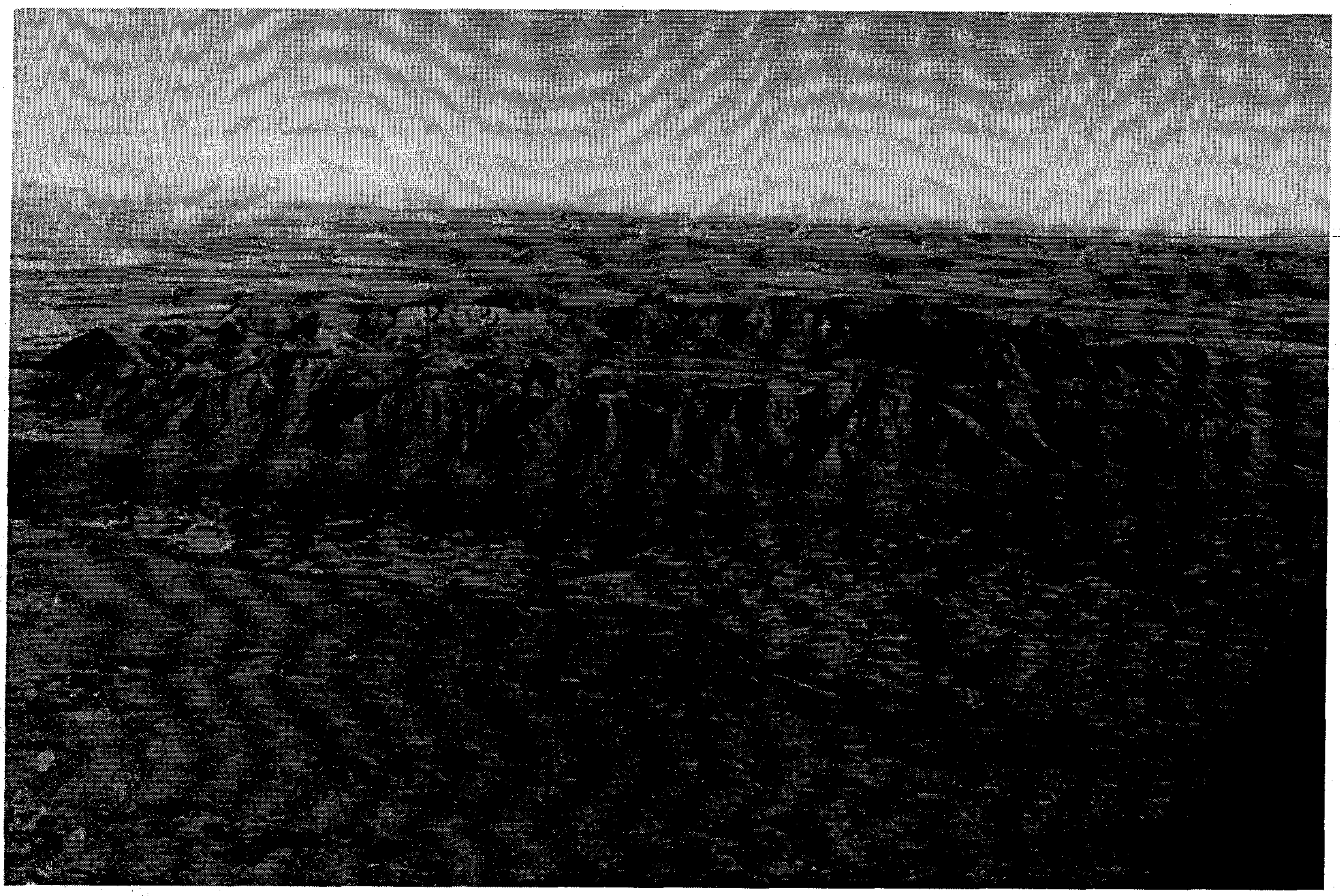
ISSN 1016-3115

wgn

27-3/4

june - august 1999

bimonthly journal of the international meteor organization



The Gosses Bluff Crater, an impact structure in Central Australia as seen from an airplane at about 2000 m altitude. The impact happened 142.5 million years ago. Due to the erosion, the original crater is almost invisible. Remains of the central uplift form the obvious ring structure of 5 km diameter. (Photograph by Jürgen Rendtel.)

In this issue:

In case of non-delivery, return postage guaranteed. Please return to:

v.u.: Marc Gyssens, Heerbaan 74, B-2530 Boechout, Belgium

WGN, Vol. 27, No. 3/4, Jun-Aug 1999, pp. 141–220

Contents

Useful Information

The October issue *(WGN 27:5)*

The *October issue* will be mailed toward the end of September. Contributions are due on *September 10* at the latest. They should be sent to *Marc Gyssens.*

Subscriptions and ordering of publications

Volume 27 (1999) of *WGN* will contain at least 240 pages and costs 35 DEM or 17.90 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription/membership fees. Information can be obtained from the Treasurer, *Ina Rendtel.* Changes of address and complaints about not receiving *WGN* should also be addressed to the Treasurer.

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

From the Editor-in-Chief

Marc Gyssens

I am pleased to say that a fair number of applications for IMO *support to attend the* 1999 IMC *have been received. It means that the* IMO *through its Support Fund has found another way to bring meteor workers from different countries together. The interest in the* IMC *as well as its location are bound to make a big success of this gathering.* **So, if you have not yet decided to attend, do not longer postpone your decision: it is still not too late to register!** *To make it absolutely easy for you to register, we reprint the registration form one last time!*

The northern hemisphere summer season usually yields lots of observations. Several meteor camps have already been set up for the Perseids, often in conjunction with the total solar eclipse of August 11, which adds to the excitement, of course. I expect many European meteor observers for once do not see the Perseids but rather the total solar eclipse as the principal event they are looking forward to. However, I urge all these observers to remain vigilant and to prepare properly for the Perseids, too! There is still evidence in the rate profile of the peak attributed to the latest return of parent comet 109P/Swift-Tuttle, so we must keep on monitoring the further evolution of this peak!

Another event that is slowly but steadily approaching is this year's Leonid maximum, with the prospect of a possible meteor storm, for which European observers are best-placed. It may be somewhat unfortunate that this event follows the total solar eclipse of August 11 so closely. First, there is the stark contrast between both phenomena: an extremely well-predictable eclipse (apart from the weather, of course) versus an illusive meteor storm. After the spectacular, straightforward eclipse just a few months before this year's Leonids, and with last year's experience in mind, will people still want to go out in the cold morning of November 18 to see... maybe nothing?!

However, we can also turn the above reasoning around, and argue that the impressions that the eclipse will leave on the people that saw it will lead to increased interest for astronomy in general, from which the Leonids in particular may benefit.

For this to happen, however, it is necessary that amateurs at all levels—internationally, nationally, regionally, locally—take great efforts to inform the public properly and to make sure that reliable correct information is available immediately after the event. We should avoid at all cost a repetition of what happened last year. I can appreciate that many amateur astronomer groups in Europe are very busy now with promoting the total solar eclipse. Consequently, taking things a little bit easier in the months to follow would be a normal and understandable reaction. Nevertheless, such an attitude could have adverse effects on the public interest for the Leonid maximum. We must not forget that, should a storm materialize and be widely seen by the public, lots and lots of people are bound to be impressed so much that they will become enthusiastic meteor observers for many years to come. In the interest of meteor observing, I urge all groups to their utmost best to motivate as many people as possible to get up that morning and look out for a meteor storm!

Of course, one can specialize in just one aspect—e.g., the mere observing of meteors—of meteor work, and there is nothing wrong with that. Nevertheless, public relations are important, and informing the public and involving them in our business is an inherent task of the meteor workers' community as a whole. This brings about a lot of work of an educational, administrative, or organizational nature, but we have also a lot to gain from such efforts this year. Meanwhile, this should not keep you from enjoying plain observing, of course! I wish you a lot of clear nights (as well as a clear day on August 11 along the totality zone). Also, enjoy this issue!

The 1999 International Meteor Conference

Frasso Sabino, Italy, September 23–26, 1999

Massimo Calabresi

The 1999 *International Meteor Conference* will be held in the historical village of Frasso Sabino in Italy and the local organization is in the hands of the *Associazione Romana Astrofili*. Frasso Sabino is located at 50 km from Rome along the Via Salaria. The Conference will be held near the village (at 1 km), in a locality called Osteria Nuova, and the participants will be lodged in a new hotel at only 300 m from the lecture rooms. The conference starts on Thursday evening and ends on Sunday. The full registration fee amounts to 240 DEM, and covers accommodation in double rooms, meals, and a copy of the proceedings. Details about the registration procedure can be found on the Registration Form.

For further questions, refer to previous issues of *WGN*, or contact the *Associazione Romana Astrofili* via Mr. Fausto Porcellana (tel. +39(6)40 79 39 94, fax +39(6)40 79 36 30, e-mail `fausto_porcellana@telespazio.it`), Mr. Roberto Gorelli (e-mail `md6648@mclink.it`), and Dr. Massimo Calabresi (e-mail: `mc7851@mclink.it`).

International Meteor Conference

Frasso Sabino, Italy, September 23–26, 1999

Registration Form

Each individual participant should fill out a form and return it to *Ina Rendtel, Mehlbeerenweg 5, D-14469 Potsdam, Germany*, as soon as possible.

Your registration will be guaranteed only after Ina Rendtel has received the minimum pre-payment of 100 DEM. If you wish to participate, but cannot yet decide, simply return this form with the proper option checked to stay on the mailing list for further circulars.

Name: ______________________________ Birth date: ______________

Address: ____

____

____

Phone: ______________ Fax: ______________ E-Mail: ______________

- o wishes to register for the 1999 *IMC* from September 23 to 26;
- o intends to participate, cannot yet register, but wishes to stay on the mailing list.

I intend to travel by __________, together with ______________________________

Additional requests:

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

For participants wishing to contribute to the program:

Lecture: ____

Duration: __________min. Required equipment: ______________________________

Workshop or discussion: ____

Poster presentation: ______________________________ Space: __________ m^2

Either the entire fee of 240 DEM or a pre-payment of at least 100 DEM should be sent to the Treasurer, *Ina Rendtel*. Follow the payment instructions below. Participants paying only 100 DEM have to pay the remaining 140 DEM upon arrival in Frasso Sabino.

Date and signature: ____

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

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

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

Letters to WGN

compiled by Marc Gyssens

A note concerning the occurrence of bright Taurids

I must express my gratitude to Marc Gyssens and the other members of the *WGN* editorial team for their assistance in bringing my recent "Bright Taurids" paper (*WGN* 27:1, February 1999, pp. 53–56) to print for me. I completed the paper only with considerable difficulty after my illness began last December, and several minor problems remained in the final draft text I was able to submit. I am delighted the team were able to eradicate them in the published version.

I should like to comment, however, on the editorial note on p. 55, concerning the *WGN Report Series* volumes only containing magnitude distributions for intervals containing five or more meteors. In fact, this restriction applies only from Volume 8 of the series (observations from 1995) onwards. Prior to that, as far as I can establish from the published texts, all the magnitude data available at the time of publication were printed in the Reports. Obviously, this could not include data submitted after the final publication deadline, which is doubtless where the increased Taurid numbers in the *VMDB* originate for years before 1995. Part of these belated reports would have been discarded in any case, under the criteria for data selection outlined in my paper, but following discussions with Rainer Arlt, we feel even adding the extra reports would not significantly change the overall findings of that paper. The discussed details and conclusions concerning the Taurids thus remain valid.

I am grateful to Rainer and Marc for drawing attention to this particular point, which, had I been in better shape at the time, I would undoubtedly have commented on sooner.

