-rev)	+0.008	0.116	4.9 ± 1.0	720	236°267	[8]
2000	1866 (4-rev)	+0.008	0.116	4.3 ± 0.7	420	236°272	[6]
2000	1932 (2-rev)	−0.0012	0.30		270	235°274 ± 0°003	[6]

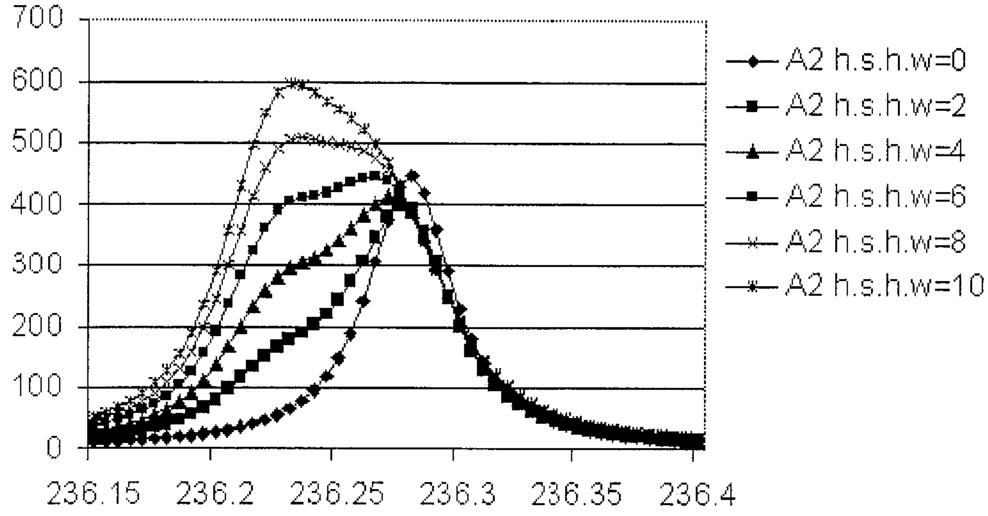

Figure 2 – The 2000, 4-revolution (1866) ZHR change with A2-distribution width parameter (half-strength half-width). Best fits around 4 to 7; data from [7,8]

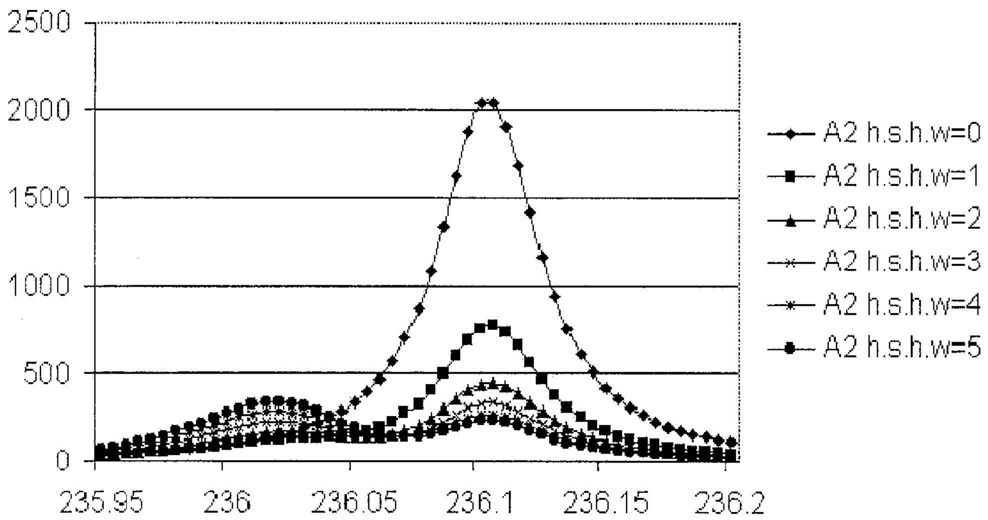

Figure 3 – The 2000, 8-revolution (1733) ZHR change with A2-distribution width parameter. Best fit 3.2; data from [7].

We needed values that correspond to the values that we have in our A2 model, for least-squares fits. Different fits are shown in Table 1. The fits with derived A2-width parameter are fits with the A2 model. There are only two free parameters in it, namely the A2-width parameter and the other that corresponds to the strength (linearly). The solar longitudes for these fits refer to the highest point in the corresponding graph, except for the 8-revolution encounter, for which the model clearly gives two peaks. The other fits are typical ("free" Lorentz) fits.

Figures 2 and 3 show how the 1866 (4-revolutions) and 1733 (8-revolutions) ZHR curves behave upon altering the A2 distribution-width. For the 1866 trail, the effect of increasing the A2 width parameter is a shift of the peak time of the outburst earlier in time and a flat-topped profile. For the 1733 trail, we find a large difference between the cases with A2 width parameter equal to 0 and the case with A2 width parameter equal to 1, where the peak activity has dropped significantly. Without an A2 effect, the encounter would have happened with a short piece of trail. Even with a small A2 effect, however, the piece will disperse effectively. The increase of the A2 width parameter gives rise to a second maximum earlier in time (see Figure 3). In the A2-parameter fits, some share from the other nearby peak was subtracted, but no annual background was subtracted.

It is expected that the A2 parameter value increases with the original Δa (a being the orbital semi-major axis or "mean" distance). It is not expected that this dependency truly is a simple power law over a wide range of Δa. However, by lack of better knowledge, a simple power law is assumed in the predictions. In the 2000 4-revolution data, more weight is given to the [6] and [8] data than to [7], because of a better fit with the model curve and their better mutual consistency. We accept power 0.7 and expect the curve go trough the 2000 8-revolution data point.

The trail profile of the 2000 encounter with the 1932 trail (2-revolutions) is not well recorded in the *IMO* compilation [7], but a more accurate profile (Figure 4) was obtained from aircraft. Figure 4 [6] also shows the fit to similar data from the 1733 and 1866 trails. The 1932 trail is the best example of a large passing distance with no expected A2 effect. In general, with such a 2-revolution trail, the apparent effects of changing the A2 width parameter are small and indistinguishable within the original Δa distribution. The effects typically increase quite rapidly from around 4-revolutions upward. It is also very much dependent on each individual case, reflecting close encounters with Jupiter. Indeed, we find a generally good fit to the 1932 dust trail data even without A2 effect. A good fit is obtained for a Lorentz width value consistent with the 1999 storm, rather than an increased width with $r_E - r_D$. We conclude that much of the spread perpendicular to the Earth's orbit (in the comet orbit plane) occurs as an accumulation in later revolutions.

The year 2000 data were also applied to update the course of the function fn(Δa) in the basic model. The function fn gives the ZHR of a 1-revolution encounter at exact hit. A relatively good fit with the earlier approximation was achieved, although the 4-revolution *IMO* data gives a point somewhat (almost by a factor of 2) below the general profile. (The fitted McLeod data have an agreement with the general profile to better than 10%.) The earlier-known 11-revolution encounter in 1903 and the newly found 8-revolution encounter in 1868 were also used for this purpose. In addition, a re-treatment of the 1866 storm was done according to the A2 model. The fn values in the smaller Δa range (below 0.1 AU) were increased because of new data points. The result is shown in Figure 5. In the constructed numeric model (fit curve), the 1999 storm data point was given more weight than the other points nearby.

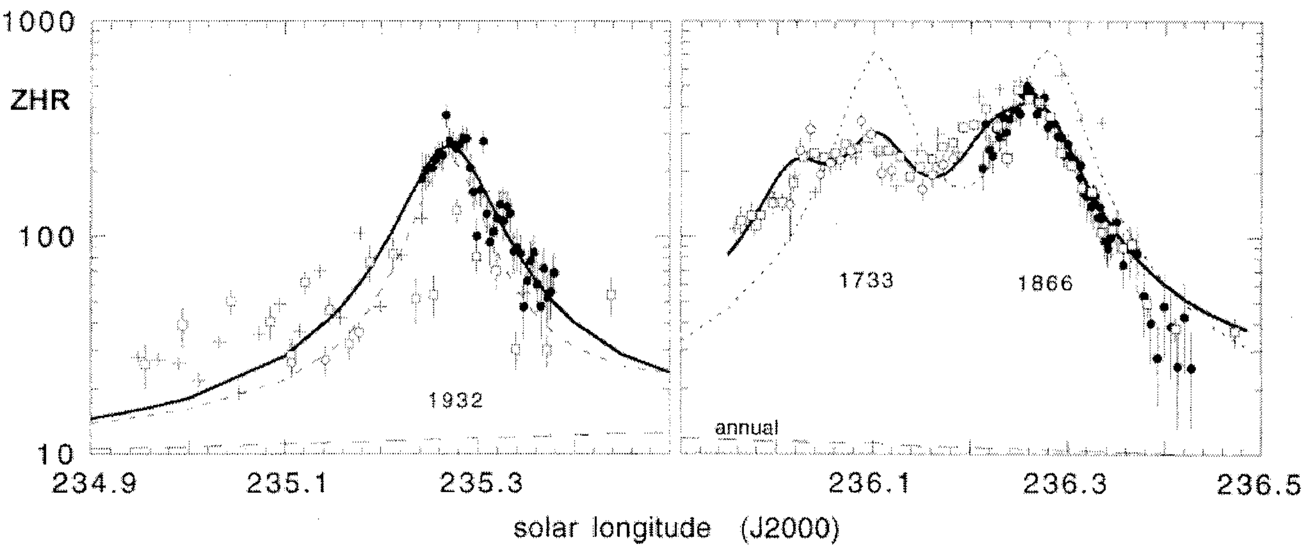

Figure 4 – Fit to the 1932, 1733 and 1866 dust trails in the 2000 encounter, from aircraft measurements (*courtesy of P. Jenniskens and B.-S. Gustafson*) [6].

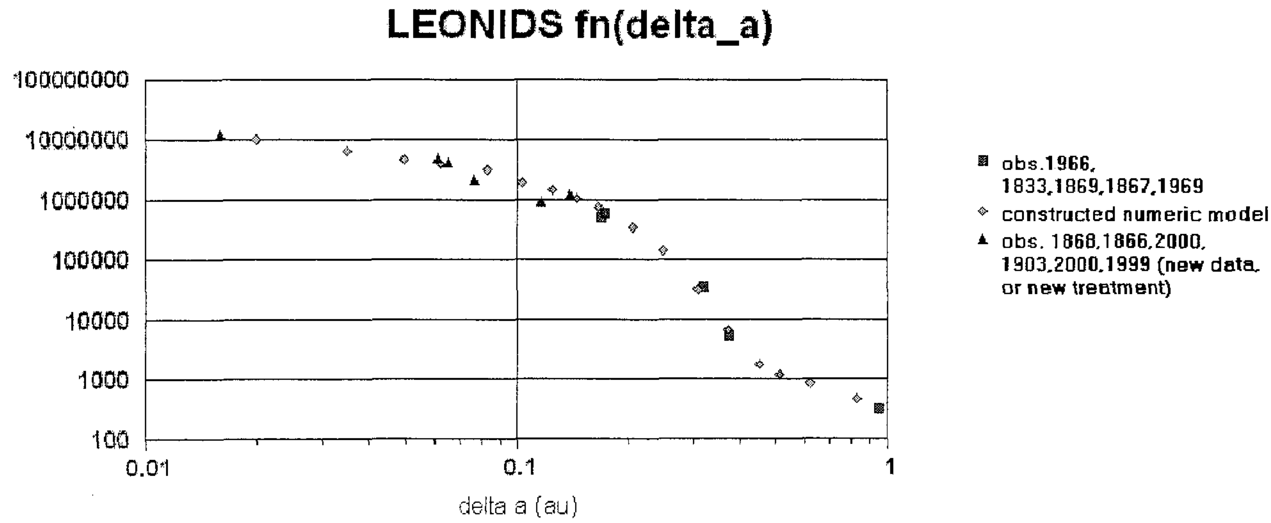

Figure 5 – The function fn(Δa). (The 1866 and 1999 data points have been moved to the "new data group" after applying an A2 model.)

Further refinements from the 1999 encounters

The 1866 passage during the 1999 encounter is interesting because of the large Δa involved (Table 1). The nominal miss distance $r_{\rm E} - r_{\rm D}$ is about +0.0016 AU. Interestingly enough, the observed maximum time was significantly earlier than predicted.

We now find that the A2 effect with assumed Lorentz shape and parameter values will bring particles closer to the Earth's orbit at the observed time ($\lambda_\odot = 235.^\circ8$–$235.^\circ9$). The effect on the flux rate is not large (Figure 6), however, because the perturbation is not quite strong enough.

In order to bring the particles sufficiently far in, one has to introduce an additional amount of the particle's direct spread. We introduced a very small additional direct effect to $r_{\rm D}$ directly proportional to the A2 value. That does result in an activity curve much as observed (Figure 7). The direction of the increase is as expected from non-symmetric reflections on dust grains (assuming the A2 effect is caused by the seasonal Yarkovsky effect).

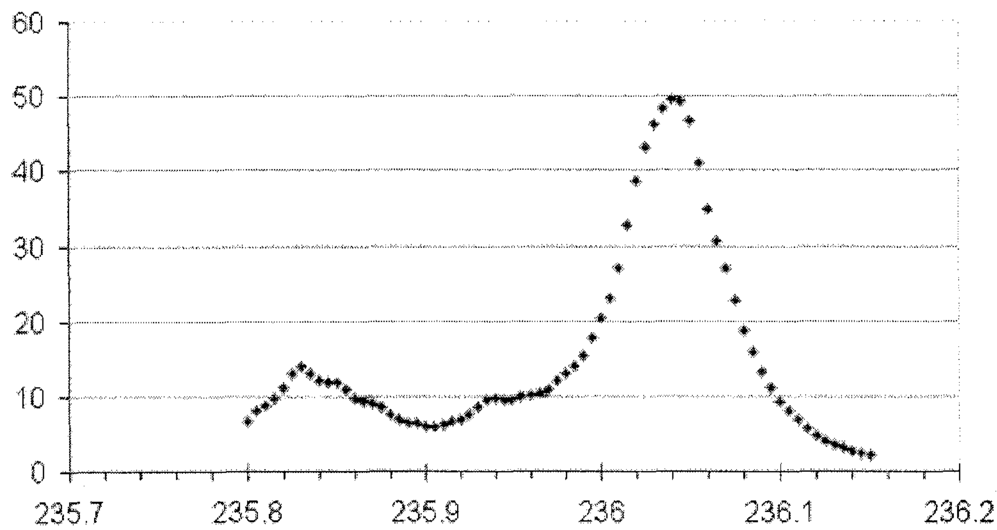

Figure 6 – The 1999 encounter of the 1866 trail. The A2 effect introduces a feature at $\lambda_\odot = 235.^\circ8$–$235.^\circ9$. The A2 width parameter is 3.7.