Alastair McBeath, March 25, 1999

A multitude of Leonids

Our attention was caught, and our imaginations fired by the caption to the cover photograph of the April issue of *WGN*. The picture was described as showing *"a bunch of Leonids."* Our trusty *Concise Oxford English Dictionary* describes "bunch" as *"a cluster of things growing or fastened together,"* and, indeed, small quibbles aside about meteors either growing or being fastened, the photograph is aptly captioned as showing a "bunch" of Leonids. So, why this letter? Well, in short, perhaps it boils down to the issue of a missed opportunity. How sad, in a literary sense, it seems to simply call a spectacular display of Leonids "a bunch." Surely, there is a more regal and inspiring term for a multitude of Leonids?

Knowing the appropriate nouns of multitude was once an important part of a "gentleman's" education. Sir Arthur Conan Doyle provides a wonderful sequence on this very topic in his novel *Sir Nigel*. The young Nigel is asked by his tutor what he would call a group (bunch?) of lions. Nigel replies that he would call them a *"number of Lions."* To this, his tutor, Sir John Buttesthorn, head huntsman to the King, replies *"Nay, Nigel, a huntsman would have said that he had seen a pride of lions, and so proved that he knew the language of the chase."* The origin of the expression "a pride of lions" is unknown, but it is certainly contained in the venereal terms listed in *The Hors, Shepe and the Ghoos*, published by William Caxton in 1476, and *The Book of St. Albans* published in 1486. "Venereal" is used here in the sense of the Latin *venari* meaning "to hunt game." Izaak Walton used the expression, for example, in his *The Complete Angler* (first published in 1653) to describe Piscator's hunting companion, Venator.

Since meteor showers are typically named after the constellation in which the radiant resides at the time of shower maximum, it seems appropriate to seek nouns of multitude that reflect the heritage of the parent constellations. Since the Leonids gain their name through an association with Leo, surely we should have "a pride of Leonids." Here is a term that carries both expression and symbolism.

Well, why stop at the Leonids? What about the other major annual meteor showers? Here are our suggestions for the major showers from the January Bootids to the December Ursids. In English folklore, Bootes is called the Ploughman, since he follows the asterism of the Plough (more commonly the Big Dipper) around the sky. It seems fitting that we should have therefore "a furrow of Bootids." "A stave of Lyrids" seems appropriate and symbolizes the set of lines and their intermediate spaces upon which musical notes are arranged, the parent constellation, of course, being that of The Harp. Clearly, one should have "a cloud-burst of Aquarids," given that Aquarius is the water-bearer. Perseus, being the rescuer of Andromeda, (St. Lawrence's tears aside) prompts the term "a chivalry of Perseids." What else could one have but "a run of Taurids" to honor the running of the bulls held each year during the feast of San Fermin in Pamplona, Spain? In similar vein, "a quarry of Orionids" seems appropriate for meteors radiating from the constellation of The Hunter. Since Castor and Pollux, the brightest stars in the constellation of Gemini, are the Patrons of all seafarers, it seems appropriate to have "a fleet of Geminids." There are many mythologies relating to Ursa Major and Ursa Minor, the Great and Small Bears. In one Greek legend, the bears symbolize the nymphs Adrasteia and Io who raised Zeus when an infant. In honor of the beauty of nymphs we suggest "a charm of Ursids."

So, there you have it, a bunch of suggested terms describing multiple collections of shower meteors. We reflect upon the fact that it is sad there is no major shower from the constellation Horologium, The Clock, since then we could have introduced the term "a passing of Horologids," which has a nice "ring" to it. Likewise, we are glad there is no major shower from the constellation of Antila, The Air Pump, since then we might well have suffered from "an evacuation of Antilids," which sounds painful.

Martin and Georgette Beech, July 17, 1999

Perseids during the 1999 August 11 Total Solar Eclipse?

Alastair McBeath

People interested in astronomy living in Europe will doubtless be making every effort to observe the last total solar eclipse of the millennium in mid-August. Most meteor observers will also realize that the eclipse means perfect lunar conditions for viewing the Perseid maxima on August 12-13, and will be making plans accordingly. As I have examined elsewhere [1,2], this proximity in time means there is a 30–40% chance of a magnitude +2 or brighter Perseid appearing over a given site during totality. The chance that any such event will be seen is naturally smaller, though the brighter and nearer the eclipsed Sun it is, the better. Any bright Perseid that does chance-by during the critical circa 2-minute period should thus be enjoyed as an extra treat, not something that can reasonably be expected as definite!

References

[1] A. McBeath, "A bonus from the eclipse", *Astronomy and Geophysics* 39, 1999, p. 5.7.

[2] A. McBeath, "Perseid observing during the 1999 total solar eclipse over Europe", in *1998 IMC Proceedings*, Stará Lesná, R. Arlt, A. Knöfel, eds., IMO, 1999, p. 52.

Meteor Shower Calendar: October 1999–March 2000

compiled by Alastair McBeath and Rainer Arlt

1. October to December

Ecliptical minor shower activity reaches what might be regarded as a peak in early to mid November, with the Taurid streams in action. Before then is a moonless Draconid epoch, together with badly Moon-affected ε-Geminid and Orionid maxima, all in October. The Orionids' central peak is likely around 20^h UT on October 21 for radio observers. The Leonids in November may still be capable of producing high to storm activity this year, but the α-Monocerotids (November 22, 1^h UT) are lost to the Moon. December's New Moon is excellent news for covering the χ-Orionids, Phoenicids, Puppid-Velids, Monocerotids, and σ-Hydrids, along with the Geminids. The downside is losing the Coma Berenicids and Ursids (peak due circa December 22, 23^h UT) to Full Moon.

Draconids

Active: October 6–10; Maximum: October 9, 3^h UT ($\lambda_\odot = 195.^\circ4$);
ZHR: periodic—up to storm levels;
Radiant: $\alpha = 262°$, $\delta = +54°$; radiant drift: negligible; $V_\infty = 20$ km/s; $r = 2.6$;
TFC: $\alpha = 290°$, $\delta = +65°$ and $\alpha = 288°$, $\delta = +39°$ ($\beta > 30°$ N).

New Moon perfectly favors any Draconids that appear this year. Unfortunately for potential observers, although this periodic shower has produced spectacular, brief, meteor storms twice already this century, in 1933 and 1946, and lower rates in several other years (ZHRs ranging from 20 to 200+), so far, detectable activity has only been seen in years when the stream's parent comet, 21P/Giacobini-Zinner, has returned to perihelion. It did this last in November 1998. The peak time above is based on the Earth's closest approach to the comet orbit's node, but activity might be seen before or after this too (the 1998 peak time coincides with October 8, 19^h30^m UT this year). The radiant is circumpolar from many locations, but is higher in the pre-midnight and near-dawn hours on October 8–10. The shower is only properly observable from the northern hemisphere. The peak time given in the box above is based on the Earth's closest approach to the comet orbit's node, but activity might be seen before or considerably after this, too. The radiant is circumpolar from many locations, but is higher in the pre-midnight and near-dawn hours on October 8–10. The shower is only properly observable from the northern hemisphere.

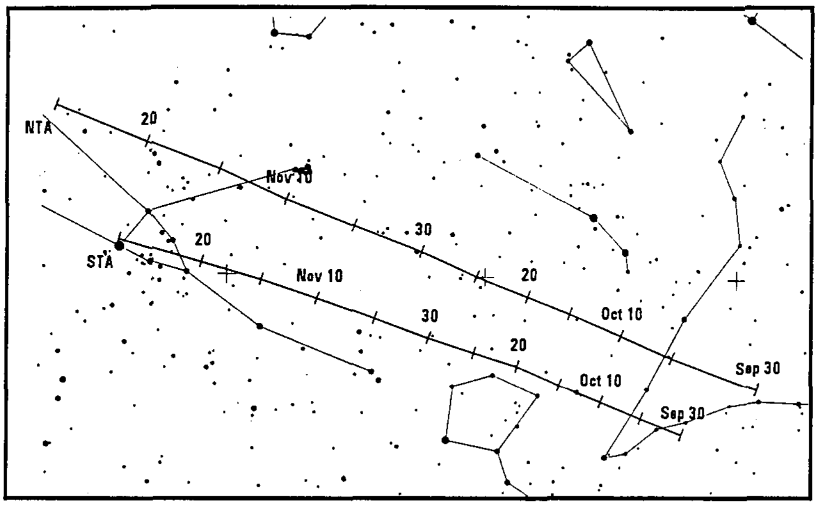


Figure 1 – Radiant position and drift of the Northern and Southern Taurids.

Southern Taurids

Active: October 1–November 25; Maximum: November 5 ($\lambda_\odot = 223°$); ZHR = 5;
Radiant: $\alpha = 52°$, $\delta = +13°$; Radiant drift: see Table 4; size: $\alpha = 20° \times \delta = 10°$;
$V_\infty = 27$ km/s; $r = 2.3$;
TFC: Choose fields on the ecliptic and $\approx 10°$ E or W of the radiants ($\beta > 40°$ S).

Northern Taurids

Active: October 1–November 25; Maximum: November 12 ($\lambda_\odot = 230°$); ZHR = 5;
Radiant: $\alpha = 58°$, $\delta = +22°$; Radiant drift: see Table 4; size: $\alpha = 20° \times \delta = 10°$;
$V_\infty = 29$ km/s; $r = 2.3$;
TFC: Choose fields on the ecliptic and $\approx 10°$ E or W of the radiants ($\beta > 40°$ S).

These two streams form a complex associated with Comet 2P/Encke. Defining their radiants is best achieved by careful visual or telescopic plotting, photography, or video work, since they are large and diffuse. The brightness and relative slowness of many shower meteors makes them ideal targets for photography, while these factors coupled with low, steady combined Taurid rates makes them excellent targets for newcomers to practice their plotting techniques on. The activity of both streams produces an apparently plateau-like maximum for about ten days in early November, and the shower has a reputation for producing some superbly bright fireballs at times, although seemingly not in every year. In 1995, an impressive crop of brilliant Taurids occurred between late October and mid-November, for instance. New Moon on November 8 means the entire Taurid peak should be treated to dark skies in 1999.

The near-ecliptic radiants for both shower branches mean all meteoricists can observe the streams, with the northern hemisphere somewhat better-placed, from where suitable radiant zenith distances obtain for much of the lengthening late autumnal nights. Even in the southern hemisphere, a good 3–5 hours watching around local midnight is possible with Taurus well above the horizon, however.

Leonids

Active: November 14–21; Maximum: November 18, $2^{\rm h}$ UT ($\lambda_\odot = 235\overset{\circ}{.}29$);
ZHR: more than 100, may reach more than 1000 in 1999;
Radiant: $\alpha = 153°$, $\delta = +22°$, radiant drift: see Table 4; $V_\infty = 71$ km/s; $r = 2.9$;
TFC: $\alpha = 140°$, $\delta = +35°$ and $\alpha = 129°$, $\delta = +06°$ ($\beta > 35°$ N);
$\alpha = 156°$, $\delta = -03°$ and $\alpha = 129°$, $\delta = +06°$ ($\beta < 35°$ N);
PFC: $\alpha = 120°$, $\delta = +40°$ before $0^{\rm h}$ local time ($\beta > 40°$ N);
$\alpha = 120°$, $\delta = +20°$ before $4^{\rm h}$ local time;
$\alpha = 160°$, $\delta = 00°$ after $4^{\rm h}$ local time ($\beta > 0°$ N);
$\alpha = 120°$, $\delta = +10°$ before $0^{\rm h}$ local time;
$\alpha = 160°$, $\delta = -10°$ after $0^{\rm h}$ local time ($\beta < 0°$ N).

The perihelion passage of the Leonids' parent comet, 55P/Tempel-Tuttle, in February 1998 means high to storm-level Leonid activity may occur in 1999. There are, of course, no guarantees that this will happen, but all observers must realize that even discovering the absence of any unusual Leonid activity would still be very valuable information—albeit not all that interesting to witness! Recent calculations and visual *IMO International Leonid Watch* observations suggest a peak timing around $\lambda_{\odot} = 235.^{\circ}29$ is most likely, but another plausible time is when the Earth passes the node of the comet's orbit, at $\lambda_{\odot} = 235.^{\circ}25$ (November 18, 1999, 1^{h} UT).

The radiant rises only around local midnight (or indeed afterwards south of the equator), by which time the waxing gibbous Moon will be setting. Either suggested peak timing would favor locations in Europe, the Near East, and North Africa. Even a minor variation in the peak's occurrence could mean places east or west of this zone may see something of the shower's best too, however. Observers at the northeastern coast of North America should be particularly attentive in the early morning hours of November 18. All observing methods should be utilized to the full, especially photography and video if a storm manifests.

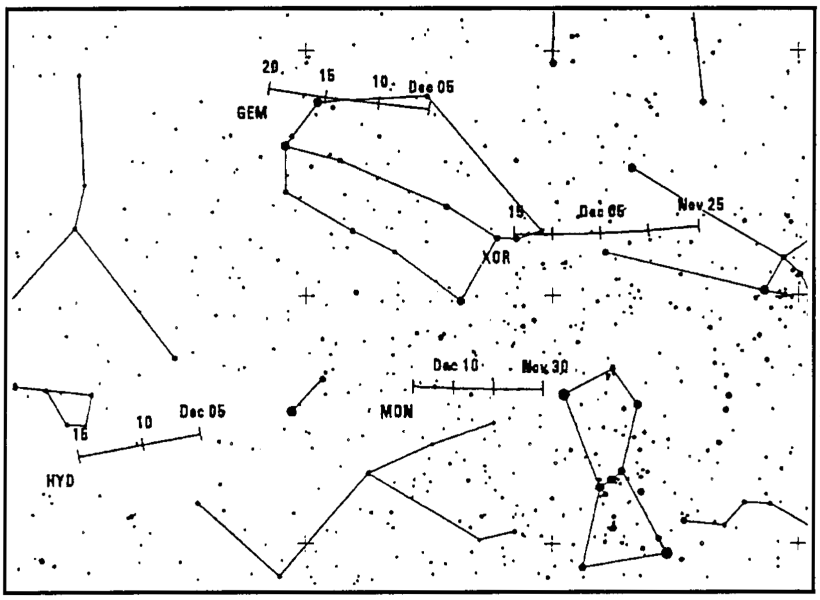


Figure 2 – Radiant position and drift of the χ-Orionids, Monocerotids, σ-Hydrids, and Geminids.

χ-Orionids

Active: November 26–December 15; Maximum: December 2 ($\lambda_{\odot} = 250°$); ZHR = 3;
Radiant: $\alpha = 82°$, $\delta = +23°$; Radiant drift: see Table 4; 8°; $V_{\infty} = 28$ km/s; $r = 3.0$;
TFC: $\alpha = 83°$, $\delta = +09°$ and $\alpha = 80°$, $\delta = +24°$ ($\beta > 30°$ S).

This weak visual stream is moderately active telescopically, although a number of brighter meteors have been photographed, too. The shower has at least a double radiant, but the southern branch has been rarely detected. The χ-Orionids may be a continuation of the ecliptic complex after the Taurids cease to be active. The radiant used here is a combined one, suitable for visual work, although telescopic or video observations should be better-able to determine the exact radiant structure. The waning crescent Moon should give few problems, as the radiant is well on display for all watchers throughout the night.

Phoenicids

Active: November 28–December 9; Maximum: December 6, 20^{h} UT ($\lambda_{\odot} = 254.^{\circ}25$);
ZHR: variable, usually 3 or less, may reach 100;
Radiant: $\alpha = 18°$, $\delta = -53°$; Radiant drift: see Table 4; $V_{\infty} = 18$ km/s; $r = 2.8$;
TFC: $\alpha = 40°$, $\delta = -39°$ and $\alpha = 65°$, $\delta = -62°$ ($\beta < 10°$ N).

Only one impressive Phoenicid return has so far been reported, that of its discovery in 1956, when the ZHR was about 100. Three other potential bursts of lower activity have been reported, but never by more than one observer, under uncertain circumstances. Reliable *IMO* data shows recent activity to be virtually non-existent. This may be a periodic shower, however, and more observations of it are needed by all methods. Radio workers may find difficulties, as radar echoes from the 1956 event were only 30 per hour, perhaps because these low-velocity meteors produce too little radio-reflecting ionization. Observing conditions this year are excellent for all southern hemisphere watchers, with New Moon on December 7. The radiant is well on view for most of the night, but culminates at dusk.

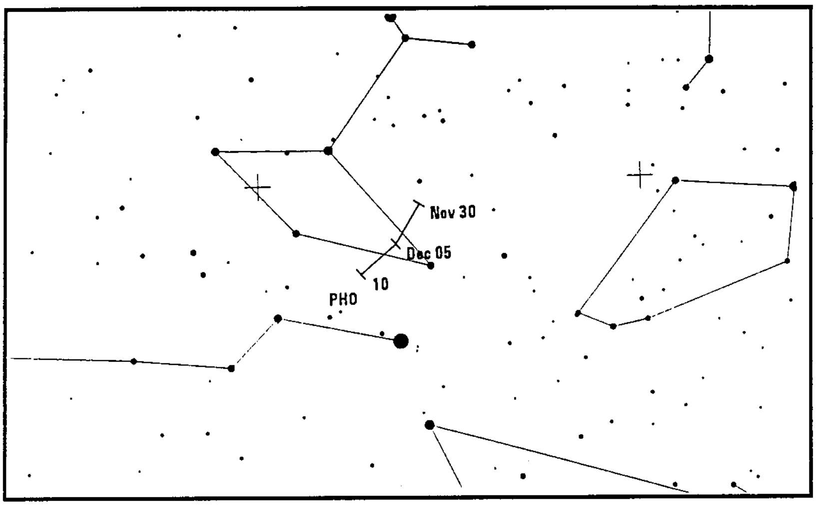


Figure 3 – Radiant position and drift of the Phoenicids.

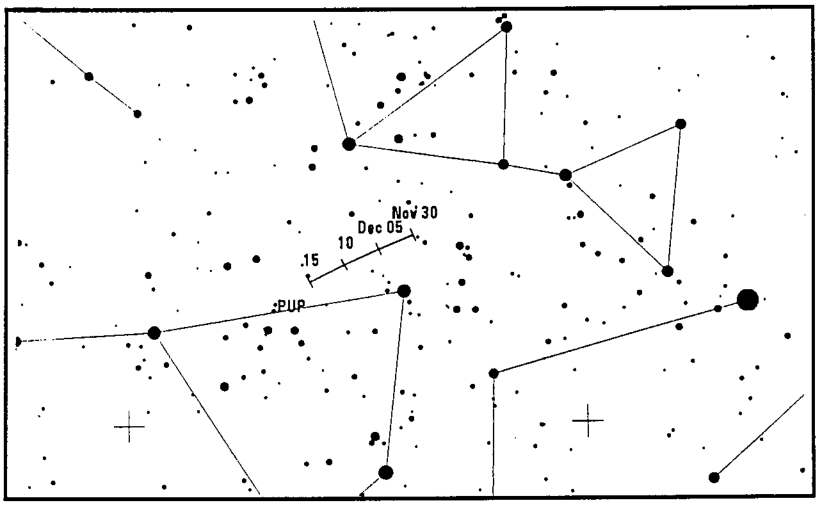


Figure 4 – Radiant position and drift of the Puppid-Velids.

Puppid-Velids

Active: December 1–15; Maximum: December 7 ($\lambda_\odot = 255°$); ZHR = 10;
Radiant: $\alpha = 123°$, $\delta = -45°$; Radiant drift: see Table 4, $V_\infty = 40$ km/s; $r = 2.9$;
TFC: $\alpha = 090°$–$150°$, $\delta = -20°$– $-60°$; choose fields separated by about 30° in α, moving eastwards as the shower progresses ($\beta < 10°$ N).

This is a very complex system of poorly-studied showers, visible chiefly to those south of the equator. Up to ten sub-streams have been identified, with radiants so tightly clustered, visual observing cannot readily separate them. Photographic, video, or telescopic work would thus be sensible, or very careful visual plotting. The activity is so badly-known that we can only be reasonably sure that the highest rates occur in early to mid December, perfect for the New-Moon period this year. Some of these showers may be visible from late October to late January. Most shower meteors are quite faint, but occasional bright fireballs, notably around the suggested maximum here, have been reported previously. The radiant is on-view all night, but highest towards dawn.

December Monocerotids

Active: November 27–December 9; Maximum: December 9 ($\lambda_\odot = 257°$); ZHR = 3;
Radiant: $\alpha = 100°$, $\delta = +08°$, Radiant drift: see Table 4, $V_\infty = 42$ km/s; $r = 3.0$;
TFC: $\alpha = 088°$, $\delta = +20°$ and $\alpha = 135°$, $\delta = +48°$ ($\beta > 40°$ N);
$\alpha = 120°$, $\delta = -03°$ and $\alpha = 084°$, $\delta = +10°$ ($\beta < 40°$ N).

Only low visual rates can be expected from this source, making accurate visual plotting, telescopic, or video work essential, particularly because the meteors are normally faint. The shower details, even including the radiant position, are rather uncertain. Recent *IMO* data shows only weak signs of a maximum as indicated above. Telescopic data suggests a later maximum, around December 16 ($\lambda_\odot = 264°$) from a radiant at $\alpha = 117°$ and $\delta = +20°$. This is a very good year for all meteor workers to make observations to help resolve these points, as the Moon is not a problem. The radiant is on-show nearly all night, culminating around 1^h local time.

σ-Hydrids

Active: December 3–15; Maximum: December 12 ($\lambda_\odot = 260°$); ZHR = 2;
Radiant: $\alpha = 127°$, $\delta = +02°$, Radiant drift: see Table 4, $V_\infty = 58$ km/s; $r = 3.0$;
TFC: $\alpha = 095°$, $\delta = 00°$ and $\alpha = 160°$, $\delta = 00°$ (all sites, after midnight only).

Although first detected in the 1960s by photography, σ-Hydrids are typically swift and faint, and rates generally low, often close to the visual detection limit. Since their radiant, just to the south-west of the "head" asterism of Hydra, a little over 10° east of Procyon (α Canis Minoris), is near the equator, all observers can cover this shower. The radiant rises in the late evening hours, but is best viewed after local midnight. This means the waxing crescent Moon will have set long before σ-Hydrid watching can begin at their peak in 1999. Recent data indicates the peak may occur up to six days earlier than suggested above, and would benefit from visual plotting, telescopic, or video work to pin it down more accurately.

Geminids

Active: December 7–17; Maximum: December 14, 11^h UT ($\lambda_\odot = 262.°0$); ZHR = 120;
Radiant: $\alpha = 112°$, $\delta = +33°$; radiant drift: see Table 4; $V_\infty = 35$ km/s; $r = 2.6$;
TFC: $\alpha = 87°$, $\delta = +20°$ and $\alpha = 135°$, $\delta = +49°$ before 23^h local time;
$\alpha = 87°$, $\delta = +20°$ and $\alpha = 129°$, $\delta = +20°$ after 23^h local time ($\beta > 40°$ N);
$\alpha = 120°$, $\delta = -03°$ and $\alpha = 84°$, $\delta = +10°$ ($\beta \leq 40°$ N).
PFC: $\alpha = 150°$, $\delta = +20°$ and $\alpha = 60°$, $\delta = +40°$ ($\beta > 20°$ N);
$\alpha = 135°$, $\delta = -05°$ and $\alpha = 80°$, $\delta = 00°$ ($\beta \leq 40°$ N).