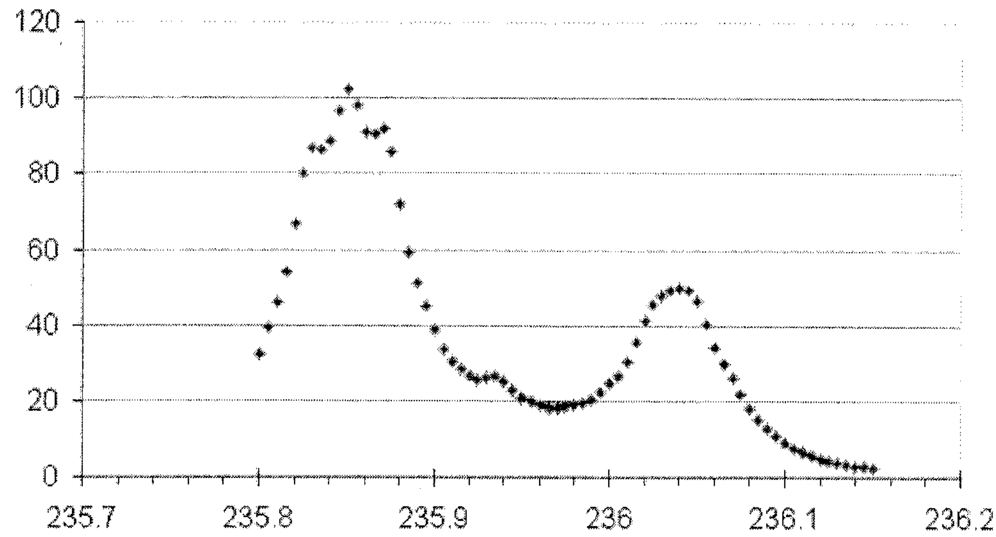

Figure 7 – As Figure 6, with an additional slight dependency on the A2 width parameter in the direct spread. The feature is much enhanced and in good agreement with observations. The A2 width parameter is 3.7 and the additional r_D dependency ("shift") is 0.000008 AU times the (particle) individual A2 value (in millionths).

Applying this so-modified model to the 2000 4-revolution and 8-revolution trails did not improve the fits, however. Indeed, the effect is thought to be important only for very large A2 values and other explanations may account for the particles being closer to the Earth's orbit. Given the limited amount of justification for such an additional complication, we will for the time being not include the additional direct effect described above in our ongoing work.

4. Predictions for the year 2001

In November 2001, the Earth is about to encounter several dust trails ranging from 4 to 11 revolutions old. The encounters with the 4-, 7-, 9, 10, and 11-revolution trails were treated with the A2 model to improve predictions of ZHRs and peak times. The Δa values are known from earlier work [1], and the assumed direct proportionality gave values for this parameter to be used in the predictions. The results are shown in Table 2 and in Figures 8 and 9.

Most interesting is the 7-revolution encounter, which is visible in the Americas, because it is expected to give new data for the A2 distribution. This trail encounter is not disturbed by other nearby trails. The A2 effect seems to shift the maximum later by almost half an hour, to 10^h28^m UT (November 18). Figure 9 shows the predicted ZHR-curves for different A2 distribution parameter values. There is only a very small effect in the maximum value but a clear shift and widening of the peak with increasing A2 width. An A2 width parameter value of about 4 was assumed to give the best prediction, based on the previous section.

A parameter value close to 4 is used for the 7-revolution trail encounter prediction. The strongest storm peak of the 4-revolution (1866) encounter is only very little affected by the A2 effect. Typically, central encounters with young trails are very little affected. The modeling shifts the 4-revolution trail encounter maximum only about five minutes earlier and keeps the maximum ZHR practically unchanged. The peak is anticipated at 18^h14^m UT (November 18).

This study resulted in an increase in the fn(Δa) profile by a factor of about 2 (compared to its counterpart in [1]) in the small Δa range that corresponds the encounters with the 10- and 11-revolution trails. The most remarkable result, however, is a marked asymmetry in the ZHR profiles. This asymmetry may be detected as a tail in the storm profile after the main peak. The 9-revolution trail encounter is predicted to be somewhat shifted towards the 4-revolution storm and occurs almost simultaneously and inseparably. With the 9-revolution trail encounter, fn increases by a factor 1.75 (as above), yielding a maximum ZHR of about 2600.

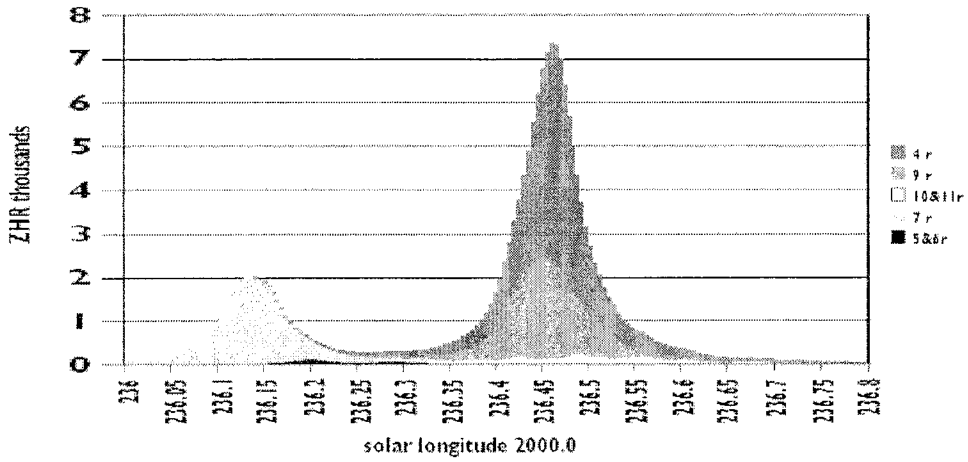

Figure 8 – The predictions for the year 2001 (stacked bars).

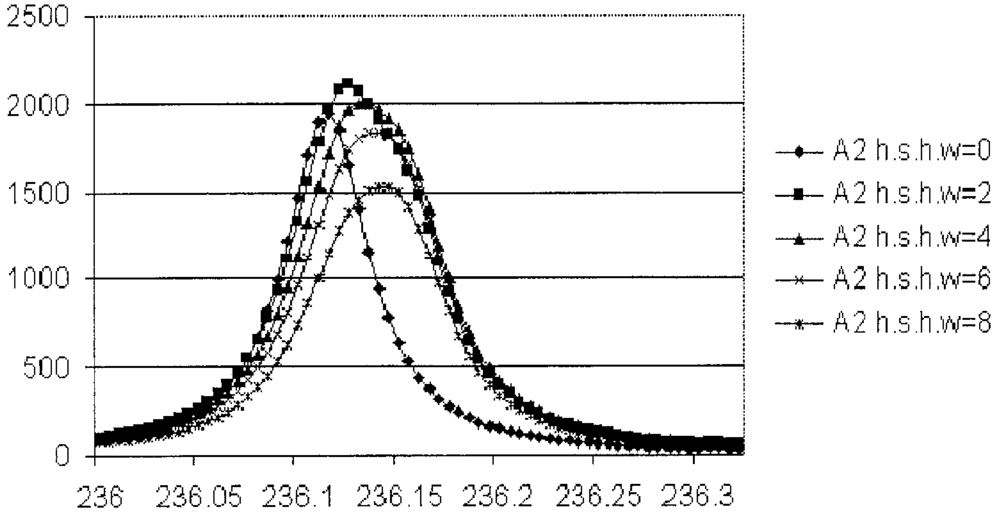

Figure 9 – The 2001, 7-revolution trail encounter ZHR-change with A2-distribution width parameter.

Table 2 – Predictions for 2001, in UT. Conversion into J2000 solar longitudes, on November 18, 2001, were made according to the formula $\lambda_{\odot} = 235\overset{\circ}{.}692 + 1\overset{\circ}{.}009 \times d$, where d is the time in days from the start of the day (November 18, 0^{h} UT). The predicted peaks values for trails 10 and 11 are rounded to the nearest ten minutes.

Trail	Nodal encounter (in original model)	Predicted peak (in A2 modeling)	Half-width (minutes)	ZHR
4 – rev	$18^{\mathrm{h}}26^{\mathrm{m}}$	$18^{\mathrm{h}}20^{\mathrm{m}}$	43	5000
5 – rev	$14^{\mathrm{h}}10^{\mathrm{m}}$	A2 modeling not applied	(29)	60
6 – rev	$12^{\mathrm{h}}00^{\mathrm{m}}$	A2 modeling not applied	(30)	110
7 – rev	$10^{\mathrm{h}}04^{\mathrm{m}}$	$10^{\mathrm{h}}28^{\mathrm{m}}$	58	2000
		(non symmetric	$-53/+62$)	
9 – rev	$17^{\mathrm{h}}38^{\mathrm{m}}$	$18^{\mathrm{h}}03^{\mathrm{m}}$	62	2600
		(non symmetric	$-58/+65$)	
10 – rev	$17^{\mathrm{h}}23^{\mathrm{m}}$	$19^{\mathrm{h}}10^{\mathrm{m}}$	≥ 140	150
11 – rev	$17^{\mathrm{h}}26^{\mathrm{m}}$	$19^{\mathrm{h}}10^{\mathrm{m}}$	≥ 90	150

We did not make full A2 models for the 5- and 6-revolution trails, but we made trail integrations with a few A2 values. The results show that there is no major enhancement because of the effect. Because these outbursts are predicted to be quite weak and are not expected be observed as separate peaks, we did not make a more elaborate study on these.

5. Discussions

In general, according to this study the A2 effect is stronger than assumed in the early days of trail modeling. It cannot be concluded from this study how good an approximation the Lorentz distribution shape is for the distribution of the A2 effect. However, it is expected that the width of the distribution have greater relevance to the predictions of strong outbursts than the adopted shape.

The model does not produce an exact match with the observed ZHR curves during the 2000 encounter (see Figure 1), but seems to give a clear improvement in post-predictions as compared to models without the A2 effect. So, we feel confident that this is a real improvement in the modeling.

This model produced two peaks in the 8-revolution (1733) trail outburst in 2000, but the observed curve did not show the peaks as distinctly. It also appears that at the edges of the encounters (and consequently also between the 4- and 8-revolution trail encounters), the observed values are typically higher than the model predicts. On the other hand, the fit to the data [8] gave a clearly better agreement at longitude $\lambda_\odot = 236\overset{\circ}{.}2$ and after that.

The model assumes that the precession of the particle spin axes is negligible and that the radiation pressure effect will be the same in each revolution. This is probably only a coarse approximation. It is probable that some dependency or correlation exists between the direct spread and the A2 value within the particles. These were assumed mutually independent in this study. A treatment of the 1999 distant 4-revolution (1866) trail encounter showed increased amounts of particles around the peak observed "too early" [9], as observed, but not quite enough. A small correlation between the effects or possibly also a correlation between the widths of direct spread and A2 absolute value could explain the observations. Introducing such a correlation can not be made without further study and consideration of all the recent observations.

A further weakness of this model is that an old trail encounter, when computed according to this model, will have particles at considerably different Δa values. Because the A2-distribution width parameter itself is dependent on this Δa, one value (corresponding to just one Δa value) for the A2 distribution parameter cannot be overall the best possible.

Acknowledgements

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Ongoing Meteor Work

Thirteen Years of Lyrids from 1988 to 2000

Audrius Dubietis and Rainer Arlt

The whole set of observations of the *Visual Meteor Database* was analyzed to obtain population indices and activity profiles of the Lyrids between 1988 and 2000. The combined activity profile of the shower delivers a maximum with $ZHR_{max} = 18 \pm 1$ at $\lambda_\odot = 32.^\circ 32$. The time of maximum varies though; deviations of peak times from the average come along with lower maximum ZHRs. Strongest variations are shown by the peak width; the FWHM varies from $0.^\circ 6$ to $2.^\circ 5$. The population index near the maximum is 2.0–2.1. Additionally, a jump in the population index to 2.3–2.5 right at the time of maximum is found in several profiles, a feature which was already detected earlier this century.

1. Introduction

The annual activity of the Lyrid meteor shower delivers about 10–15 meteors per hour at maximum with the radiant reaching appreciable elevations above the horizon for all northern hemisphere observers before dawn.

The Lyrid meteor shower belongs to a category of meteor sources which occasionally exhibit enhanced activity, but are not easily accessible to modeling because of the long orbital period of more than 100 years. The parent comet, C/1861 G1 (Thatcher), has an orbital period of 415 years, and even finding the precise perihelion passages in the past, which give the start points of the particle motion, is not very accurate.

Outbursts of Lyrid activity have been observed on several occasions between 1803 and 1982, giving rise to the assumption of a 12-year periodicity ([1]; see also compilation in [2]). Numerical integration of stream particles ejected at four perihelion passages of the Comet back to AD 399 shows the formation of a hollow stream in which particles perform helical motions around the orbit center [3]. The two intersections of the hollow structure with the orbit of the Earth lie at solar longitudes of $31.^\circ 72$–$31.^\circ 84$ and $31.^\circ 94$–$32.^\circ 06$. The observed outbursts only cover the second intersection with this ring stream. No dust trail integrations such as those giving precise predictions for the Leonids are available. The annual activity of the Lyrids peaks later as shown in this analysis.

Although 1994 would fit the alleged 12-year period, no outburst was predicted for that year in [4] according to empirical considerations relating the motion of solar system's gravity center to meteor outbursts. The present analysis confirms that prediction but cannot entirely rule out a short-lived feature in the activity profile.

Since 1988, the *Visual Meteor Database* (*VMDB*) contains world-wide data of at least the major meteor showers [5]. We are interested in the common features and possible variations in the activity profiles of the Lyrids and will describe our results below. The period covered by this analysis is certainly short compared with the orbital period, yet consistent data about activity level and peak duration of 13 years is hoped to supply information on the structure of the Lyrid meteoroid stream.

During these 13 years, 524 observers have reported Lyrid observations to the *VMDB*.

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from the following countries which cover excellently the entire globe:

Australia, Belarus, Belgium, Bulgaria, Canada, China, Croatia, Cuba, Czech Republic, Denmark, Finland, France, Germany, Hungary, India, Ireland, Israel, Italy, Japan, Lithuania, Malta, the Netherlands, Norway, Poland, Romania, Slovakia, Slovenia, South Africa, Spain, Switzerland, UK, USA, Yugoslavia.

A compilation of the datasets available to this analysis is listed in Table 1. Files of the years before 1988 are not covering the entire year and provide almost no Lyrids. For 1988, additional comprehensive data as recorded by one of the authors (AD) were included in the population index computation as well as in the activity profile. We had to omit 1989 from our population index and activity analysis because of a data set too small to be useful for meaningful results.

Table 1 – Lyrid data per year as supplied by the *Visual Meteor Database*. Note that the number of periods and the number of magnitude distributions do not mean the number of individual observers. The data set of 1988 contains *VMDB* records and the data obtained by DUBAU. The Lyrid maximum in 1989 coincided with a full Moon and delivered very poor information; that year was not included in the analysis.