One of the finest annual showers presently observable. The waxing crescent Moon will have set by about 22^h–23^h local time at their peak, so much of the second half of the night at least will be available for observing them. Well north of the equator, the radiant rises around sunset, and can be usefully observed from the local evening hours onwards, but in the southern hemisphere, the radiant appears only around local midnight or so. Even here, this is a splendid stream of often bright, medium-speed meteors, a rewarding sight for all watchers. The peak has shown slight signs of variability in its maximum rates and the actual peak timing, so the best activity may occur a little after the suggested time above, perhaps up to 15^h–16^h UT. This means North-American to Far-Eastern sites are most likely to see the best from the 1999 Geminids. Some mass-sorting within the stream means the fainter telescopic meteors should be most abundant almost 1° of solar longitude ahead of the visual maximum, with telescopic results indicating these meteors radiate from an elongated region, perhaps with three sub-centers. Further results on this topic would be useful, but all observing methods can be employed to observe the shower.

2. January to March

The year's first quarter brings several low activity showers, including the diffuse ecliptical stream complex, the Virginids, active from late January to mid-April. Both major showers, the northern-hemisphere Quadrantids and the southern-hemisphere α-Centaurids, are excellently-placed with regard to the Moon this year. The minor δ-Cancrids are lost in the near-Full Moon glare in January, but the weak δ-Leonids in late February and the γ-Normids in mid-March fare better. Daylight radio peaks are theoretically due from the Capricornid/Sagittarids around 2^h UT on February 2, and the χ-Capricornids on February 14, around 3^h UT. Recent radio results suggest the Capricornid/Sagittarid peak may fall 2–3 days later than this however, while no significant enhancement in radio rates was found near the expected χ-Capricornid peak between 1994–1999. As both showers have radiants less that 10° to 15° west of the Sun at maximum, they cannot be regarded as visual targets even from the southern hemisphere.

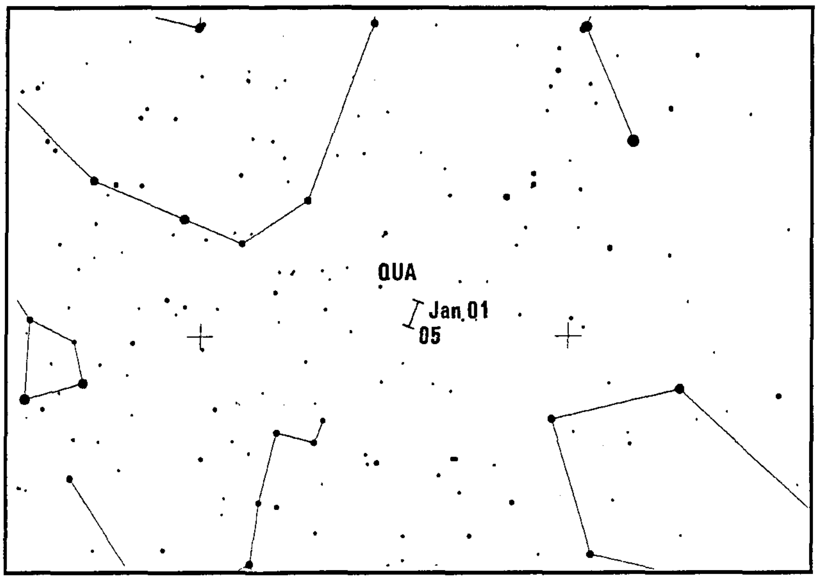


Figure 5 – Radiant position and drift of the Quadrantids

Quadrantids

Active: January 1–5; Maximum: January 4, $5^{\rm h}$ UT ($\lambda_\odot = 283^\circ\!.16$);
ZHR = 120 (can vary $\sim$ 60–200);
Radiant: $\alpha = 230°$, $\delta = +49°$; Radiant drift: see Table 4; $V_\infty = 41$ km/s; $r = 2.1$ at maximum, but variable;
TFC: $\alpha = 242°$, $\delta = +75°$ and $\alpha = 198°$, $\delta = +40°$ ($\beta > 40°$ N);
PFC: $\alpha = 150°$, $\delta = +70°$ before 0^h local time;
$\alpha = 180°$, $\delta = +40°$ and $\alpha = 240°$, $\delta = +70°$ after $0^{\rm h}$ local time ($\beta > 40°$ N).

The year opens with a superb return of the Quadrantids for northern hemisphere observers, as the Moon is just two days before New on January 4. Since the shower's radiant is in northern Bootes, it is circumpolar for many northern locations, but it attains a useful elevation only after local midnight or so, and gets higher towards morning twilight. An interesting challenge is to try spotting the occasional long-pathed shower member from the southern hemisphere around dawn, but sensible Quadrantid watching cannot be carried out from such locations.

The maximum time given above is based on the best-observed return of the shower ever analyzed, from *IMO* 1992 data, confirmed by radio results in 1996, 1997, and 1999. A repeat of this time in 2000 would favor sites from Europe to the east coast of North America. The peak itself is normally short-lived, and can be easily missed in just a few hours of poor winter weather in the north, which may be why the ZHR level apparently fluctuates from year to year, but some genuine variability is probably present too. For instance, visual ZHRs in 1998 persisted for over two hours at their best. An added level of complexity comes from the fact that mass-sorting of particles across the meteoroid stream may make fainter objects (radio and telescopic meteors) reach maximum up to 14 hours before the brighter (visual and photographic) ones, so observers should be alert throughout the shower!

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

α-Centaurids

Active: January 28–February 21; Maximum: February 8, $16^{\rm h}$ UT ($\lambda_\odot = 319^\circ\!.2$);
ZHR is variable, usually $\sim$ 6, but may reach 25+;
Radiant: $\alpha = 210°$, $\delta = -59°$; Radiant drift: see Table 4; $V_\infty = 56$ km/s; $r = 2.0$.

The α-Centaurids are one of the main southern hemisphere high points in the opening months of the year, producing many very bright, even fireball-class objects (meteors of at least magnitude −3). Their peak ZHR is normally around 5–10, but in 1974 and again in 1980, bursts of only a few hours duration that yielded activity closer to 20–30 were detected.

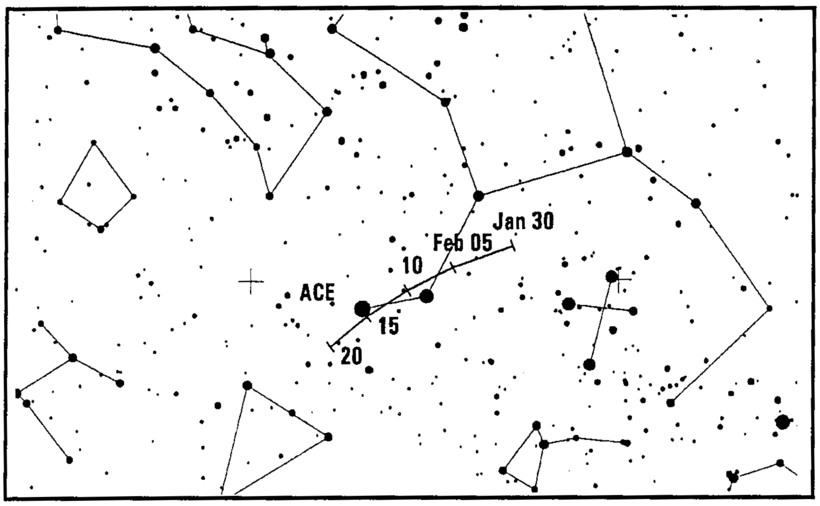


Figure 6 – Radiant position and drift of the α-Centaurids.

As we have no means of telling when another such event might happen, photographic,video and visual observers are urged to be alert, especially this year, as the Moon is New just three das before their maximum. Thanks to their brilliance, even a normal α-Centaurid return is worth looking out for, and almost one-third routinely leave fine persistent trains after them. The radiant is nearly circumpolar for much of the sub-equatorial inhabited Earth, and is at a useful elevation from late evening onwards.

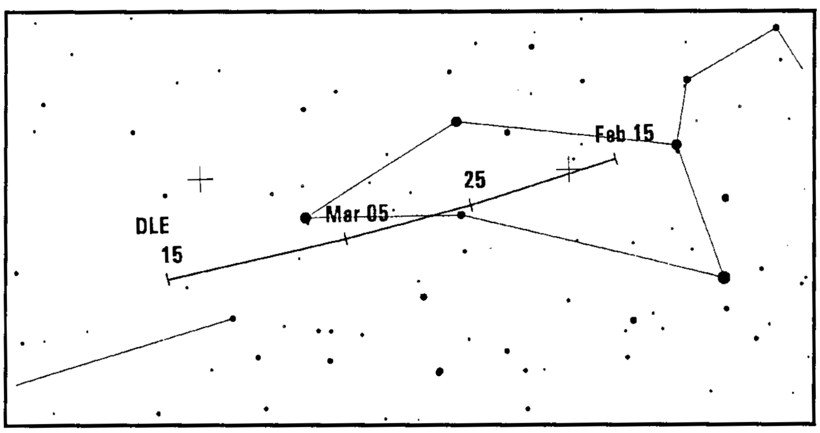


Figure 7 – Radiant position and drift of the δ-Leonids.

δ-Leonids

Active: February 15–March 10; Maximum: February 24 ($\lambda_{\odot} = 336°$); ZHR = 2;
Radiant: $\alpha = 168°$, $\delta = +16°$, Radiant drift: see Table 4; $V_{\infty} = 23$ km/s; $r = 3.0$;
TFC: $\alpha = 140°$, $\delta = +37°$ and $\alpha = 151°$, $\delta = +22°$ ($\beta > 10°$ N);
$\alpha = 140°$, $\delta = -10°$ and $\alpha = 160°$, $\delta = 00°$ ($\beta < 10°$ N).

This minor shower is probably part of the early Virginid activity. Rates are normally low, and its meteors are predominantly faint, so it is a prime candidate for telescopic investigation. Visual observers must make very accurate plots of the meteors to distinguish them from the nearby Virginids and the sporadics.

Northern hemisphere sites have a distinct advantage for covering this stream, especially this year as the waning gibbous Moon will rise around or after midnight at the peak for sites north of 35° N latitude. Southern hemisphere watchers should not ignore the stream, as they are better-placed to note many of the other Virginid radiants, but with moonrise as early as $22^{h}30^{m}$ local time at 35° S latitude on February 25, conditions are not ideal. At least, the δ-Leonid radiant in mid-Leo is well on view for most of the night near the peak.

γ-Normids

Active: February 25–March 13; Maximum: March 14 ($\lambda_\odot = 353°$); ZHR = 8;
Radiant: $\alpha = 249°$, $\delta = -51°$; radiant drift; see Table 4; $V_\infty = 56$ km/s; $r = 2.4$;
TFC: $\alpha = 225°$, $\delta = -26°$ and $\alpha = 215°$, $\delta = -45°$ ($\beta < 15°$ S).

The γ-Normid meteors are similar to the sporadics in appearance, and for most of their activity period, their ZHR is virtually undetectable above this background rate. The peak itself is normally quite sharp, with ZHRs of 3+ noted for only a day or two to either side of the maximum. Activity may vary somewhat at times, with occasional broader, or less obvious, maxima having been reported in the past. Post-midnight watching yields best results, when the radiant is rising to a reasonable elevation from southern-hemisphere sites. First Quarter Moon on March 13 is thus excellent news, as it will set before midnight. All forms of observation can be carried out for the shower, though most northern observers will see nothing from it.

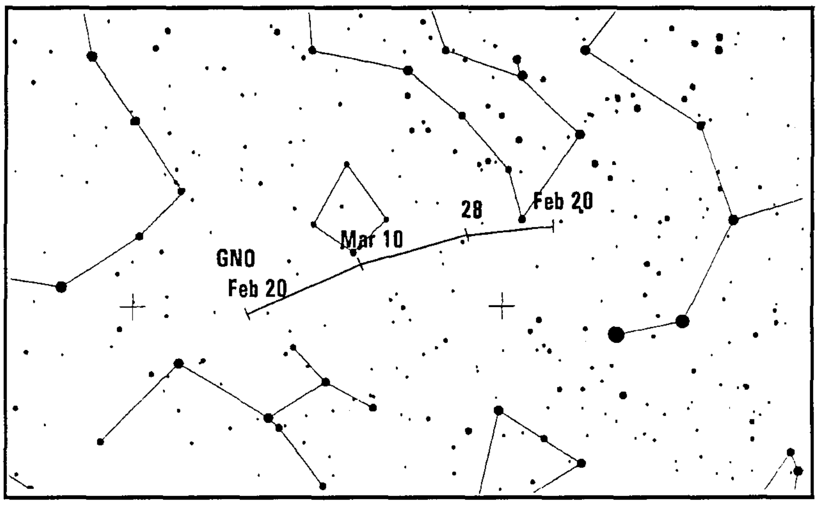


Figure 8 – Radiant positions and drift of the γ-Normids.

3. Lunar phases

Table 1 – Lunar phases for October 1999–March 2000.

New Moon	Oct 09	Nov 08	Dec 07	Jan 06	Feb 05	Mar 06	Apr 04
First Quarter	Oct 17	Nov 16	Dec 16	Jan 14	Feb 12	Mar 13	Apr 11
Full Moon	Sep 25	Oct 24	Nov 23	Dec 22	Jan 21	Feb 19	Mar 20
Last Quarter	Oct 10	Oct 31	Nov 29	Dec 29	Jan 28	Feb 27	Mar 28

4. Daytime radio meter streams

Table 2 – Working list of daytime radio meteor streams. The "Best Observed" columns give the approximate local mean times between which a four-element antenna at an elevation of 45° receiving a signal from a 30-kW transmitter 1000 km away should record at least 85% of any suitably positioned radio-reflecting meteor trails for the appropriate latitudes. Note that this is often heavily dependent on the compass direction in which the antenna is pointing, however, and applies only to dates near the shower's maximum.

Shower	Activity	Max	$\lambda_\odot$	Radiant		Best Observed		Rate
		Date	2000.0	α	δ	50° N	35° S	
Sextantids	Sep 09–Oct 09	Sep 27	184°3	152°	00°	06^h–12^h	06^h–13^h	medium
Cap/Sagittarids	Jan 13–Feb 04	Feb 02	312°5	299°	−15°	11^h–14^h	09^h–14^h	medium
χ-Capricornids	Jan 29–Feb 28	Feb 14	324°7	315°	−24°	10^h–13^h	08^h–15^h	low

5. Working list of meteor showers

Table 3 – Working list of meteor showers for the period October 1999–March 2000. Streams marked with an asterisk are periodically or occasionally active, and therefore no ZHR is cited. The "maximum" dates cited for the Virginids and the Puppid/Velids should be seen as reference dates only.

Shower	Activity	Maximum		Radiant		V_∞	r	ZHR
		Date	$\lambda_\odot$	α	δ	(km/s)		
δ-Aurigids (DAU)	Sep 05–Oct 10	Sep 08	166°	60°	+47°	64	3.0	6
Piscids (SPI)	Sep 01–Sep 30	Sep 20	177°	5°	−01°	26	3.0	3
Draconids* (GIA)	Oct 06–Oct 10	Oct 08	195.°4	262°	+54°	20	2.6	
ε-Geminids (EGE)	Oct 14–Oct 27	Oct 18	205°	102°	+27°	70	3.0	2
Orionids (ORI)	Oct 02–Nov 07	Oct 21	208°	95°	+16°	66	2.9	20
Southern Taurids (STA)	Oct 01–Nov 25	Nov 05	223°	52°	+13°	27	2.3	5
Northern Taurids (NTA)	Oct 01–Nov 25	Nov 12	230°	58°	+22°	29	2.3	5
Leonids (LEO)	Nov 14–Nov 21	Nov 17	235.°2	153°	+22°	71	2.9	var
α-Monocerotids (AMO)	Nov 15–Nov 25	Nov 21	239.°3	117°	+01°	65	2.4	var
χ-Orionids (XOR)	Nov 26–Dec 15	Dec 02	250°	82°	+23°	28	3.0	3
Dec Phoenicids (PHO)	Nov 28–Dec 09	Dec 06	254.°3	18°	−53°	22	2.8	var
Puppid/Velids (PUP)	Dec 01–Dec 15	Dec 07	255°	123°	−45°	40	2.9	10
Dec Monocerotids (MON)	Nov 27–Dec 17	Dec 09	257°	100°	+08°	42	3.0	3
σ-Hydrids (HYD)	Dec 03–Dec 15	Dec 12	260°	127°	+02°	58	3.0	2
Geminids (GEM)	Dec 07–Dec 17	Dec 14	262.°0	112°	+33°	35	2.6	120
Coma Berenicids (COM)	Dec 12–Jan 23	Dec 20	268°	175°	+25°	65	3.0	5
Ursids (URS)	Dec 17–Dec 26	Dec 22	270.°7	217°	+76°	33	3.0	10
Quadrantids (QUA)	Jan 01–Jan 05	Jan 04	283.°2	230°	+49°	41	2.1	120
δ-Cancrids (DCA)	Jan 01–Jan 24	Jan 17	297°	130°	+20°	28	3.0	4
α-Centaurids (ACE)	Jan 28–Feb 21	Feb 08	319.°2	210°	−59°	56	2.0	6
δ-Leonids (DLE)	Feb 15–Mar 10	Feb 25	336°	168°	+16°	23	3.0	2
γ-Normids (GNO)	Feb 25–Mar 22	Mar 13	353°	249°	−51°	56	2.4	8
Virginids (VIR)	Jan 25–Apr 15	Mar 24	4°	195°	−04°	30	3.0	5

Table 4 – Radiant positions in α and δ.

	NTA	STA	ORI	DAU				
Oct 5	25o +12°	27° +7°	85° +14°	89° +49°		GIA		
Oct 10	29° +14°	31° +8°	88° +15°	95° +49°		262° +54°		
Oct 15	34° +16°	35° +9°	91° +15°		EGE			
Oct 20	38° +17°	39° +11°	94° +16°		99° +27°			
Oct 25	43° +18°	43° +12°	98° +16°		104° +27°			
Oct 30	47° +20°	47° +13°	101° +16°		109° +27°			
Nov 5	53° +21°	52° +14°	105° +17°					
Nov 10	58° +22°	56° +15°		LEO	AMO			
Nov 15	62° +23°	60° +16°		150° +23°	112° +02°			
Nov 20	67° +24°	64° +16°	XOR	153° +21°	116° +01°			
Nov 25	72° +24°	69° +17°	75° +23°		120° 00°	MON	PUP	PHO
Nov 30			80° +23°	HYD		91° +8°	120° −45°	14° −52°
Dec 5	COM	GEM	85° +23°	122° +03°		96° +8°	122° −45°	18° −53°
Dec 10	169° +27°	108° +33°	90° +23°	126° +02°		100° +8°	125° −45°	22° −53°
Dec 15	173° +26°	113° +33°	94° +23°	130° +01°	URS	104° +8°	128° −45°	
Dec 20	177° +24°	118° +32°	DCA		217° +75°			
Jan 0	186° +20°	QUA	112° +22°					
Jan 5	190° +18°	231° +49°	116° +22°					
Jan 10	194° +17°		121° +21°					
Jan 20	202° +13°		130° +19°	ACE	VIR			
Jan 30				200° −57°	157° +16°	DLE		
Feb 10				214° −60°	165° +10°	155° +20°	GNO	
Feb 20				225° −63°	172° +06°	164° +18°	225° −53°	
Feb 28					178° +03°	171° +15°	234° −52°	
Mar 10					186° 00°	180° +12°	245° −51°	
Mar 20					192° −03°		256° −50°	
Mar 30					198° −05°			

Ongoing Meteor Work

The Limiting Magnitude Problem

Peter Zimnikoval

It is argued that the star-counting method to determine the stellar limiting magnitude may give poor results under poor sky conditions. For poor sky conditions, it is recommended to use sequences of stars with known magnitudes. For this purpose, a system of maps is proposed.

To reduce meteor observations to standard sky conditions and calculate ZHRs, the determination of the stellar limiting magnitude (Lm) is required. The value of Lm is defined as the magnitude of the faintest star visible by the naked eye in the observed part of the sky. There are several methods to determine Lm, each pf which has advantages and disadvantages. The method used by the *IMO* is based on counting the visible stars in specified areas (*WGN* 27:1, February 1999, pp. 6–18). The method is very easy to use, but has some drawbacks, too, mainly that the number of stars in a single magnitude class is not uniform, especially for the brighter magnitude classes. Of course, for most observations, when an observer uses two or more areas for Lm determination simultaneously, that disadvantage is not very significant. Moreover, the worldwide use of the *IMO* method over a long period of time makes the *IMO Visual Meteor Database* quite homogeneous and the data well-corrected to a standard Lm. One may safely conclude that the method is reasonably precise in the Lm range from, say, +5.5 to +6.5, i.e., for observations under normal conditions.

The situation becomes problematic, however, for observations with limiting magnitudes worse than +5.0 (e.g., due to the influence of the Full Moon or city lights). With such sky conditions, only a few stars are visible in a single counting area, and, therefore, Lm is evaluated only very roughly. It used to be recommended not to observe under such sky conditions, but, the last few years, an awareness has grown that every observation may yield unique information, particularly if the Earth crosses a meteoroid stream near its parent body. In addition, an ever growing number of potential observers is confronted with severe light pollution.