Year	Rate data		Magnitude data	
	Periods	Lyrids	Distributions	Lyrids
1988	117	415	35	173
1989	12	28	1	8
1990	100	675	39	498
1991	96	473	43	331
1992	114	249	37	202
1993	337	1322	127	1162
1994	47	271	21	205
1995	365	1714	169	1713
1996	709	2663	257	2415
1997	61	142	26	128
1998	343	1182	119	1099
1999	218	924	87	610
2000	265	585	118	568
Totals	2784	10643	1079	9112

2. The population index over the years

The magnitude distributions of all single Lyrid observations are not well filled; typically less than 20 meteors are available. Individual population indices will thus not be accurate. We chose the method also used in [6, 7] for the analysis of the 2000 Perseids and 2000 Leonids. The computation of the population index involves the knowledge of the probability of detection of a meteor, which is supposed to be a function of the difference of limiting magnitude and meteor magnitude, $\Delta m = \mathrm{lm} - m$. Writing all meteor magnitudes as such differences makes all observations compatible, since the correction for detection probability will then be independent of lm. Now it turns out that the average $\overline{\Delta m}$ of all meteors is a unique function of the population index r. It thus needs a conversion table from $\overline{\Delta m}$ to r which has to be obtained only once from numerical integration.

We used this method of "stacked" magnitude distributions for the present analysis. Typically, an average r near the maximum can be achieved. The datasets of some years even allowed the derivation of an entire profile for the Lyrids' population index. There is no overlap in the data, that is, each magnitude distribution was used only once for an r-average. A compilation of four r-profiles from 1993, 1996, 1998, and 1999 is shown in Figure 1.

A peculiar feature of the of population-index profiles of 1996 and 1998 is the sudden jump of r near the maximum. Also the profiles of 1993 and 1999 show such an increase in r. All these jumps occur between the solar longitudes $32.^\circ 2$ and $32.^\circ 5$ (see Figure 1). A very similar jump coinciding with the maximum of Lyrid activity was already noticed in [8] upon analyzing data of 1945–1952. The change in r was most obvious in 1946 then—the year which saw enhanced Lyrid rates in general.

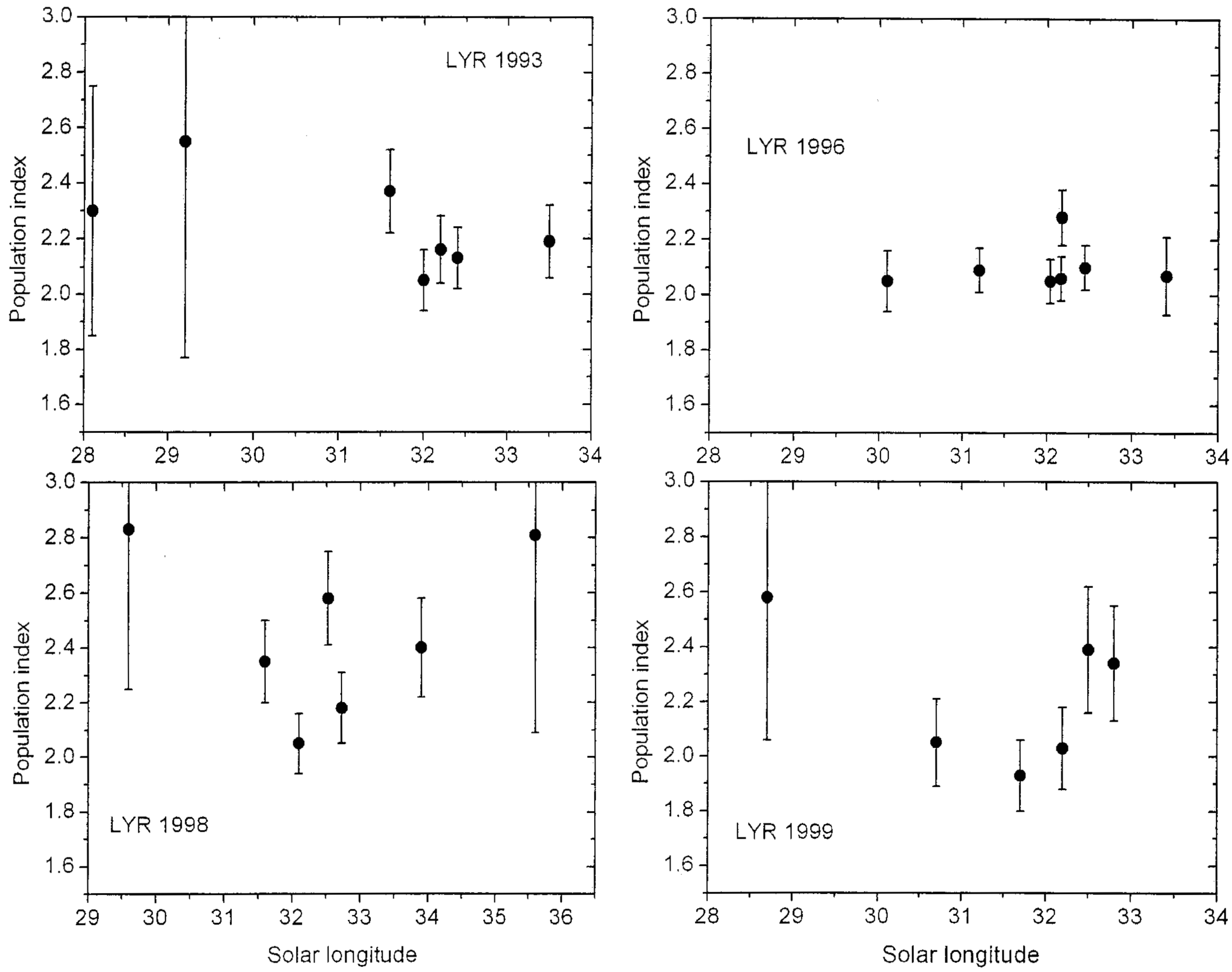

Figure 1 – Population index profiles for 1993, 1996, 1998 and 1999. An adaptive bin size was used here to keep the meteor number on which each population index is based roughly constant.

3. The activity profiles of 1988–2000

Small-number statistics will often apply to the Lyrid counts, and we use the averaging of [9] as described in detail for the 2000 June Bootids. Given the limiting magnitude lm, possible field obstruction factors F, and the elevation of the Lyrid radiant, h_R, the total correction for an individual (index i) observing period amounts to

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

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

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

Again no additional smoothing is applied apart from the overlap of periods due to $T_{\mathrm{eff},i} > 0$. No additional selection criteria for the observational data were applied, instead of

$$C_i < 5,$$

which is the standard for *IMO* data processing. The exception was made for the 2000 Lyrids, when the maximum period has been strongly interfered with the full Moon. In this case,

$$C_i < 8$$

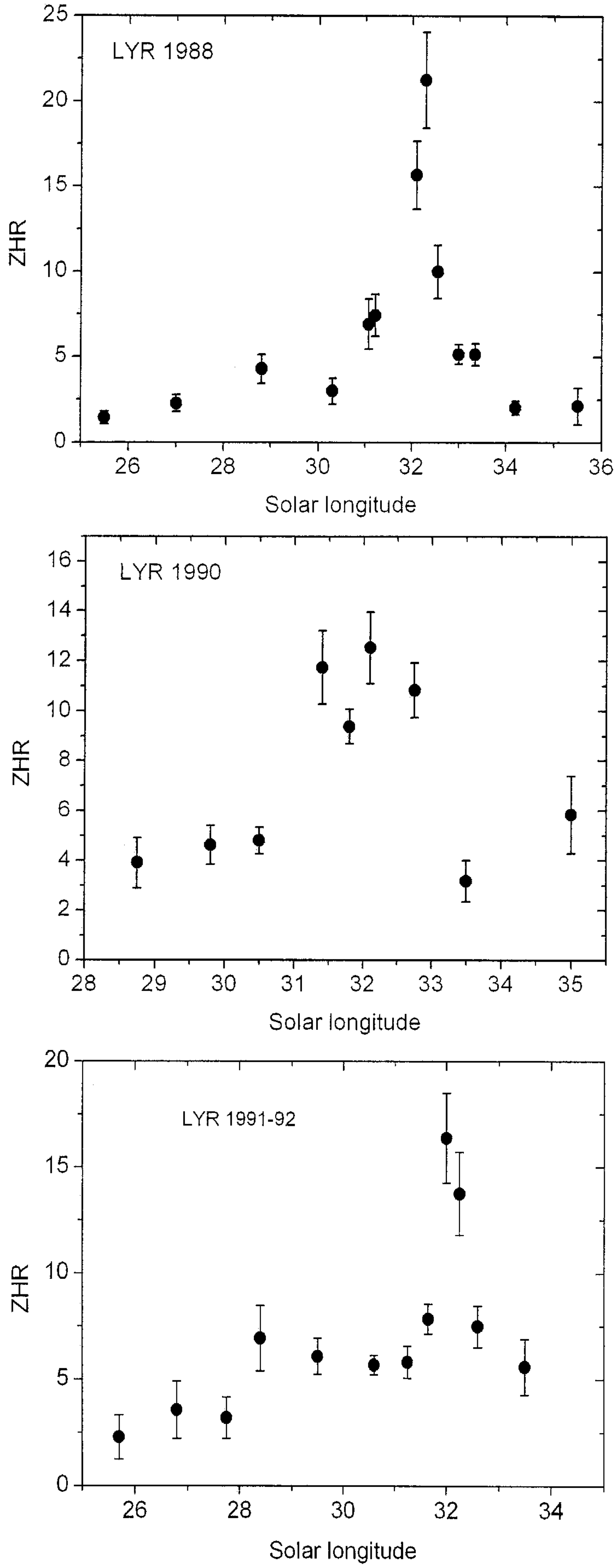

Figure 2 – Activity profiles for 1988, 1990, and a combined profile for 1991 and 1992.

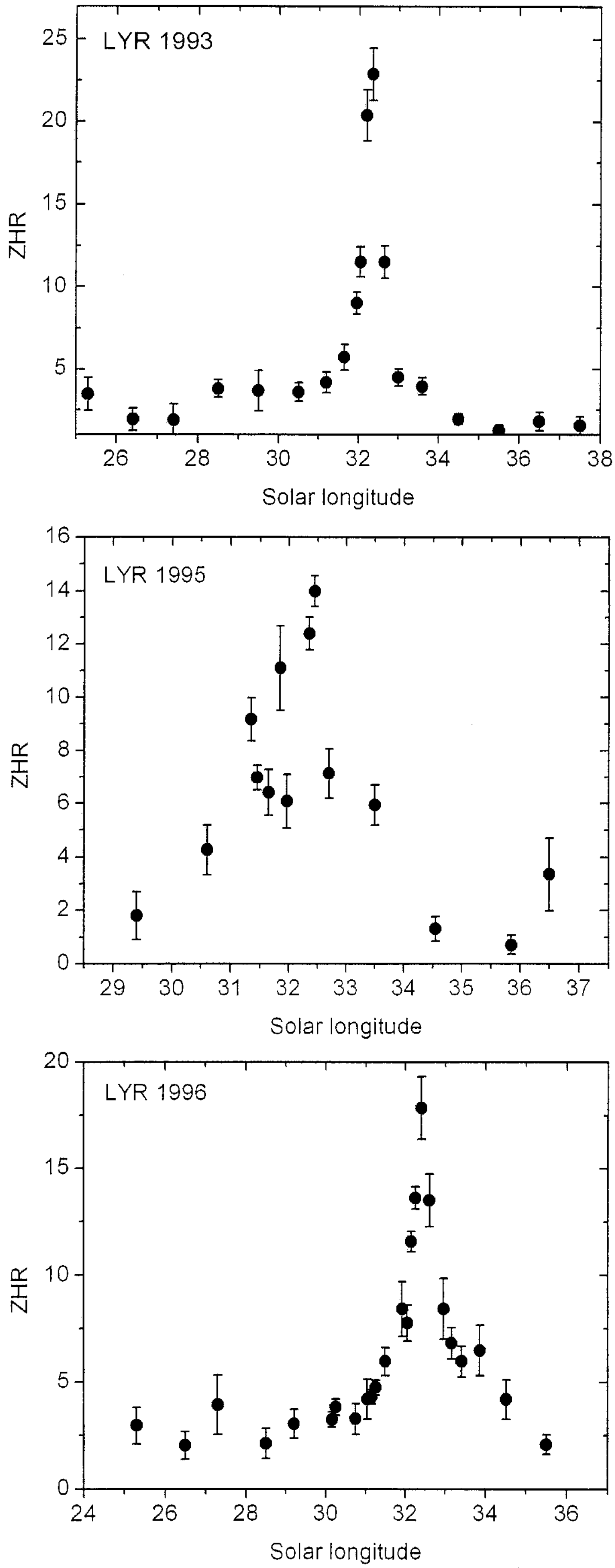

Figure 3 – Activity profiles for 1993, 1995, and 1996.

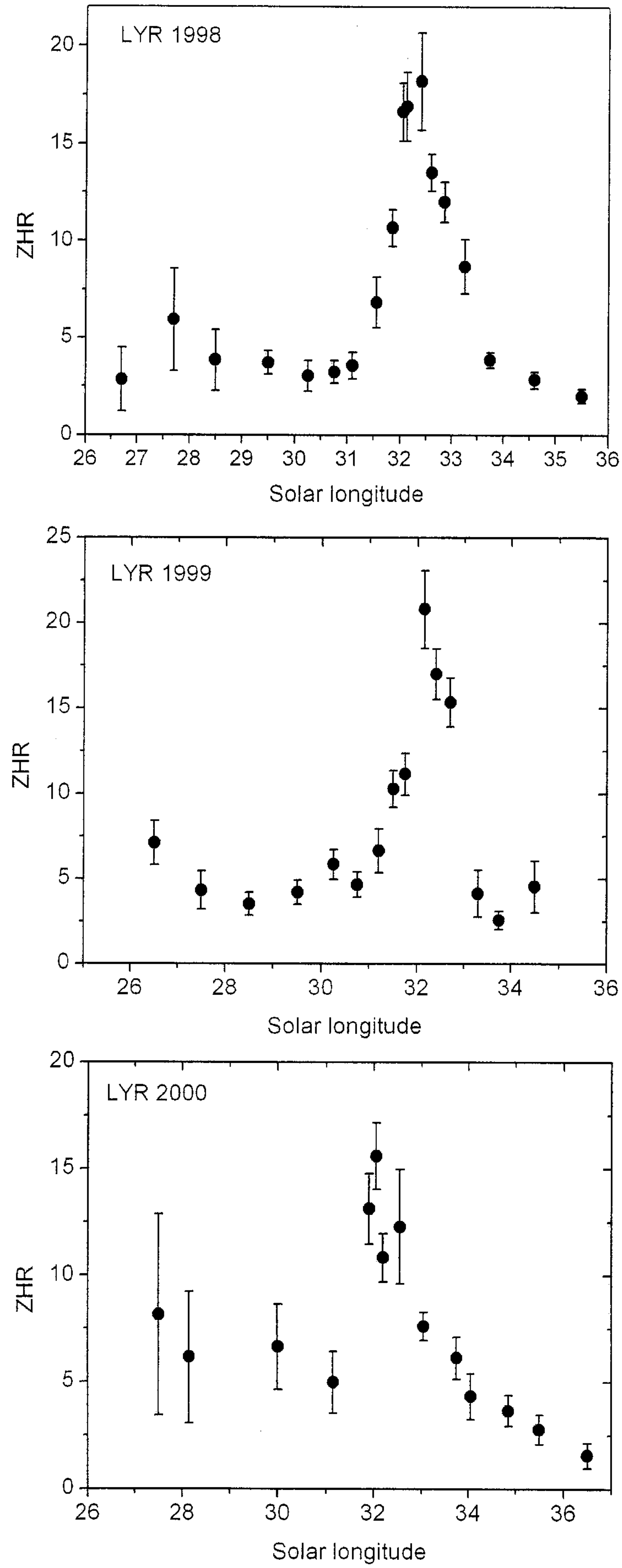

Figure 4 – Activity profiles for 1998, 1999, and 2000.

has been applied. For the ZHR estimates, 1° bins were applied far from the maximum (solar longitudes from 24° to 30°, and 34° to °38), whereas 0°.1–0°.5 bins were used around the maximum, with the width depending on the amount of data available. Where possible, we tried to avoid small bins which include just a few observing periods. The activity graphs for the Lyrids of 1988, 1990, the combination of 1991/1992, 1993, 1995, 1996, and 1998–2000 are shown in Figures 2–4.