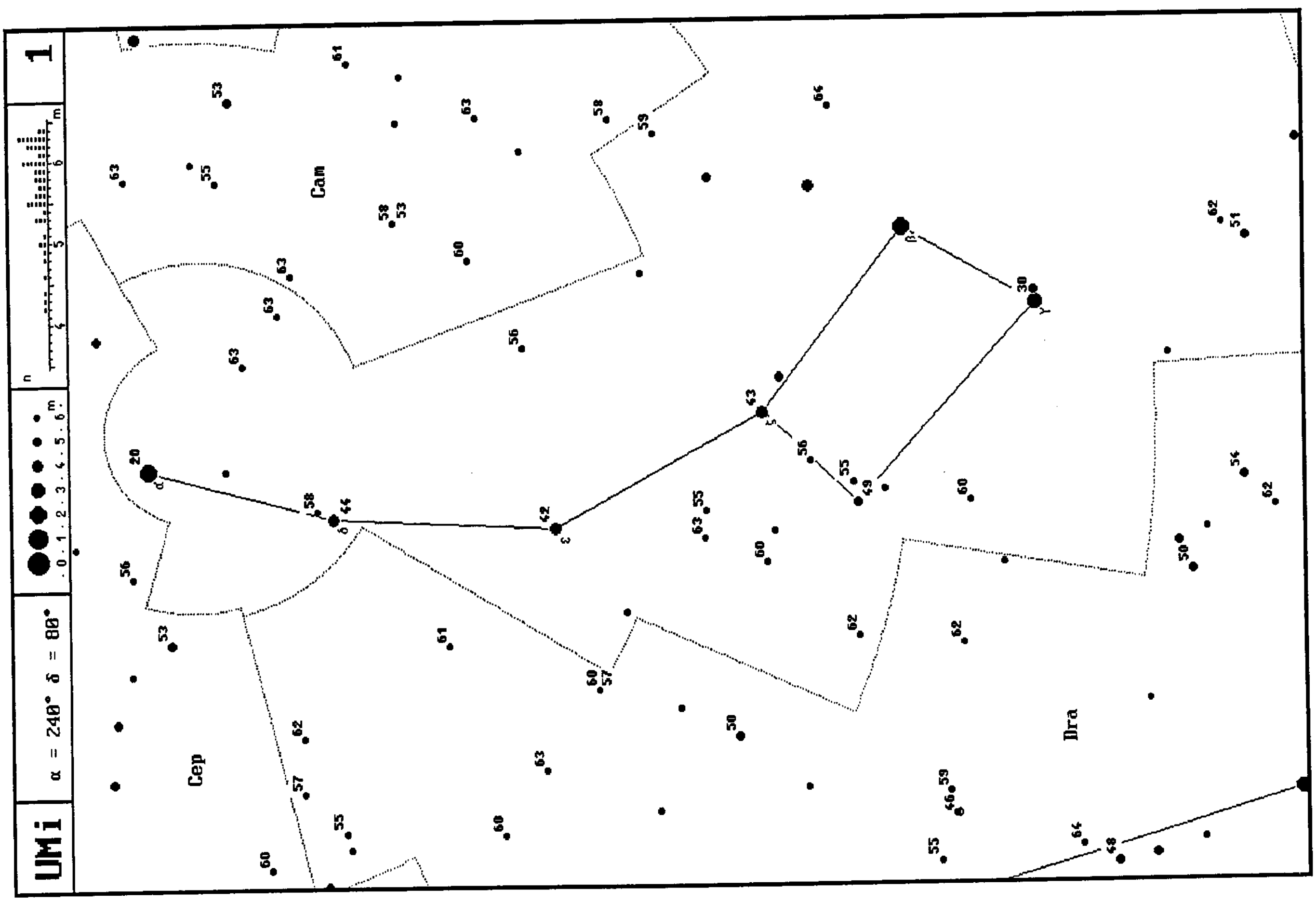
For the reasons described above, I suggest to use another method of Lm determination under conditions with low limiting magnitude. The method is not new: it is based on star maps of some selected areas of the sky, on which magnitudes are printed for suitable stars. The limiting magnitude is determined as the magnitude of the faintest star visible in that area. The main disadvantage of this method is the necessity to use a source of light to see the map. Of course, in the case of a Full Moon, this disturbance is not too important. The second problem is self-suggestion: an observer may have the illusion that he sees some faint star when he knows its position. Self-suggestion is present in all methods of Lm determination, however. The method we propose may yield more precise ZHR values for observations near a Full Moon and may enable the evaluation of observations carried out near cities. The limiting magnitudes determined by both methods may differ, and, therefore, it would be interesting to do observations using both methods simultaneously to see if systematic deviations occur.

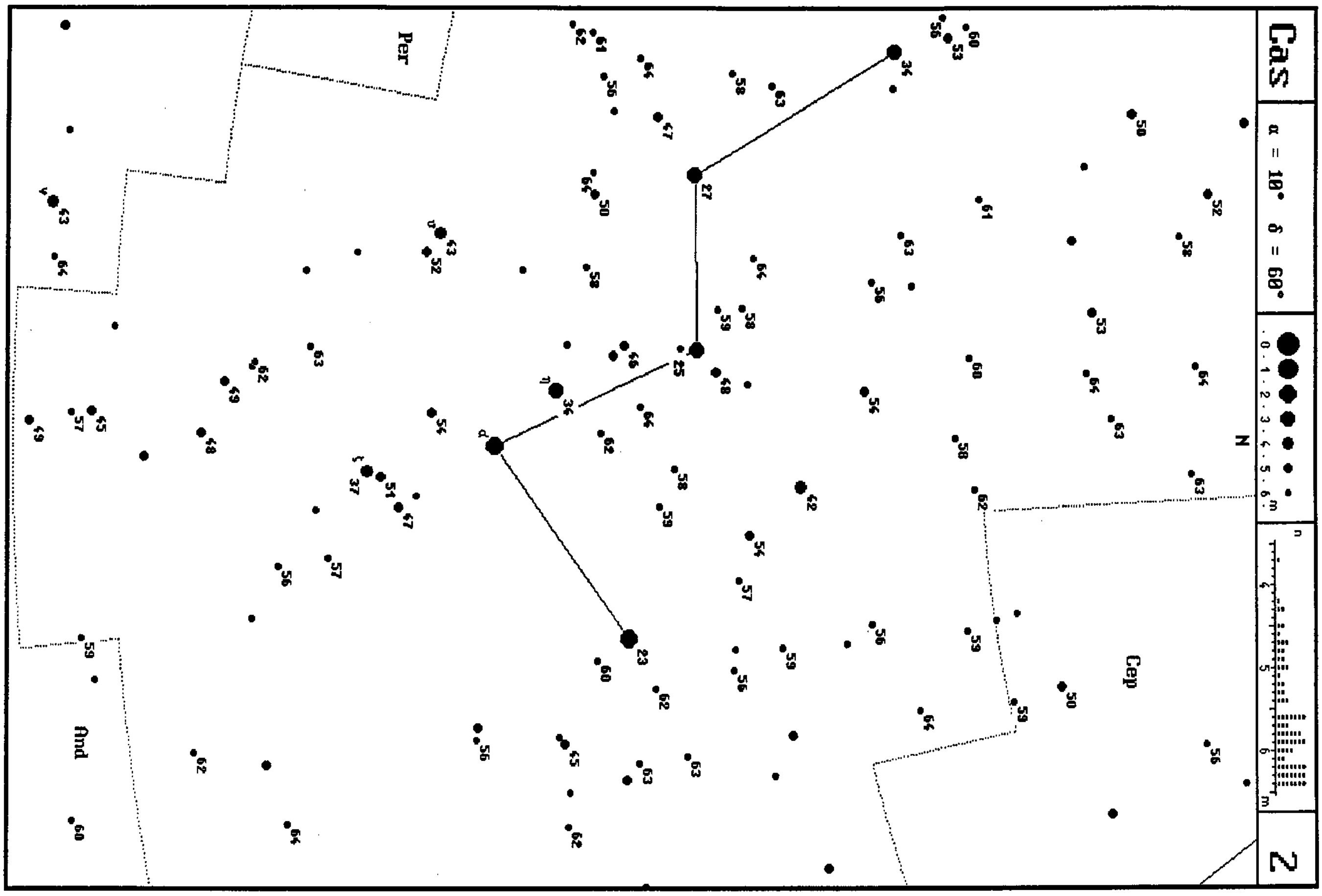
For the method proposed here, we suggest to use the included maps. Star positions and magnitudes are based on *Yale's Bright Star Catalogue* (BSC), which seems to be quite ideal for this purpose. We propose 19 maps of selected areas distributed over the entire celestial sphere. Areas were not selected very systematically, but in such a way that they contain significant parts of constellations for better orientation. One map is located near the northern celestial pole, three maps are located around $\delta = +60°$, three maps around $\delta = +30°$, six maps around the celestial equator, three maps around $\delta = -30°$, and three maps around $\delta = -60°$. There is no map located near the southern celestial pole, due to the absence of a suitable area in this part of the sky. This system of maps makes it possible to use, from each location on Earth at each time, at least 5 areas in a reasonable way.

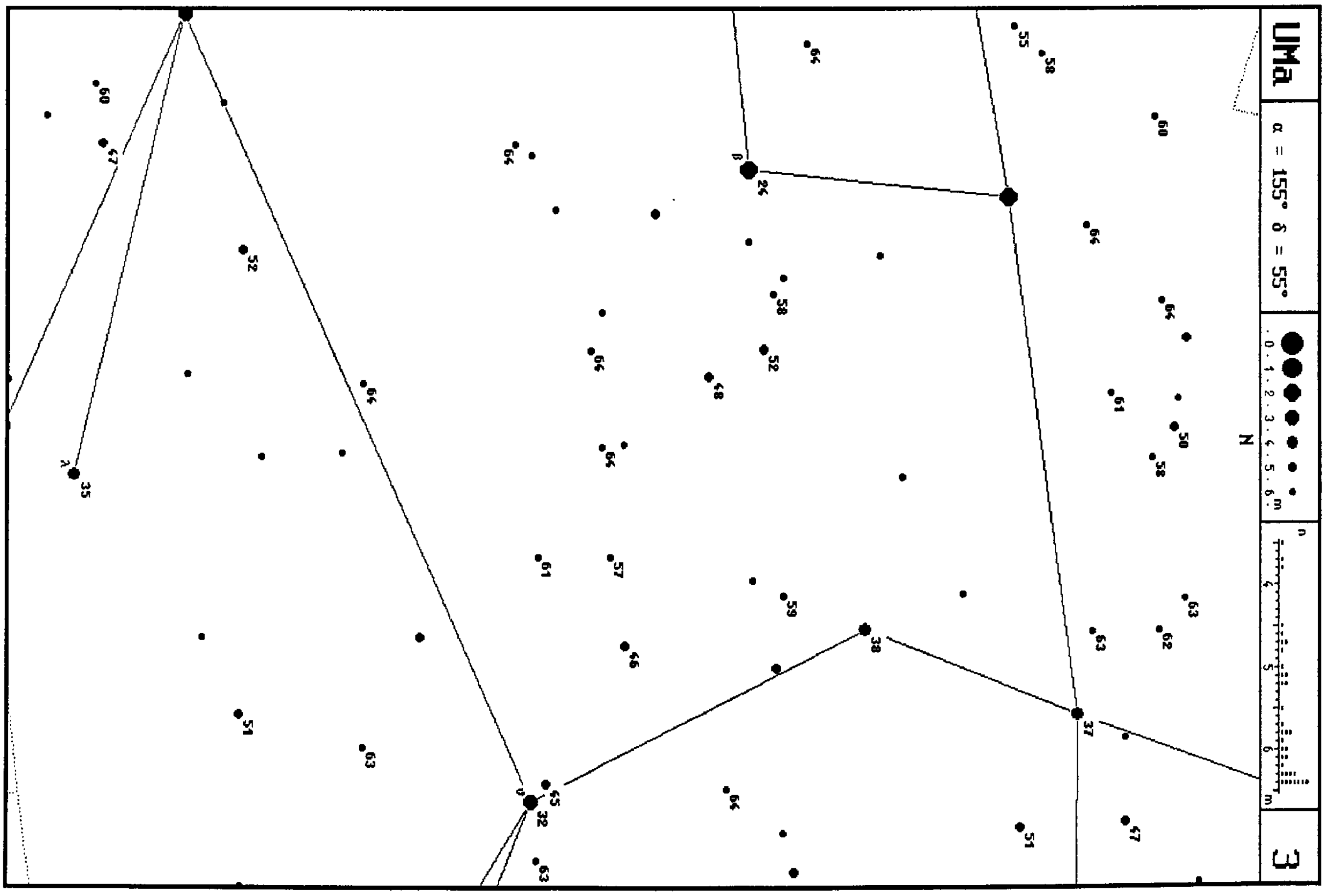
The maps contain stars up to magnitude +6.5. Suitable stars have their brightness printed in tenths of a magnitude. Stars were considered suitable if they are not variables and have a color index with a reasonably low absolute value. Selected stars are in the spectral classes O, B, A, F, or G. Some stars which meet all these criteria were not selected due to lack of space. In the header of each map, a histogram shows the distribution of stars in single magnitude classes (with steps of 0.1 magnitude), which provides information about the accuracy of Lm determinations for concrete sky conditions. The suggested areas are summarized in Table 1. The maps 2–13 are oriented to the northern celestial pole, and the maps 14–19 are oriented to the southern celestial pole. We recommend to use this system of limiting magnitude determination *under sky conditions below magnitude* +5.5.

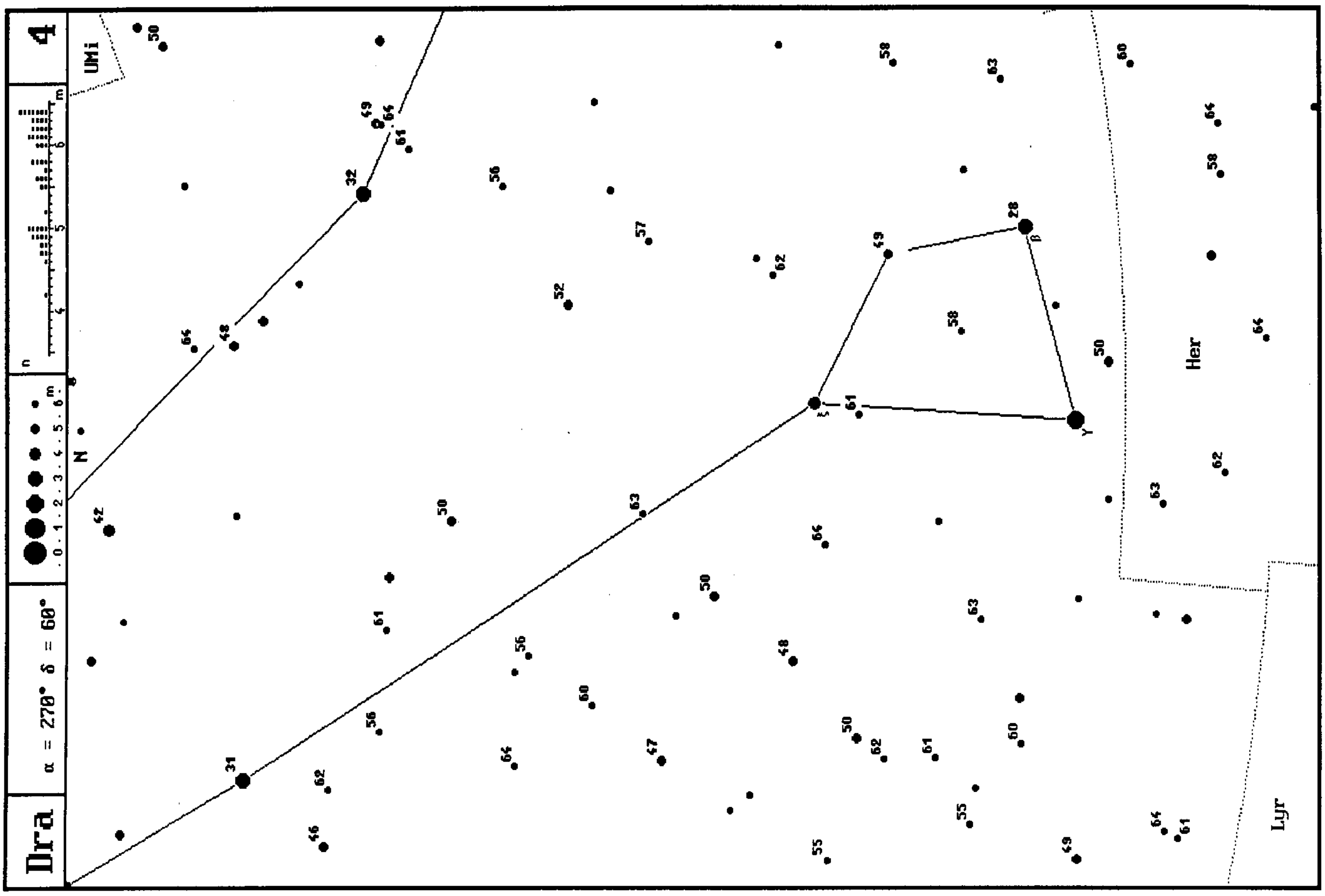
Table 1 – Areas for limiting magnitude determination.

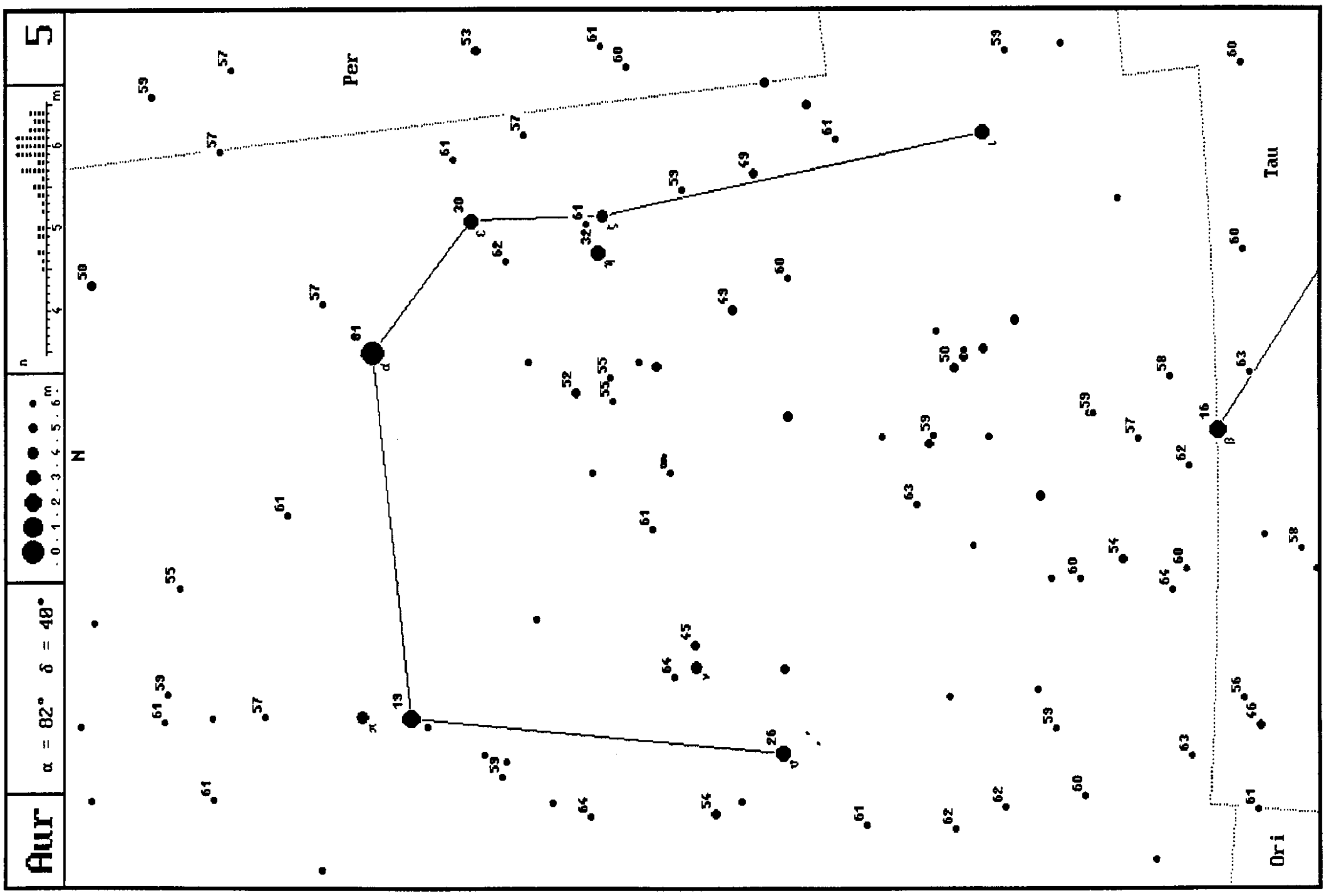
No.	Const.	α	δ	No.	Const.	α	δ
1	UMi	240°	+80°	11	Vir	180°	+05°
2	Cas	10°	+60°	12	Oph	248°	00°
3	UMa	155°	+55°	13	Aql	297°	+10°
4	Dra	270°	+60°	14	CMa	105°	−28°
5	Aur	82°	+40°	15	Cen	210°	−40°
6	Boo	225°	+30°	16	PSa	338°	−30°
7	Lyr	285°	+35°	17	Phe	17°	−57°
8	Ari	35°	+25°	18	Vel	150°	−60°
9	Ori	85°	+03°	19	Ara	255°	−56°
10	Cnc	130°	+15°				