In order to derive estimates for the activity level (maximum ZHR) and the width of the profiles, we used exponential functions such as described in [10]:

$$\mathrm{ZHR} = \mathrm{ZHR}_0 \exp\left(B\left|\lambda_\odot - \lambda_\odot^{(\max)}\right|\right), \tag{1}$$

where the three free parameters ZHR_0, B, and $\lambda_\odot^{(\max)}$ represent the maximum activity level, the inverse of the width of the profile, and the time of maximum, respectively. In an attempt to improve the fits by adding a constant background level, we did not find the fitting curve matching the peak period any better. A sophisticated attempt to add two exponential functions as

$$\mathrm{ZHR} = \mathrm{ZHR}_1 \exp\left(B_1\left|\lambda_\odot - \lambda_\odot^{(\max)}\right|\right) + \mathrm{ZHR}_1 \exp\left(B_1\left|\lambda_\odot - \lambda_\odot^{(\max)}\right|\right),$$

where B_1 should represent the slope near the maximum, B_2, the slope of a wide background component. In order to keep the number of parameters low, we chose the same peak longitude for both components. However, because of these additional degrees of freedom, the peak component essentially fits three ZHR averages, and the remaining curve is fitted by the background component. We suppose that an "over-fitting" takes place here and reject this way of activity-graph representation. In the end, a window of $\lambda_\odot = 30°$ to 34° was chosen for all years to obtain a fit for Function (1). The results of the fits in this window are shown graphically in Figures 5–7 using a logarithmic vertical axis.

4. The individual profiles

1988

The 1988 ZHR profile shows no peculiarities, and we obtained reasonable fits for the above parameters in (1). The result for such an old year shows, by the way, that the acquisition of meteor observing has—on average—not changed over more than a decade. No rate inflation trend or regression was found. Too few records are available to derive a graph for 1989, and we continue with 1990.

1990

The profile of 1990 exhibited a broad maximum with ups an downs. Scrutinization of the data showed a considerable number of Australian observations with radiant elevations about 20°. This should be acceptable, but the actual perception of WOOJE was found to be high, $c_\mathrm{p} = 2.0$, giving a limiting-magnitude shift of $\Delta\mathrm{lm} = +0.63$. We applied this correction in terms of a limiting-magnitude offset and recalculated the profile for 1990. Nevertheless, no fit parameters were computed for that year. In addition, there is an uncovered gap from $\lambda_\odot = 32°.21°$ to 32°.46°, and observed ZHR = 12.5 at solar longitude 32°.1 does not represent the real maximum.

1991/1992

Since 1991 and 1992 provide only a scarce number of observing periods, we combined them in one activity profile using a constant population index of $r = 2.2$. The fit of function (1) between $\lambda_\odot = 30°$ and 34° suffers from data scatter near the interval edges. We would like to emphasize that the fit data given below in the Conclusions are rough estimates whence in brackets (Table 2).

1993

In 1993 somewhat exceptional steep peak with ZHR = 23 has been observed. The FWHM of the peak as derived from the fit was just 0°62, i.e. twice as short as that of the usual maximum. High accuracy of the data points (note small error bars) makes no doubt about that.

1994

No exceptional activity was observed in 1994—12 years after the Lyrid outburst of 1982 as was already indicated by the reports of two observers [11]. There are still two four-hour gaps between solar longitudes 31°83–31°98 and 32°22–32°44. Most of the past outbursts—even that of 1803—occurred within $\lambda_\odot = 32^\circ\!.00 \pm 0^\circ\!.05$. A bright Moon disturbed the observations in 1994, and not many reports are available in general. There is only one single European observation of April 21-22 (RENJU). We would be grateful if more observations could be supplied, for the period April 22, 2^h30^m–6^h30^m UT in particular. Spanish, Canary, and eastern North-American longitudes were best suited for a possible peak.

1995

Although the observational dataset for 1995 was quite rich, there is still the gap right on the suspected maximum period from $\lambda_\odot = 32.06°$ to 32.30°. Thus, the summary of the observational data shows a somewhat late maximum at $\lambda_\odot = 32.45°$. All other years studied show a peak time before that of 1995. No reliable fit has been generated for this year observations.

1996

An outstanding amount of observations was reported in 1996, mostly by the European observers. Several groups have reported their data independently with ZHRs ranging from 15 [12] to 24.5 [13]. The processing of the overall data revealed $ZHR_0 = 15.6$ to be the most probable value. The observed peak is ZHR = 17.8 which looks slightly fallen-out from the whole trend; nevertheless, it coincides with the maximum time, which was deduced from the fit.

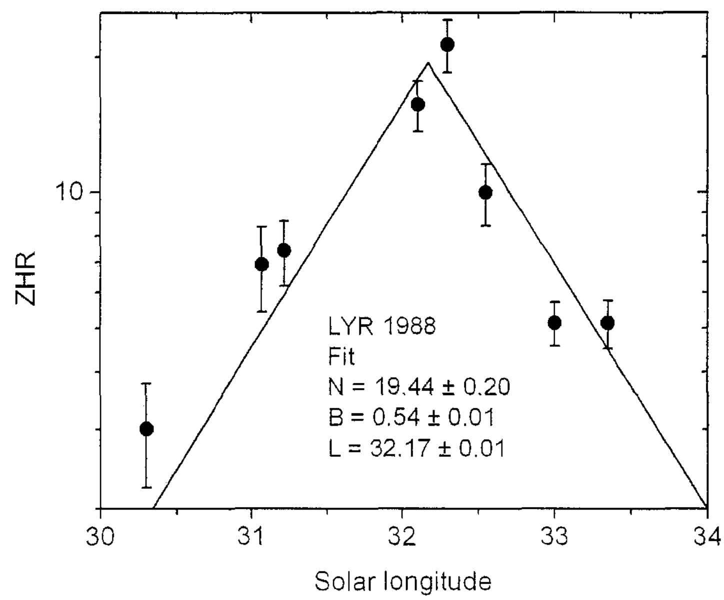

Figure 5 – Logarithmic activity profile near the maximum of 1988 with best-fit functions according to Equation (1). The line "N" represents ZHR_0 and "L" is $\lambda_\odot^{max}$.

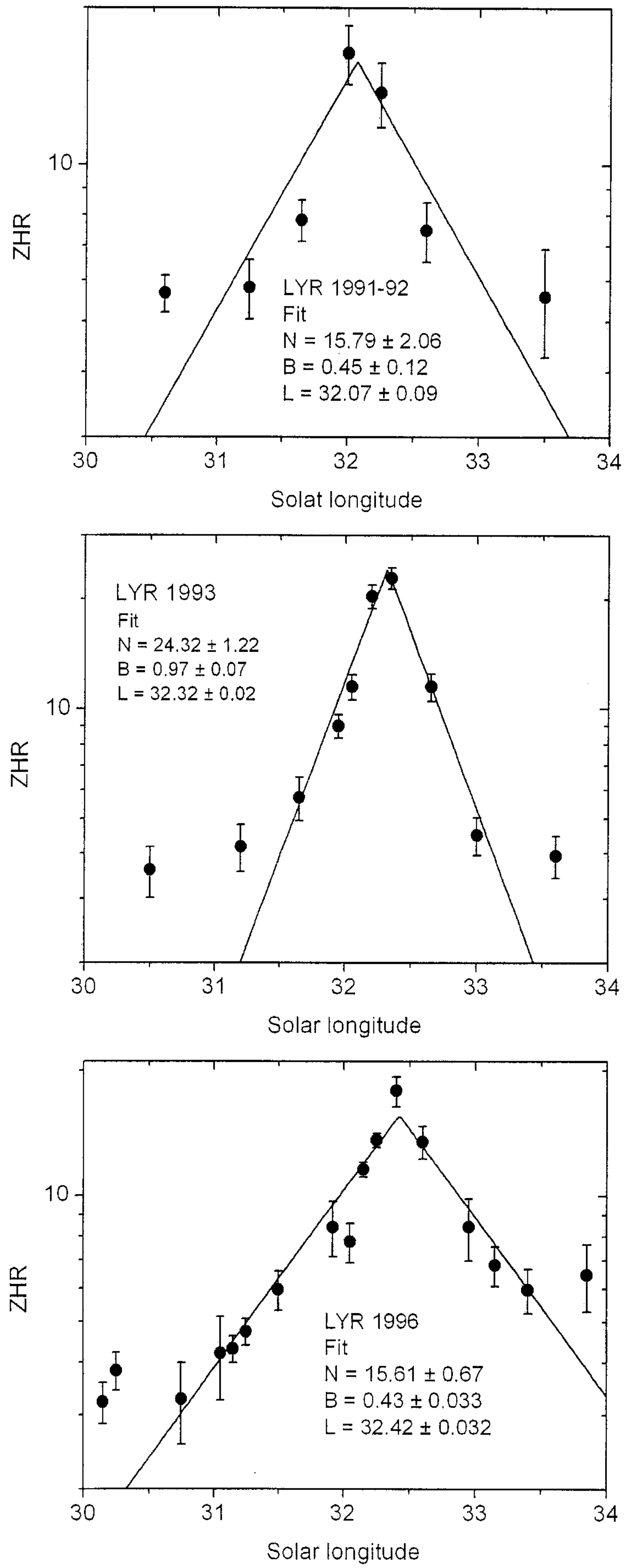

Figure 6 – Logarithmic activity profiles near the maxima of 1991, 1993, and 1996 with best-fit functions according to Equation (1).

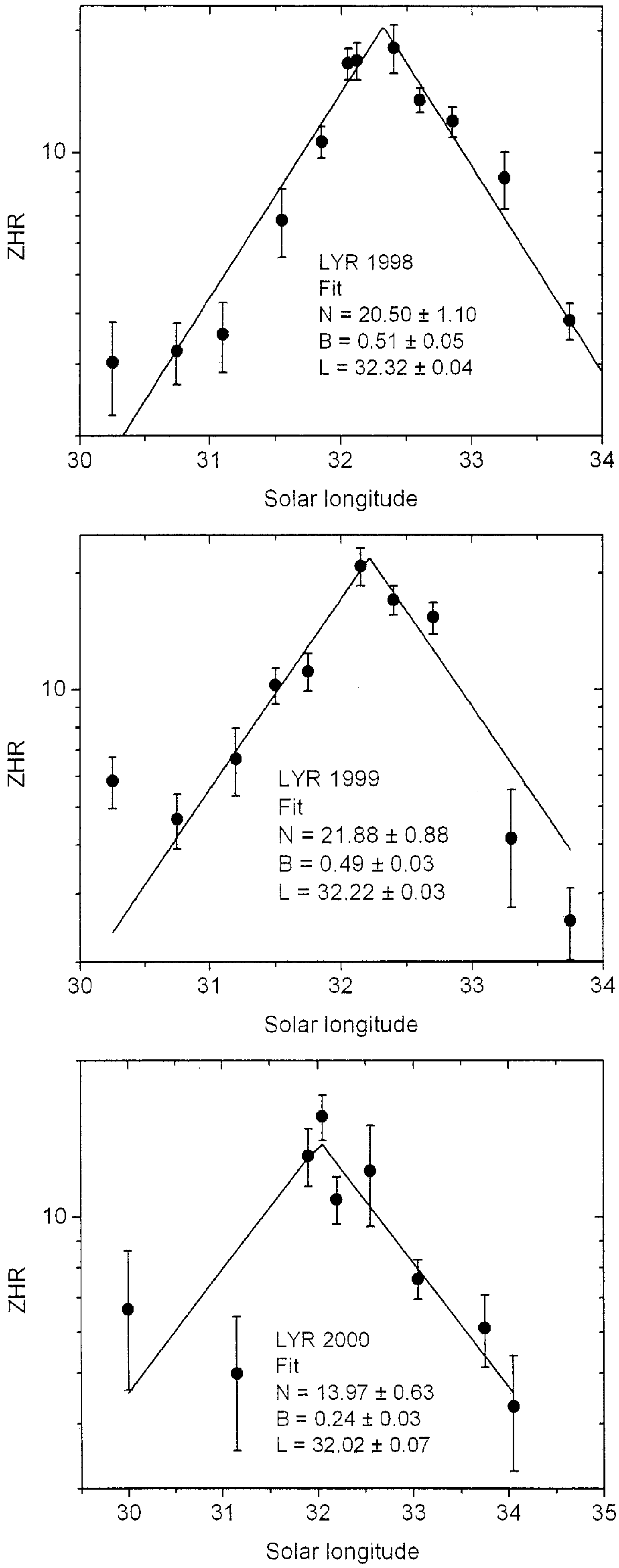

Figure 7 – Logarithmic activity profiles near the maxima of 1998, 1999, and 2000 with best-fit functions according to Equation (1).

1998

A comprehensive set of data allowed a well defined activity profile. A gibbous waning Moon disturbed the morning hours of the early days before the maximum only. The jumps in the r-profile did not alter the activity profile heavily as compared with a ZHR profile derived with constant r. A very satisfying exponential fit was derived.

1999

The 1999 observations miss data for the interval 31°9–32°1. Even so, the maximum was clearly detected, and an accurate fit was obtained.

2000

A correction for perception was necessary here, too, since the average ZHR near $\lambda_\odot = 31^\circ\!.9$ was strongly influenced by the data of SUMKA who reports high meteor numbers despite a very low (due to the Moon) limiting magnitude. His average sporadic rate in the entire Lyrid data set was 47.2, the sporadic rate of all the other contributors was 13.9—a very typical value. The resulting c_p is 3.4 for SUMKA, represented by an upwards shift of his limiting magnitude of $\Delta\mathrm{lm} = +1.11$. Such a large lm shift is expected for an observing beginner who is not sure about lm-determination rather than for a regular observer like SUMKA, but we have anyway used this lm correction for the final 2000 activity profile.

The ascending part of the 2000 activity curve was not recorded due to the full Moon, and thus the whole 2000 activity trend is not available. Since there are no reliable data up to a solar longitude of 31°7, the fit was built relying only on later data. Observations of 2000 yielded a somewhat different picture as compared with the years discussed above. A very slow activity decline ($B = 0.24$, corresponding to a FWHM of 2°5) agrees well with that obtained by Jenniskens ($B = 0.22$ [10]) analyzing data before 1988. All our other profiles exhibit shorter maxima, i.e. larger B.

5. Conclusions

In an attempt to evaluate the population index and activity profile of Lyrid returns between 1988 and 2000, we obtained activity graphs for nine out of these years; most reliable information on the characteristics of the individual maxima are given for six years, 1988, 1993, 1996, 1998, 1999, and 2000. The results as read from the graphs are summarized in Table 2.

Table 2 – Overview of results obtained for the Lyrid meteor shower from 1988 to 2000. The quantity of $r^{(\max)}$ is an estimate of the population index near the activity maximum. N_obs is the number of observing periods defining the peak time and activity level; it is not the total number of observations in the respective activity graph.

Year	$r^{(\max)}$	$\mathrm{ZHR}_\max$	$\lambda_\odot^{(\max)}$ (J2000)	N_obs	Gaps and comments
1988	2.2 ± 0.1	21.3 ± 2.8	32°3	7	None
1990	2.3 ± 0.1	(12.5 ± 1.4)	(32°1)	6	32°21–32°46
1991/2	(2.2 ± 0.2)	16.4 ± 2.1	32°0	10	Combined
1993	2.1 ± 0.1	22.9 ± 1.6	32°35	15	None
1994	2.0 ± 0.1	17.3 ± 1.3	32°1	11	32°22–32°44
1995	2.2 ± 0.1	14.0 ± 0.6	32°45	75	32°06–32°30
1996	2.0 ± 0.1	17.8 ± 1.5	32°4	15	None
1997	2.6 ± 0.4	–	–	–	–
1998	2.1 ± 0.1	18.2 ± 2.5	32°4	7	None
1999	2.0 ± 0.1	20.8 ± 2.3	32°15	15	31°9–32°1
2000	2.3 ± 0.1	15.6 ± 1.6	32°05	28	None; full Moon

The first major conclusion concerns the population index which is not anywhere near the listed 2.9 but turned out to be *very typically between $r = 2.0$ and $r = 2.1$* during the day near the maximum, essentially based on 1993, 1996, 1998, and 1999. Some years with much fewer magnitude distributions show high population indices of 2.3 to 2.5, but we gave them low weight for our conclusion on r.

An upward jump in r right at the time of maximum is found for several of the years investigated. The population index then increases from the level of 2.0–2.1 to 2.3–2.5. As is was also present in data of 1940s and as well in the 2001 activity profile [14] we consider this a distinct feature of the stream, present over a relatively long period of 55 years. Particle sorting producing such population index jumps will be a challenge for dust simulations of the Lyrid meteoroid stream.

Table 3 – Results for fitting Lyrid near-maximum profiles with two-side exponential functions for 1988 to 2000, according to Equation (1). The full width at half maximum is FWHM $= \lg 2 \times 2/B$. In 1991, the maximum time was not covered by observations.

Year	$\lambda_\odot^{(\max)}$ (J2000)	ZHR$_0$	B	FWHM
1988	$32\overset{\circ}{.}17 \pm 0\overset{\circ}{.}01$	19.4 ± 0.2	0.54 ± 0.01	$1\overset{\circ}{.}11$
1991–1992	$(32\overset{\circ}{.}07 \pm 0\overset{\circ}{.}09)$	(15.8 ± 2.1)	(0.45 ± 0.12)	$(1\overset{\circ}{.}34)$
1993	$32\overset{\circ}{.}32 \pm 0\overset{\circ}{.}02$	24.3 ± 1.2	0.97 ± 0.07	$0\overset{\circ}{.}62$
1996	$32\overset{\circ}{.}42 \pm 0\overset{\circ}{.}03$	15.6 ± 0.7	0.43 ± 0.03	$1\overset{\circ}{.}40$
1998	$32\overset{\circ}{.}32 \pm 0\overset{\circ}{.}04$	20.5 ± 1.1	0.51 ± 0.05	$1\overset{\circ}{.}18$
1999	$32\overset{\circ}{.}22 \pm 0\overset{\circ}{.}03$	21.9 ± 0.9	0.49 ± 0.03	$1\overset{\circ}{.}23$
2000	$32\overset{\circ}{.}02 \pm 0\overset{\circ}{.}07$	14.0 ± 0.6	0.24 ± 0.02	$2\overset{\circ}{.}51$

Shower maxima fall between $\lambda_\odot = 32\overset{\circ}{.}0$ and $\lambda_\odot = 32\overset{\circ}{.}4$. There is no obvious trend of early and late maxima, so this time scatter may be in part attributed to the observational features. The times and strengths of maxima obtained by the exponential fits—given in Table 3—agree satisfactorily with those obtained from the simple peak points of the observed graph. One systematic effect is found though: Figure 8 shows the correlation between peak time and peak ZHR. Note that this is not an activity profile. Each of the points represents the result of one year. We see that maxima deviating from the average peak time show lowest level of activity. As the resolution of the profiles is similar to or smaller than the deviation from the average peak time, we cannot explain this effect simply by a miss of the true peak through the ZHR-bins.

In an attempt to show the combined 1988–99 profile, we obtained the graph presented in Figure 9. The graph is based on 2646 observations between April 14 and 27 and includes 9595 meteors. The data selection was as usual—$C_i < 5$, using $r = 2.1$. The maximum is then $\mathrm{ZHR}_{\max} = 15.1 \pm 0.5$ at $\lambda_\odot = 32\overset{\circ}{.}3$. The bin sizes across the graph are as follows: one degree for the edges, $0\overset{\circ}{.}2$ and $0\overset{\circ}{.}1$ at the maximum—solar longitudes 32° to $32\overset{\circ}{.}5$. Smaller bin size causes some spikes, nevertheless giving $\mathrm{ZHR}_{\max} = 17.9 \pm 0.9$ at $\lambda_\odot = 32\overset{\circ}{.}32$. We consider these values the final average of the maximum despite Figure 9 showing a somewhat smoother result. The combined population index profile is shown in Figure 10 which was obtained with the constraint of $\mathrm{lm} \geq +5.8$. The strong jump at $\lambda_\odot = 32\overset{\circ}{.}2$ is remarkably visible.

We obtained maximum ZHR-averages between 14 and 23; a very low average ZHR of 12 for the poorly defined profile of 1990. The peak time seems missing in the data, and we do not consider that year's results for our conclusions. Typical full widths at half maximum lie between $1\overset{\circ}{.}1$ and $1\overset{\circ}{.}4$. The regular maximum of the Lyrids thus covers more than one day. The striking exceptions are 1993 (sharp peak) and 2000 (broad maximum). Those years coincide with the highest maximum ZHR and the second-lowest ZHR, respectively.

No systematic trend of ZHRs and peak width is found, and we conclude that the Lyrids exhibit a fairly stable annual activity profile of ZHRs 15–20, at solar longitudes $32\overset{\circ}{.}05$–$32\overset{\circ}{.}45$. The shower parameter which suffers from strongest variations is the FWHM ranging from well over half a day to 2.5 days (Table 3).

Skewness near the maximum is not obvious from the activity profiles. Years such as 1999 and 2000 suggest some skewness to different sides. We rather suppose that the change of dataset size in the course of the activity period gives rise to the impression of skew profiles. However, the combined profile shows a shoulder of background activity between solar longitudes 27° to 30° which is significantly higher than the corresponding part of the descending branch of the activity curve. This shoulder is detectable in particular in the 1991–1993 individual profiles, tentatively also in the 1998 profile. Theoretical modeling of the Lyrid meteoroid stream may provide support for this asymmetry in the profile such as was found—much stronger though—for the Perseid stream [15].

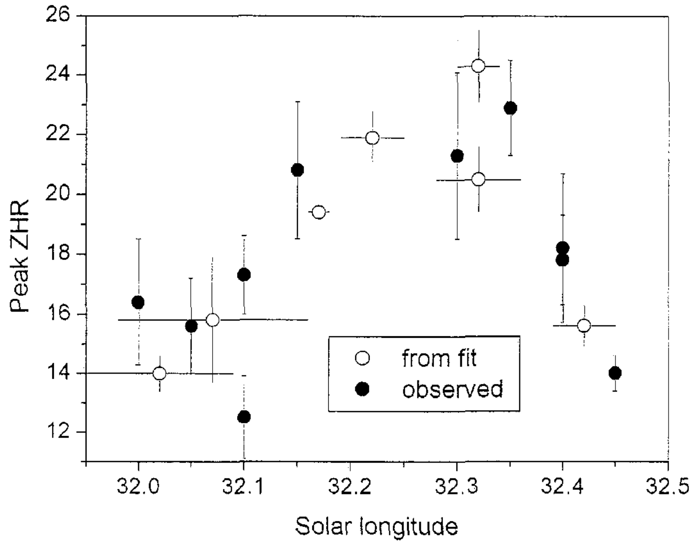

Figure 8 – Correlation of peak time and peak ZHR; the graph is not an activity profile. The points with error bars are time-ZHR estimates from the highest points in the graph; the grey horizontal and vertical margins are from the exponential fits of each of the annual graph.

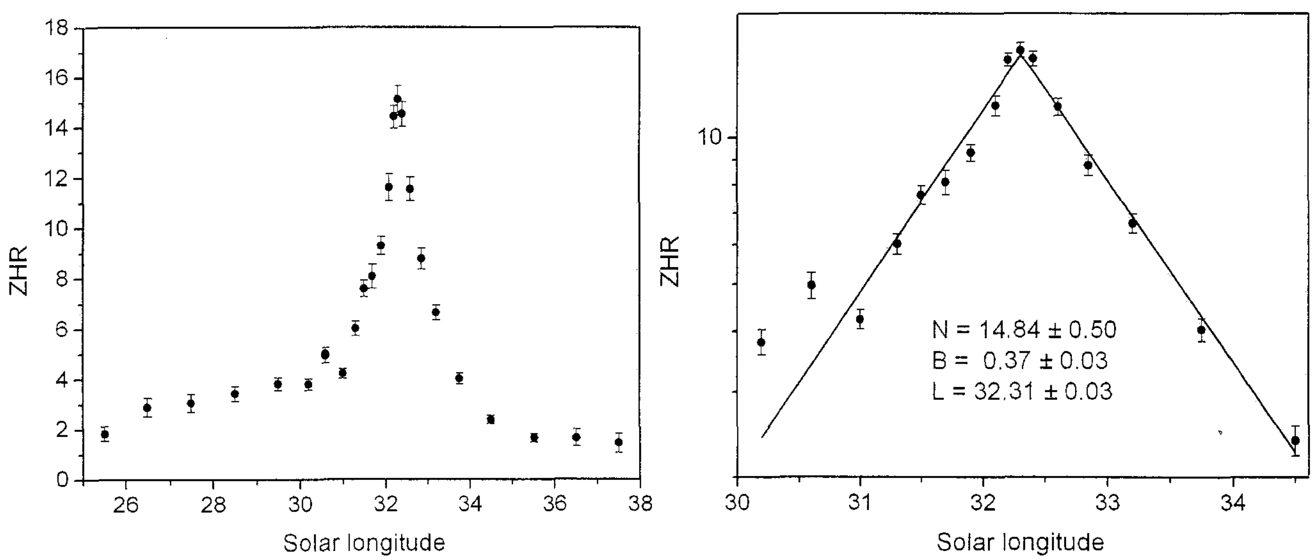

Figure 9 – ZHR profile of the entire set of data from 1988 to 2000 using an estimated, constant population index of $r = 2.1$ (left). The right graph shows an two-side exponential fit in the solar longitude window from 30° to 34°.5. Increasing the resolution of the binning, the maximum can actually be driven a little higher to $\mathrm{ZHR}_{\max} = 18 \pm 1$ before the onset of noise fluctuations.

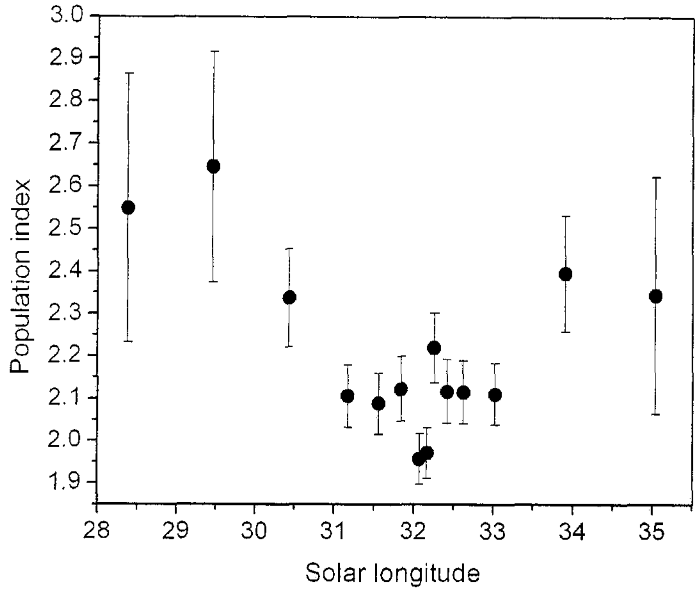

Figure 10 –Combined population index profile for 1988–2000 obtained from magnitude distributions under conditions with lm $\geq +5.8$.

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Fully Correcting for the Spread in Meteor Radiant Positions Due to Gravitational Attraction

Peter S. Gural

The zenith attraction formulae of Schiaparelli and Andreev do not fully account for the Earth's gravitational effects on meteor radiant estimation from the perspective of a single observer. This paper provides the necessary correction formulae to eliminate the gravitational component of radiant diffuseness seen in low-elevation, slow-encounter meteors.

In the late nineteenth century, Schiaparelli derived a formula for correcting the influence of the Earth's gravitation on the trajectory of a meteor, and subsequently improved the estimation of meteor radiant positions. When comparing the relation between a meteor's observed radiant zenith angle Z_o with the true radiant zenith angle Z_t as given by Schiaparelli's expression, we find a shift towards the observer's zenith. This is known as the *zenith attraction*, and is caused by the bending of the meteor's path towards the center of the Earth. It is most readily seen in low-velocity meteors. Schiaparelli's formula for finding the shift $\Delta Z = Z_\mathrm{t} - Z_\mathrm{o}$ is

$$\Delta Z = 2\arctan\left[\frac{W - V_g}{W + V_g}\tan\frac{Z_\mathrm{o}}{2}\right], \tag{1}$$

where V_g is the meteor's geocentric velocity at an infinite distance from Earth and W the enhanced meteor speed due to the gravitational pull by the Earth at some height h over the surface. Note that W and V_g, when specified in km/s, are related through

$$W^2 = V_g^2 + \frac{2GM_\mathrm{e}}{r_\mathrm{e} + h} = V_g^2 + 123.06, \tag{2}$$

with the constant shown determined for a typical meteor altitude of $h = 100$ km, $r_\mathrm{e} = 6378$ km (the Earth's radius), and $GM_\mathrm{e} = 3.986 \times 10^5$ km^3/s^2 (the gravitational constant times the Earth's mass). The value 123.06 shown in equation (2) differs from the more commonly quoted value of 125 typically seen in the literature, because the latter has been evaluated at the Earth's surface rather than at the altitude of the meteor!

The inverse formula that solves for the zenith angle of the observed radiant Z_o in terms of the zenith angle of the true radiant Z_t is also of interest and was derived in Olivier [1]. However, that book's expression contains typos, which have been corrected here:

$$Z_\mathrm{o} = \frac{Z_\mathrm{t}}{2} + \arcsin\left[\frac{V_g}{W}\sin\frac{Z_\mathrm{t}}{2}\right]. \tag{3}$$

More recently in two papers by Andreev [2,3], a refinement to equation (1) was presented to correct the Schiaparelli formula, which had been found to only apply to meteors seen at an observer's zenith. Andreev generalized the expressions by assuming both an arbitrary observer location and arbitrary meteor sighting angle. His first step was to compute the observed zenith angle of the radiant for a new location as if the observer were moved to a position directly under the meteor. This last position will be referred to as the meteor sub-point on the Earth and Z^* as the radiant zenith angle computed for the sub-point location. The relation between Z^* and Z_o is given by equation (5) after computing the Earth-centered angle γ between the observer's position and the sub-point location using equation (4):

$$\gamma = Z_\mathrm{m} - \arcsin\left[\frac{r_\mathrm{e}}{r_\mathrm{e} + h}\sin Z_\mathrm{m}\right] \tag{4}$$

$$\cos Z^* = \cos Z_\mathrm{o}\cos\gamma + \sin Z_\mathrm{o}\sin\gamma\cos(A_\mathrm{m} - A_\mathrm{o}) \tag{5}$$

One also needs to know the observer's zenith angle ($Z_{\rm m}$) and azimuth ($A_{\rm m}$) to the meteor, and the observer's observed radiant zenith angle ($Z_{\rm o}$) and azimuth ($A_{\rm o}$). The new sub-point observed zenith angle Z^* was then substituted by Andreev into Schiaparelli's formula (1) to get the zenith attraction:

$$\Delta Z^* = 2\arctan\left[\frac{W - V_g}{W + V_g}\tan\frac{Z^*}{2}\right] . \tag{6}$$

The problem with these expressions is that they assume the zenith attraction correction is the same vertically oriented vector independent of the observer's position. To a first-order approximation, this is a reasonable assumption. However, for low-velocity meteor encounters and observations taken at low elevation angles, this approximation breaks down. In point of fact, the gravitational influence on the meteor acts towards the center of the Earth and produces a shift not only in elevation but also in azimuth of the observed radiant position. This is because the plane containing the meteor trajectory tilts at greater angles the further away (lower elevation) the observer records a meteor. At the meteor's sub-point, the zenith attraction does lie strictly in the vertical plane, but, in general, observations are taken elsewhere on the Earth's surface, and the tilt in the meteor's trajectory plane skews the observed radiant position. Thus, the derived formulae need to account for the tilting of the correction as seen from the perspective of the original observer's location.

To illustrate the issue, a simulation was run to generate a set of meteor trajectories originating from the same radiant. A meteor fly-out simulation has been developed by the author and was first introduced by Gural and Jenniskens [4]. The simulation originally assumed straight-line flight, since it was modeling the Leonid stream, and the impact of zenith attraction was assumed small for such high-velocity meteoroids. For this study, however, the simulation was modified such that the meteor stream particles were allowed to travel in geocentric hyperbolic orbits with the Earth's center at one of the foci and the trajectory's inbound asymptote parallel to the true radiant direction. This simulation includes the full three-dimensional effects of a centralized single point gravitation source and atmospheric cap curvature at the meteor ablation altitude. For the baseline case, a moderately low shower velocity of $V_g = 35$ km/s was used, being representative of the Geminid stream observed at a true radiant elevation of 15° and azimuth of 45°. A Monte Carlo simulation of several thousand three-dimensionally, uniformly-distributed, randomly placed particles were propagated down to the atmosphere. Those above the observer's horizon upon reaching an altitude of 100 km had their observed radiant and zenith attraction formulae computed. The effects of atmospheric drag and refraction were ignored.

As can be seen in Figure 1, (*a*), the observed radiant positions are displaced higher in elevation relative to the true radiant by an average of 2° owing to the standard influence of zenith attraction. The plotted points were obtained by projecting back the tangent to the hyperbolic meteor trajectory at 100 km altitude for all meteors visible above the observer's horizon (all-sky viewpoint). Note, however, that the observed radiants from this ensemble of meteors not only have the expected general bias towards the zenith, but also have a *spread in both azimuth and elevation* of nearly three-quarters of a degree! To this author's knowledge, this fact has not been pointed out in the past, and arises from the plane of the meteor trajectory tilting outwards from the observer for low elevation look directions.

As seen in Figure 1, (*b*), the Schiaparelli expression takes out the large zenith attraction bias but does not address the spread of the radiant. This is because equation (1) only applies for meteors at the zenith (the center of the spread in the observed radiants plotted) and shifts all the observed radiants to lower elevation angles in nearly equal amounts.

Andreev tried to address the more common problem of meteors observed in arbitrary look directions, by computing the zenith attraction at the meteor sub-point where the Schiaparelli equation is applicable.

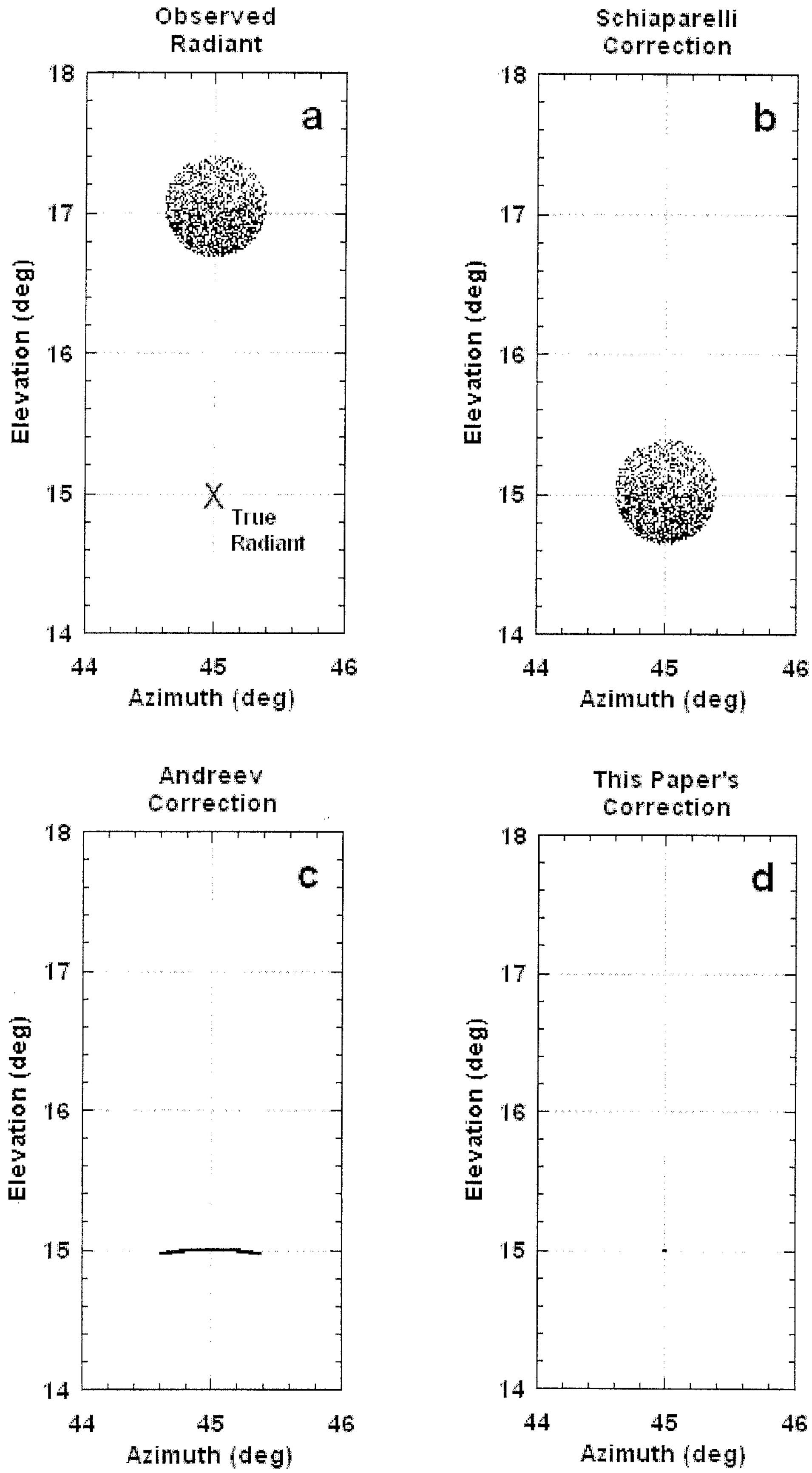

Figure 1 – The projected radiants as seen by a single observer (a) have their gross bias removed after applying the Schiaparelli correction (b), are further corrected in elevation using the Andreev formula (c), and fully corrected using the formulations derived in this paper (d).

However, as seen in Figure 1, (*c*), the Andreev correction only adjusts the elevation component but ignores the azimuth shifts that are possible. The Andreev correction is fine for the zenith attraction at the meteor sub-point, but an azimuth offset in the observed radiant position needs to be made for the translation from the observer to the sub-point locations.

An alternative solution that works within the structure of these previous corrections, is to determine the projection of the sub-point zenith attraction of Andreev from the point of view of the original observer. By examining Figure 2 and applying some spherical trigonometry, one can obtain the final zenith and azimuth corrections ΔZ and ΔA, respectively shown in equations (7) and (8).

$$\cos(Z_o + \Delta Z) = \frac{\cos Z_o \sin(Z^* + \Delta Z^*) - \sin \Delta Z^* \cos \gamma}{\sin Z^*} \tag{7}$$

$$\cos(\Delta A) = \frac{\cos \Delta Z^* - \cos Z_o \cos(Z_o + \Delta Z)}{\sin Z_o \sin(Z_o + \Delta Z)} \tag{8}$$

Note that the correct sign of ΔA after taking the inverse cosine is the sign of the quantity $\sin(A_m - A_o)$ for positive azimuth defined east of north. The true radiant is at $Z_o + \Delta Z$ and $A_o + \Delta A$ from the perspective of the observer's site. For the radiant at the zenith, the above expressions produce a division by zero, but, in that instance, the corrections are zero. No additional parameters are needed that were not already known or assumed in the Andreev expressions.

As seen in Figure 1, (*d*), using these final corrections removes all the radiant spread generated by the three-dimensional nature of the problem. Thus, all observed meteors are focused to the single-point radiant assumed in the simulation model. It is true, of course, that this spreading phenomena is small or negligible for most medium to fast meteor streams, and there is also a natural spread in the radiant due to velocity distributions in the particle stream. However, for low-elevation observations of low-velocity streams, these corrections should be properly applied. It should be noted that these latest corrections have been run through the simulation for a true radiant several degrees below the horizon and have been found to work properly in that case as well.

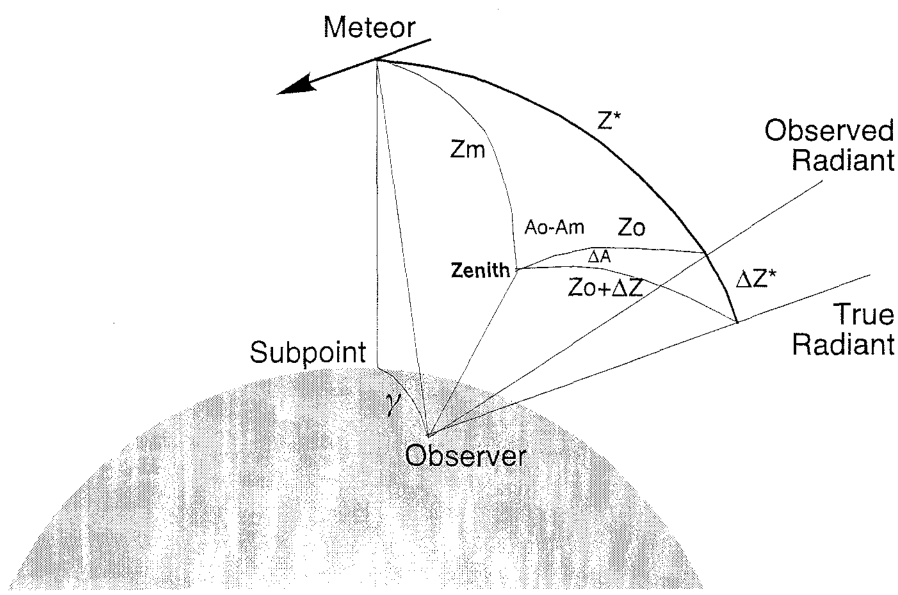

Figure 2 – Geometry to project the Andreev zenith attraction into the observer's local coordinates.

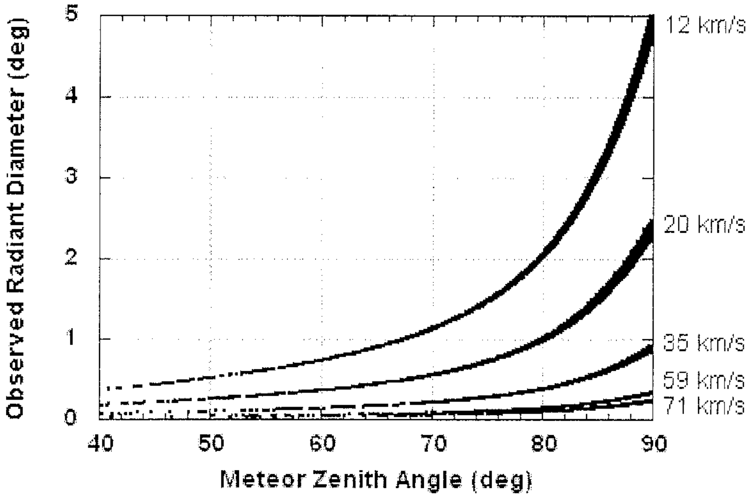

Figure 3 – Diameter of the uncorrected spread in observed radiant positions as a function of the meteor's zenith angle with respect to the observer.

To characterize the behavior of the spread in observed radiant positions, several Monte Carlo cases were run for various geocentric meteor speeds. In processing various case scenarios, the spread was found to be independent of the true radiant's elevation, and only very weakly dependent on the azimuth of the meteor as seen by the observer. The only significant parameter impacting the spread was the meteor's elevation (or zenith angle) at the chosen ablation height of 100 km. As is evident in Figure 3, most of the significant spread of greater than 1° occurs for meteors appearing within 20° of the horizon and for meteors close to the minimum encounter velocity. For even moderate speeds of $V_g = 20$ km/s, the meteors must appear within 10° of the horizon to show significant offset. Thus, only two areas of meteor research may need to seriously worry about these higher fidelity corrections. The first may be in the arena of telescopic sub-radiant estimation, where the degree of impact will depend on the zenith angle of the observations and the sub-degree accuracy of the radiants produced. The second is in the area of radiant analysis from low-elevation video cameras pointed near the horizon from mountaintop or airborne platforms. An example would be the video data collection tapes of the *Leonid Multi-Instrument Aircraft Campaign* recorded during the 1999 Leonid storm. In that particular instance, however, the geocentric meteor velocities places the worst-case radiant spread at one-quarter of a degree—less than the one-degree spread seen in the photographic Leonid records, and thus of little consequence.

Acknowledgment

The author would like to thank Sirko Molau for first raising the issue of the inverse zenith attraction formula that piqued an interest by the author in modeling the zenith attraction in a meteor simulation. The author's head is a little thinner these days after pulling his hair out originally chasing fictitious software bugs that were in fact realistic meteor phenomenology.

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Spanish Fireball Network: Current Status and Recent Orbit Data

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The current status of the *Spanish Fireball Network* is described. Orbit data obtained recently are exhibited.

1. Introduction

In a previous paper, we reported the birth of our *Spanish Fireball Network*, a project that began its activities in 1997 through a joint effort between professional and amateur astronomers. One of the objectives of the network is to develop a continuous fireball monitoring in Spain and to obtain orbital and chemical information on meteoroids. Today, our network is a solid project under the auspices of three Universities (*University Jaume I*, *University of Valencia*, and *University of Barcelona*) and one research institute (*IEEC*, the *Catalonian Institute for Space Studies*). Other researchers have been incorporated recently from the *Laboratorio de Astrofísica Espacial y Física Fundamental* (*LAEFF*) under the *National Institute for Aerospace Research* (*INTA*).

Nowadays, the *IEEC* is searching private sponsors for financing all-sky camera installations in several stations in the east of Spain. At this moment, we develop main network activities knowing well that the systematic observation of meteors using photographic, video, and CCD techniques is one of the rare fields in astronomy in which amateurs can work together with professionals and provide important contributions to science. In fact, we have obtained important support from amateur astronomers, as they offer an exceptional coverage in our network. We organized several workshops on meteor photography in the *Astrophysics Department of the Valencia University* in the last few years. Amateurs have expressed interest in the possibility of working in professional research, even though it demands special effort for them to attain the required degree of reliability.

The record of meteor events using all possible techniques (photographic, video, or CCD) provides excellent means to examine physical properties, chemical abundances (using spectroscopic tools such as diffraction gratings or prisms), and dynamic evolution using orbital data. From stereoscopic records of the same meteor from different stations, the atmospheric trajectory can be inferred, and, in the case of big events, the most probable meteorite impact area on the Earth surface can be determined. By using the trajectory data entry and calculating the meteoroid geocentric velocity (using a rotating shutter), the heliocentric orbit can be obtained, which allows to decipher the particle's origin in the Solar System (see Figure 1).

However, very large atmospheric coverage and long observation times are required for photographic recording techniques. Our first photographic network was developed in the Teruel province during the 1991 Perseids maximum, and the orbits of three members of this stream were obtained [1]. Later on, new stations were organized during the magnificent 1993 Perseid display, and a -9 fireball was registered from two of them [2]. Nowadays, we develop successive campaigns with multiple stations around the year [3]. The usual procedure consists in sending the different photographic centers using electronic mail to the different participants, which will receive a stellar chart with the center of field to point the camera according to their station coordinates.

Another important research field is related to the determination of meteoric fluxes. It is possible to use the atmosphere as a giant detector to estimate the flux of extraterrestrial matter on the Earth. In this area, we are working using our CCD and photographic exposures in the determination of photographic number densities of several streams, like the 1998, 1999, and 2000 Leonids.

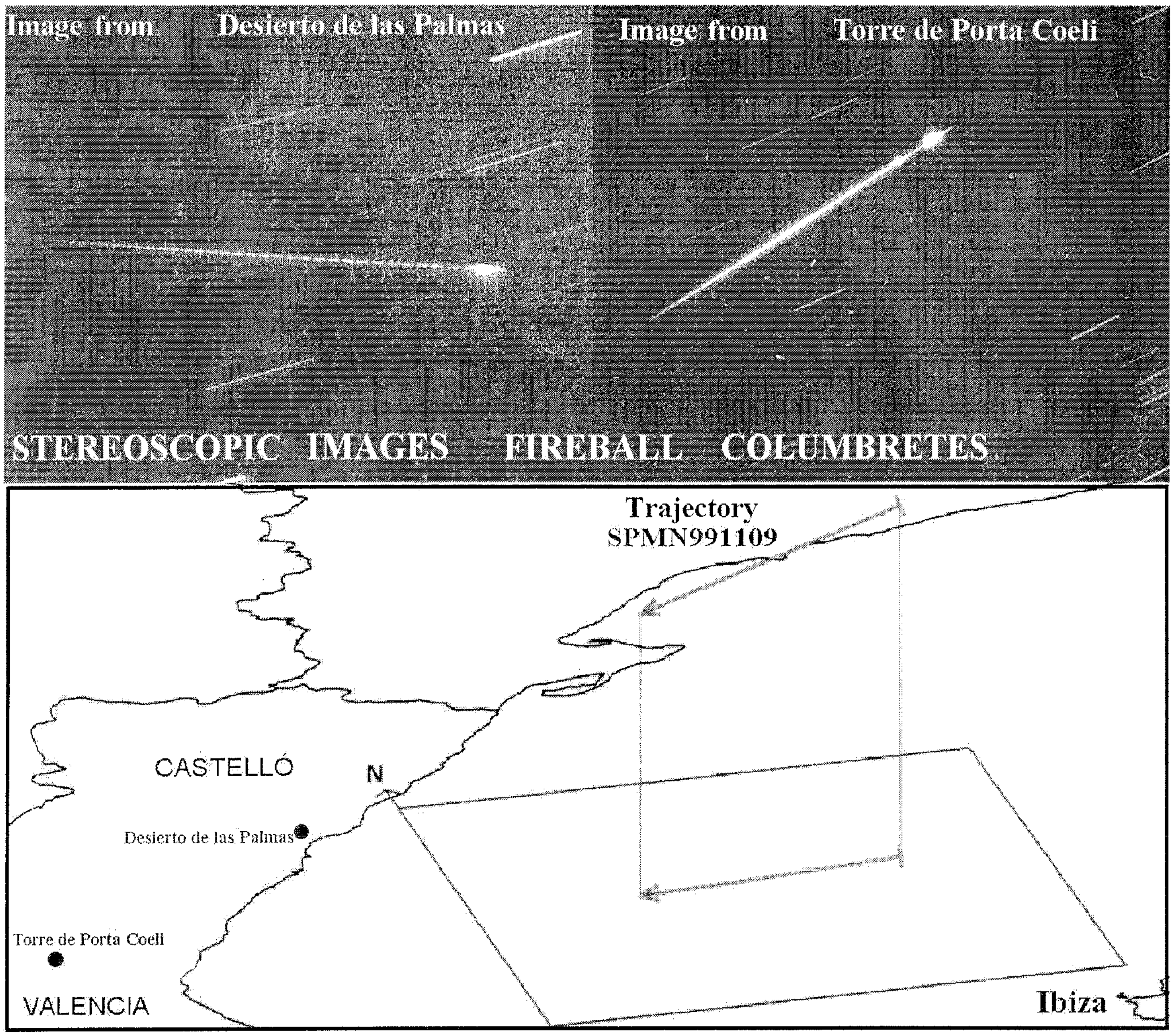

Figure 1 – The brightest fireball appeared during the 1999 Leonid storm. This fireball of magnitude −8 was registered from five stations of our network at East Spain. It was called "Columbretes fireball" because the trajectory reconstruction showed that it flew over the Columbretes Islands in the Castelló province. *SPMN* information about trajectory and orbital origin caused big excitement among the media and the general public. This kind of work is therefore an important tool to spread information on our project and to find sponsors.

2. Recent studies

Different types of studies are being performed, such as the calculation of meteoroid orbits from conventional photography, video, and CCD techniques, stream spatial fluxes, elucidation of meteor parent bodies, meteor spectroscopy, meteor atmospheric modeling, identification of meteorites, meteorite recovery, and meteorite analysis, and development of meteor software. Some of the most reliable trajectories and orbits obtained from our photographic monitoring system appear in Tables 1 and 2.

3. Meteor spectroscopy

Last year, our team has been also working on the installation of several spectral cameras to obtain high-precision spectra of meteors and fireballs. We emphasize the importance of promoting meteor spectroscopy, because it provides key advances to our knowledge of the mechanisms of meteor radiation. In this way, we can delve deep into the degradation processes of interplanetary matter during its entry into the Earth's atmosphere.

Table 1 – Trajectory data of recent *SPMN* fireballs. The table shows the photographic magnitude (M_{ph}), beginning and ending heights (in km) of the meteor trail on the Earth's surface, coordinates of the geocentric radiant (right ascension and declination) and velocity in km/s (at infinity, geocentric and heliocentric).

Code	Parent body	M_{ph}	h_{beg}	h_{end}	α	δ	V_∞	V_g	V_h
981201	3200 A/Phaeton	−5	95.1	62.9	115.°56 ± 0.°05	+30.°41 ± 0.05	37.5 ± 0.1	35.8	33.0
990801	109 P/Swift-Tuttle	−3	118.9	93.7	45.°89 ± 0.°02	+58.°32 ± 0.°02	59.5 ± 0.3	58.4	40.2
990802	109 P/Swift-Tuttle	−4	122.8	81.4	47.°3 ± 0.°2	+57.°07 ± 0.°02	59.9 ± 0.3	58.8	40.6
991101	1P/Encke	−4	90.2	75.4	63.°31 ± 0.°02	+23.°22 ± 0.°02	31.40 ± 0.08	29.3	37.4
991103	55P/Tempel-Tuttle	−4	112.9	97.6	153.°0 ± 0.°6	+21.°84 ± 0.°02	71.4 ± 0.2	70.5	41.2
991105	55P/Tempel-Tuttle	−3	110.7	98.7	152.°71 ± 0.°02	+22.°03 ± 0.°02	71.8 ± 0.2	70.9	41.6
991109	55P/Tempel-Tuttle	−8	115.5	75.9	154.°75 ± 0.°02	+21.°14 ± 0.°01	71.4 ± 0.2	70.5	41.3
991112	55P/Tempel-Tuttle	−2	104.5	90.2	154.°21 ± 0.°03	+21.°56 ± 0.°02	71.8 ± 0.3	70.9	41.7
991117	55P/Tempel-Tuttle	−3	115.7	99.6	153.°82 ± 0.°02	+21.°64 ± 0.°02	71.6 ± 0.2	70.7	41.5
991118	55P/Tempel-Tuttle	−2	119.8	105.2	153.°73 ± 0.°02	+21.°71 ± 0.°02	71.7 ± 0.2	70.8	41.6
991119	55P/Tempel-Tuttle	−2	112.8	104.9	153.°69 ± 0.°02	+21.°31 ± 0.°02	71.5 ± 0.2	70.6	41.3
991120	55P/Tempel-Tuttle	−3	106.2	90.7	153.°39 ± 0.°02	+22.°15 ± 0.°02	71.4 ± 0.2	70.5	41.3
991121	55P/Tempel-Tuttle	−3	109.6	87.2	153.°93 ± 0.°02	+21.°43 ± 0.°02	71.6 ± 0.2	70.7	41.5
991122	55P/Tempel-Tuttle	−1	108.3	97.3	153.°24 ± 0.°02	+21.°67 ± 0.°02	71.8 ± 0.2	70.9	41.7
991123	55P/Tempel-Tuttle	−2	108.3	98.9	153.°42 ± 0.°02	+20.°66 ± 0.°02	71.7 ± 0.2	70.8	41.4
991124	55P/Tempel-Tuttle	−2	111.7	101.6	153.°66 ± 0.°02	+22.°57 ± 0.°02	71.5 ± 0.2	70.6	41.5

Table 2 – Orbital elements of the fireballs listed in Table 1 (equinox 2000.0).

Code	Date	q	a	i	ω	Ω
981201	Dec 13.9416, 1998	0.1045 ± 0.0008	1.24 ± 0.01	24.°2 ± 0.°2	330.°47 ± 0.°09	261.°74997 ± 0.°00002
990801	Aug 13.0993, 1999	0.9608 ± 0.0005	10 ± 1	112.°1 ± 0.1	153.°0 ± 0.2	139.°94546 ± 0.°00002
990802	Aug 13.1118, 1999	0.953 ± 0.002	8 ± 2	114.°1 ± 0.2	150.°9 ± 0.°6	139.°957 ± 0.°008
991101	Nov 17.03951, 1999	0.3555 ± 0.0008	2.24 ± 0.02	2.°42 ± 0.°02	293.°70 ± 0.°04	234.°24657 ± 0.°00002
991103	Nov 18.1099, 1999	0.985 ± 0.002	9 ± 2	162.°7 ± 0.°4	172° ± 2°	235.°323 ± 0.°003
991105	Nov 18.11439, 1999	0.9857 ± 0.0001	14.4 ± 2.5	162.°62 ± 0.°04	173.°7 ± 0.°1	235.°32703 ± 0.°00002
991109	Nov 18.06609, 1999	0.9743 ± 0.0007	9.9 ± 0.5	162.°74 ± 0.°03	165.°8 ± 0.°1	235.°27831 ± 0.°00002
991112	Nov 18.09745, 1999	0.9743 ± 0.0007	10.1 ± 1.9	162.°41 ± 0.°06	168.°2 ± 0.°2	235.°30995 ± 0.°00002
991117	Nov 18.09876, 1999	0.9811 ± 0.0001	12.0 ± 2.6	162.°55 ± 0.°04	169.°7 ± 0.°1	235.°31126 ± 0.°00002
991118	Nov 18.10359, 1999	0.9815 ± 0.0001	13.5 ± 2.8	162.°51 ± 0.°06	170.°1 ± 0.°2	235.°31612 ± 0.°00002
991119	Nov 18.10064, 1999	0.9807 ± 0.0002	10.2 ± 1.2	163.°14 ± 0.°05	169.°5 ± 0.°2	235.°31316 ± 0.°00002
991120	Nov 18.05145, 1999	0.9833 ± 0.0001	10.1 ± 0.7	161.°96 ± 0.°03	171.°4 ± 0.°1	235.°26356 ± 0.°00002
991121	Nov 18.09381, 1999	0.9833 ± 0.0001	11.8 ± 1.2	162.°82 ± 0.°05	169.°1 ± 0.°2	235.°30625 ± 0.°00002
991122	Nov 17.19311, 1999	0.9790 ± 0.0001	11.8 ± 1.2	162.°86 ± 0.°05	168.°4 ± 0.°3	234.°39832 ± 0.°00002
991123	Nov 18.08681, 1999	0.9807 ± 0.0001	11.3 ± 2.6	164.°35 ± 0.°04	169.°5 ± 0.°2	235.°29915 ± 0.°00002
991124	Nov 18.08686, 1999	0.9832 ± 0.0001	12.1 ± 1.2	161.°17 ± 0.°03	171.°4 ± 0.°1	235.°29929 ± 0.°00002

Using diffraction gratings or prisms, meteor light can be decomposed, and the different spectral lines enable the identification of the chemical elements present in the ionized column. In addition, using calibrated spectra, the chemical abundances of the incident particle can also be obtained from line intensities.

In general, however, we encountered several limitations, because this analysis is restricted to elements which are detectable in meteor spectra, and it also depends of the detector sensitivity range (usually photographic plates or video films). Consequently, the precision of the chemical analysis made in this way is much lower than that of laboratory studies of meteorites. Despite these restrictions, meteor spectroscopy represents an excellent tool for furthering our understanding of the meteoroid-atmospheric interaction and associated processes. In fact, deposition of extraterrestrial atoms and molecules in the terrestrial atmosphere probably had an important role in the enrichment of the Earth's crust and even in the origin of life.

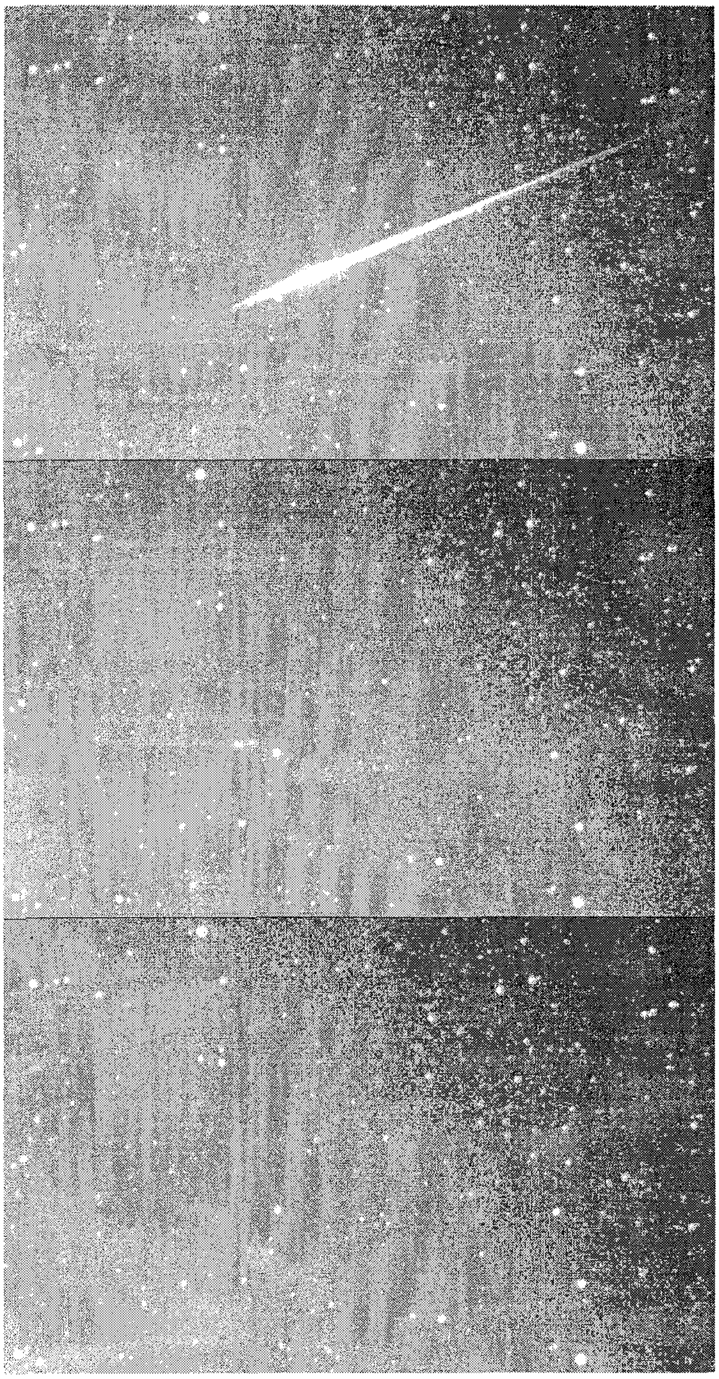

Figure 2 – Impressive Leonid fireball registered on November 18 from the El Arenosillo station (Huelva) during the 2000 Leonids return. The images show the train evolution in the atmosphere every five minutes. The train persisted in the thermosphere for more than 35 minutes. We have included recently in our homepage a nice animation to reproduce this train dispersion in the upper atmosphere.

One of us (Josep M. Trigo), guided by Dr. Jiři Borovička and Dr. Pavel Spurný has been working at the *Ondřejov Observatory* in the context of preparing his Ph.D. thesis.

This collaboration has been really interesting for the development of meteor spectroscopy and the determination of reliable orbits in Spain. With respect to spectroscopy, the contribution of Dr. Borovička to this field has been really important.

In 1993, he identified the presence of a high-temperature component at 10 000 K contributing to meteor spectra, in addition to the main 4500 K component [4]. He also used both spectral components to calculate chemical abundances, assuming chemical equilibrium in the ionized column [4]. Probably, the high-temperature component discovered by this author is produced in the meteoroid head, where the number of atomic impacts is higher.

Another interesting subject is the analysis of fragmentation processes to know the pyrolitic effect on particles during their short entry in the terrestrial atmosphere. Fragmentation of cometary meteoroids produces in some occasions luminous trains which persist long after the meteor's disappearance. Borovička et al. [5] identified the surprising presence of prominent emissions of forbidden lines of ionized atoms such as OII, SII, and OIII. The physical conditions that cause this luminescence in the train remain unknown, however. Probably, it could be caused by the interaction between ions, free electrons, and atmospheric components in the upper atmosphere. Meteoroid orbital data together with high-resolution spectra can yield new valuable information on important subjects.

We tried to obtain the first fireball spectra during the 1999 Leonid storm and the 2000 Quadrantid shower. Unfortunately, no results have been obtained to date. Future 2001 Perseids and Leonid campaigns would provide a good chance to test our new spectroscopic cameras of big format (see Figure 3).

4. Conclusions

Several processes related with the entry of interplanetary bodies in the Earth's atmosphere are still unknown. From orbital data, we can obtain interesting information on the population, composition, and links between Solar System small bodies. Fireball networks can provide an important source of data for modeling the entry of big bodies in the atmosphere [6]. This is the main reason to develop our network to cover fireball events over Spain. More information on our project can be found at the *SPMN* project homepage, `http://www.spmn.uji.es/`

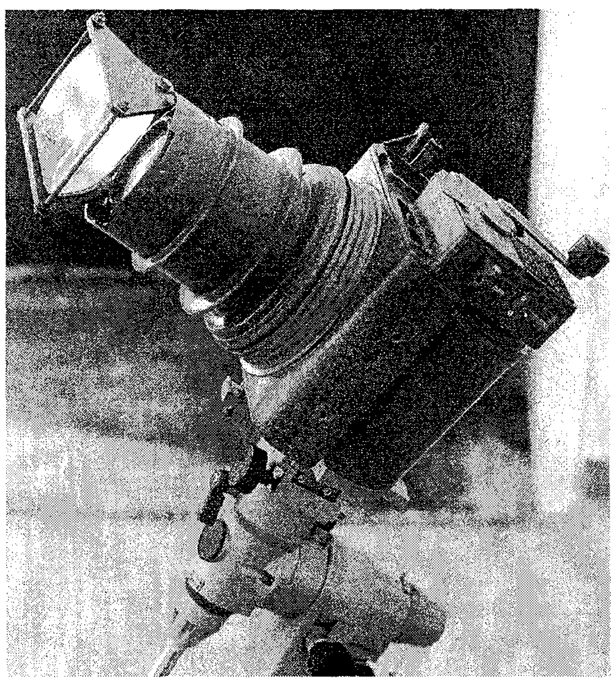

Figure 3 – F24 Aerial camera in operation in one of our stations to obtain reliable fireball spectra. This camera was used by the *Dutch Meteor Society* in the 1960s, and was included in our network by courtesy of Hans Betlem.

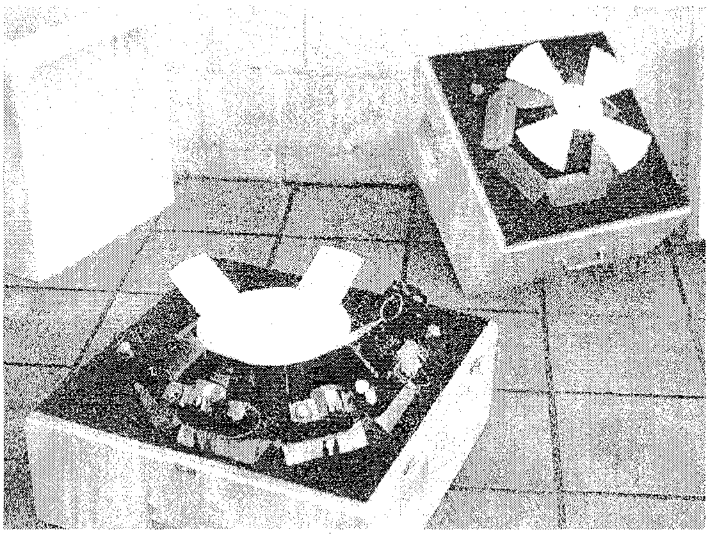

Figure 4 – Camera batteries operatives in four *SPMN* stations to obtain reliable orbital data. All batteries were developed with the support of Hans Betlem.

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Meteoroids 2001 at the Polar Cirle

Kiruna, Sweden, August 6–10, 2001

Jürgen Rendtel

Sometimes, it is said that the importance of an astronomer is proportional to the mass of the object he deals with. In this respect, Sirko Molau and I attended a very unimportant conference in the north of Sweden in early August 2001: *Meteoroids 2001*. It was the follow-up meeting to the two *Meteoroids* conferences in Slovakia, both in the past combined with the *IMO*'s *International Meteor Conference*. This time, the number of amateur meteor workers was quite small. Several Japanese observers and Ilkka Yrjölä of Finland attended the meeting. I do not know whether another date further away from the Perseid peak would have attracted more amateurs.

Anyway, *Meteoroids 2001* was worth the travel as it was good to meet many people known from joint observations, analyses or other contacts and to see the current projects. The program was quite tight with many contributions and two poster sessions. The proposed contributions about the meteor video network (by Sirko Molau) and my own analysis of activity fluctuations in the 1999 Leonids were chosen as oral presentations. When we found that sophisticated analyses of persistent meteor trains were made by Jack Drummond, we showed him a sequence of the 1998 Leonid train recordings on video. Perhaps we can obtain some more detailed results from our recordings as well.

Generally, the sessions were organized according to the methods of observation or the observed target(s). Of course, it is neither useful nor possible to list or describe all contributions. Instead, I suggest to look at the *Meteoroids 2001* web site (`http://www.srf.se/Meteoroids2001/`) or wait for the proceedings which will be published as an ESA special publication. Seen the contributions and the participants, I found two things interesting: in the past, meteor work was mainly an astronomical topic. Now we meet an increasing number of people regarding meteors as high atmospheric phenomena and dealing with the complex interactions between the matters, using lidars and radars. Connections to other upper atmospheric phenomena such as noctilucent clouds may be somewhat closer than usually thought. Another group of contributions occurred to me less systematic. Several observers using specialized radio receiving devices find that they see signatures of meteors in their data and start to analyze this data, sometimes with surprising results which need confirmation.

Last but not least I want to emphasize that the *Meteoroids 2001* in Sweden was also to honor Bertil Lindblad's continued work in the field of meteor astronomy. During the conference diner, many speakers looked back to Bertil's work and to the numerous contacts and meetings between the meteor astronomers. Bertil, who by the way is also an honorary member of the *IMO*, presented an analysis of the Perseid activity from a homogeneous data set collected within 30 years. Such long term studies together with the recent findings on meteoroid stream evolution allow to establish a more coherent model of such weak structures in our Solar System. Surprises like the Perseid's occurrence in the 1990s, the 1998 June Bootids, and the Leonid fireball night show that meteor workers of all fields still have a lot of things to deal with. We certainly will hear about some news at the *Meteoroids 2004* in London, Ontario, Canada.

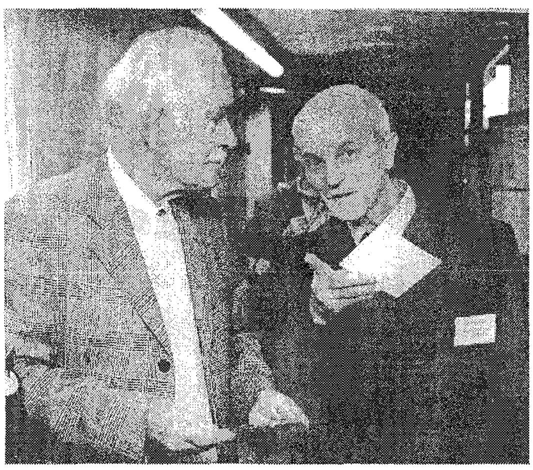

Figure 1 – *IMO* Honorary Member Bertil Lindblad discussing with Vladimir Porubčan. The conference was also meant to honor Bertil's life-long work on meteors.

Figure 2 – David Asher and Sirko Molau discussing a poster showing results obtained from *IMO* data on ecliptical meteoroid streams.

Figure 3 – Iwan Williams giving his lecture on the determination of ejection velocities of meteoroids from available meteoroid orbit data. (All photos by T. Lövgren of IRF, Kiruna.)

The International Meteor Organization

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