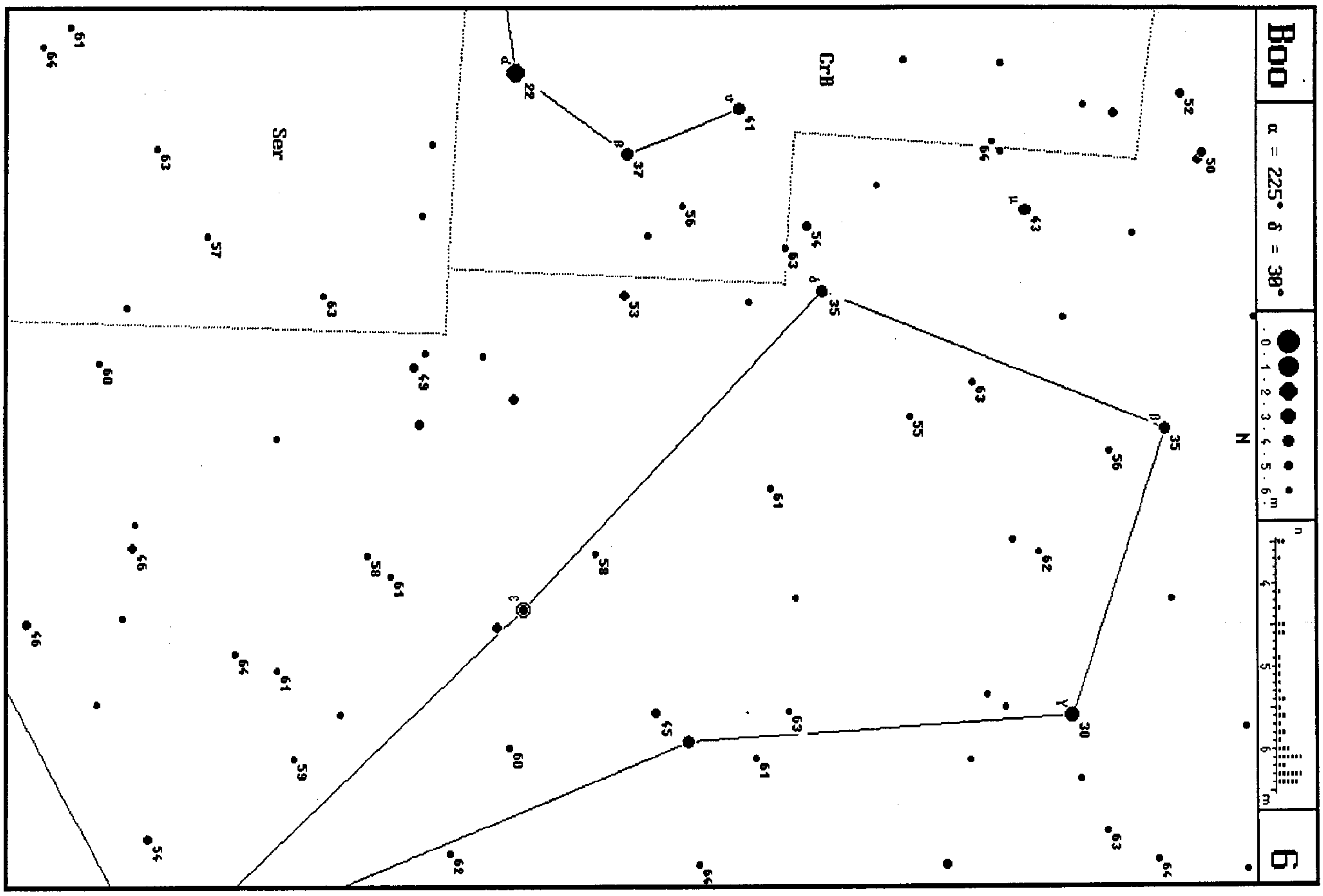


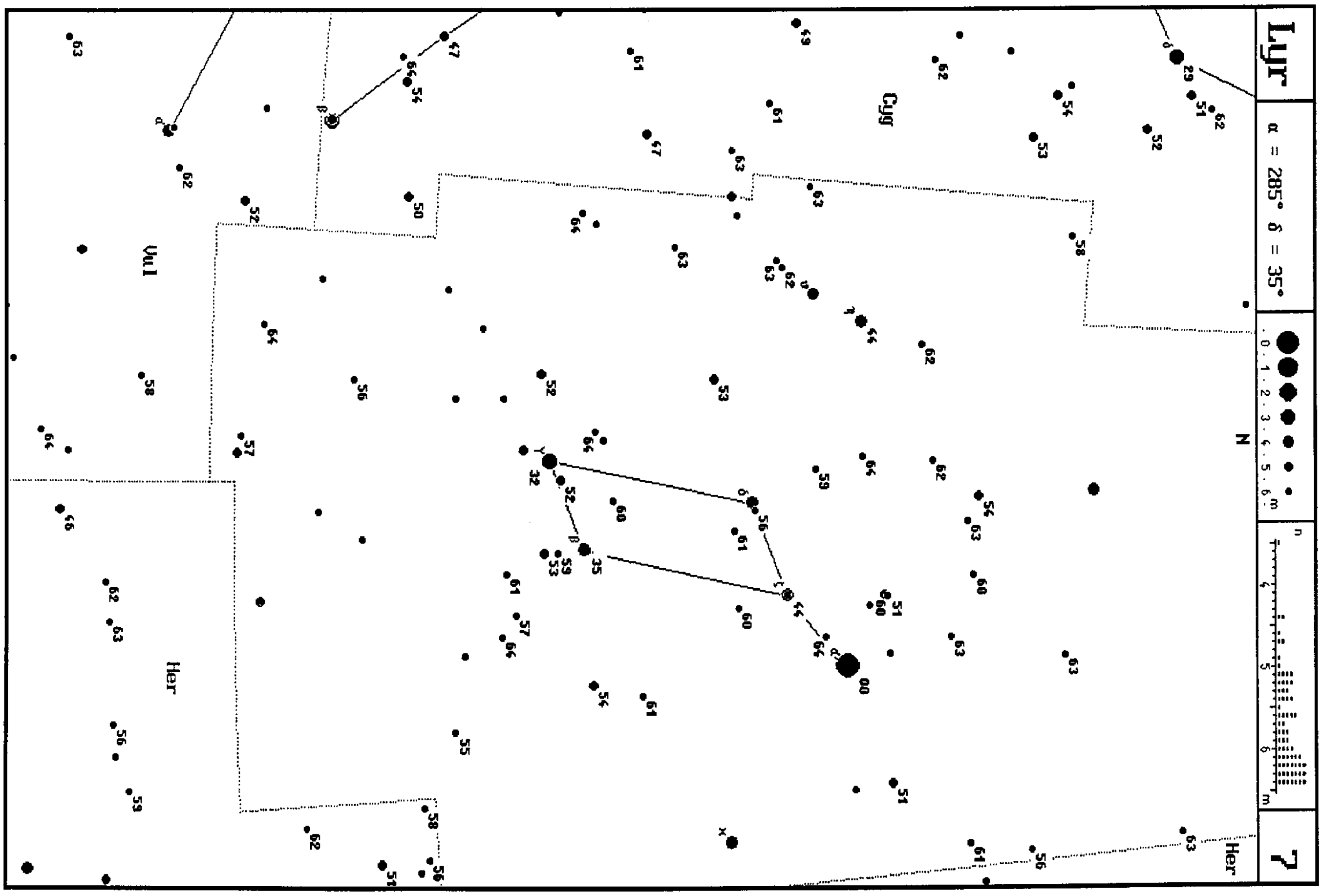

Cas
α = 10° δ = 60°
Per
And
Cep
N
2

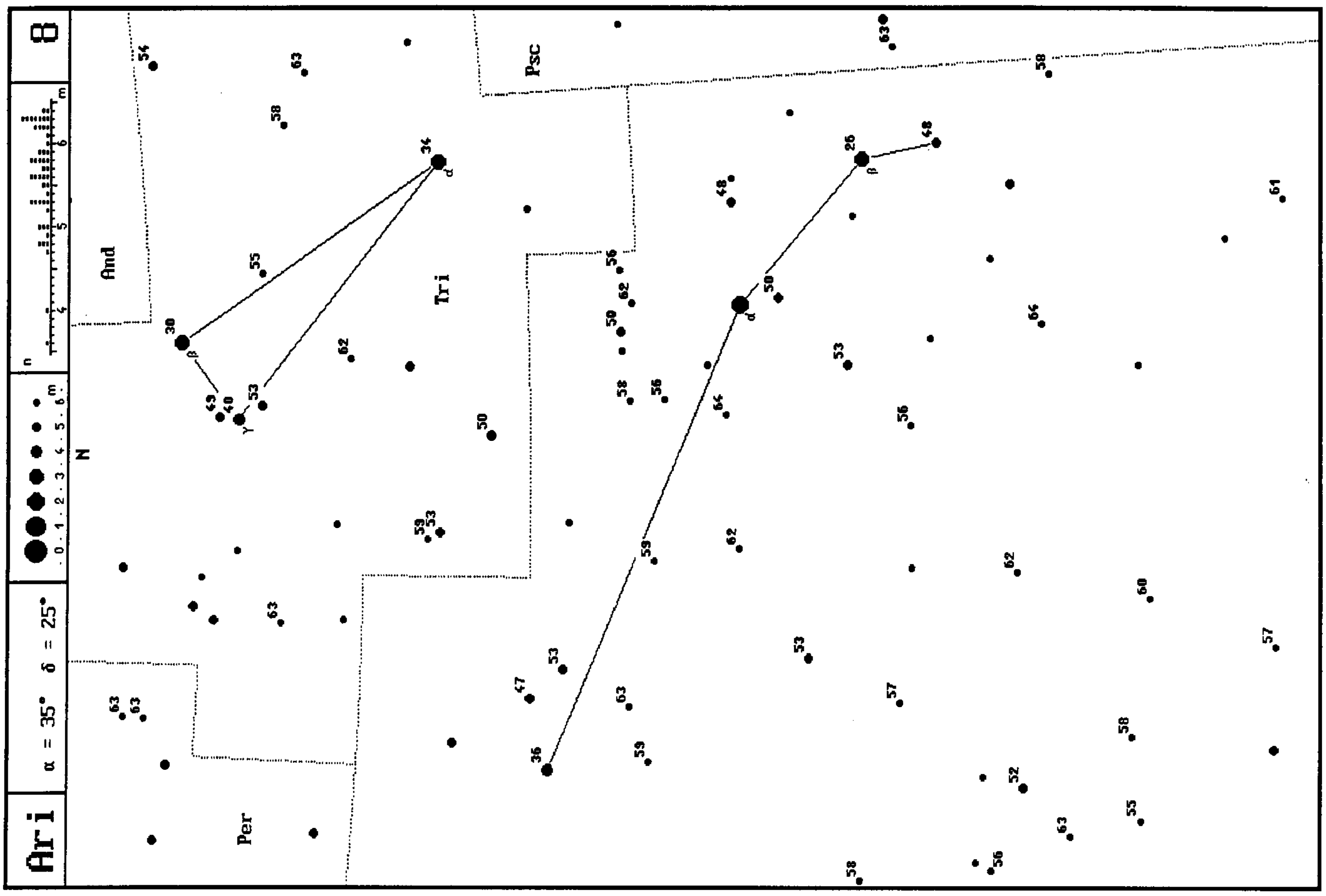

UMa
α = 155° δ = 55°
N
3

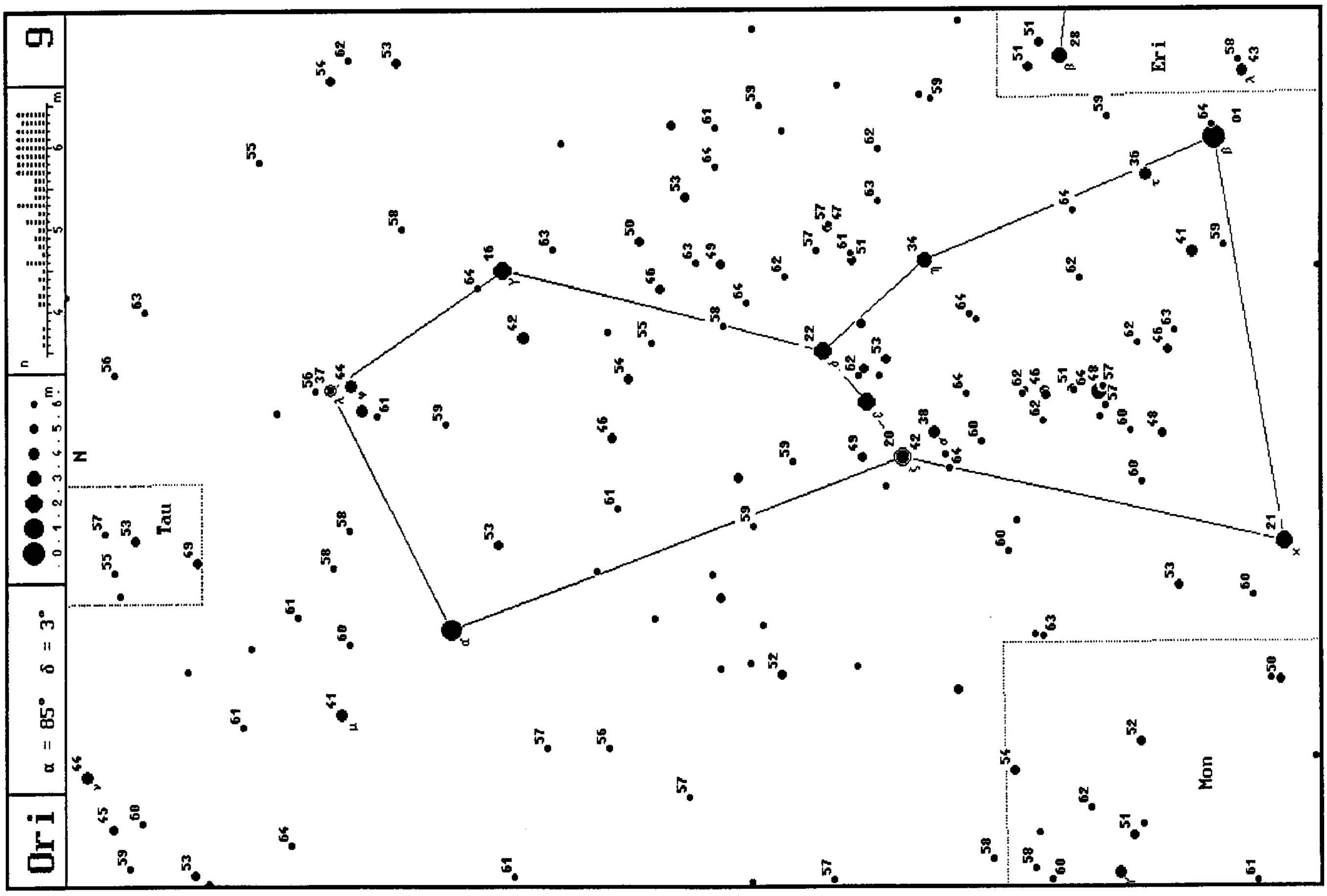

Dra
4
α = 270° δ = 60°
UMi
Her
Lyr

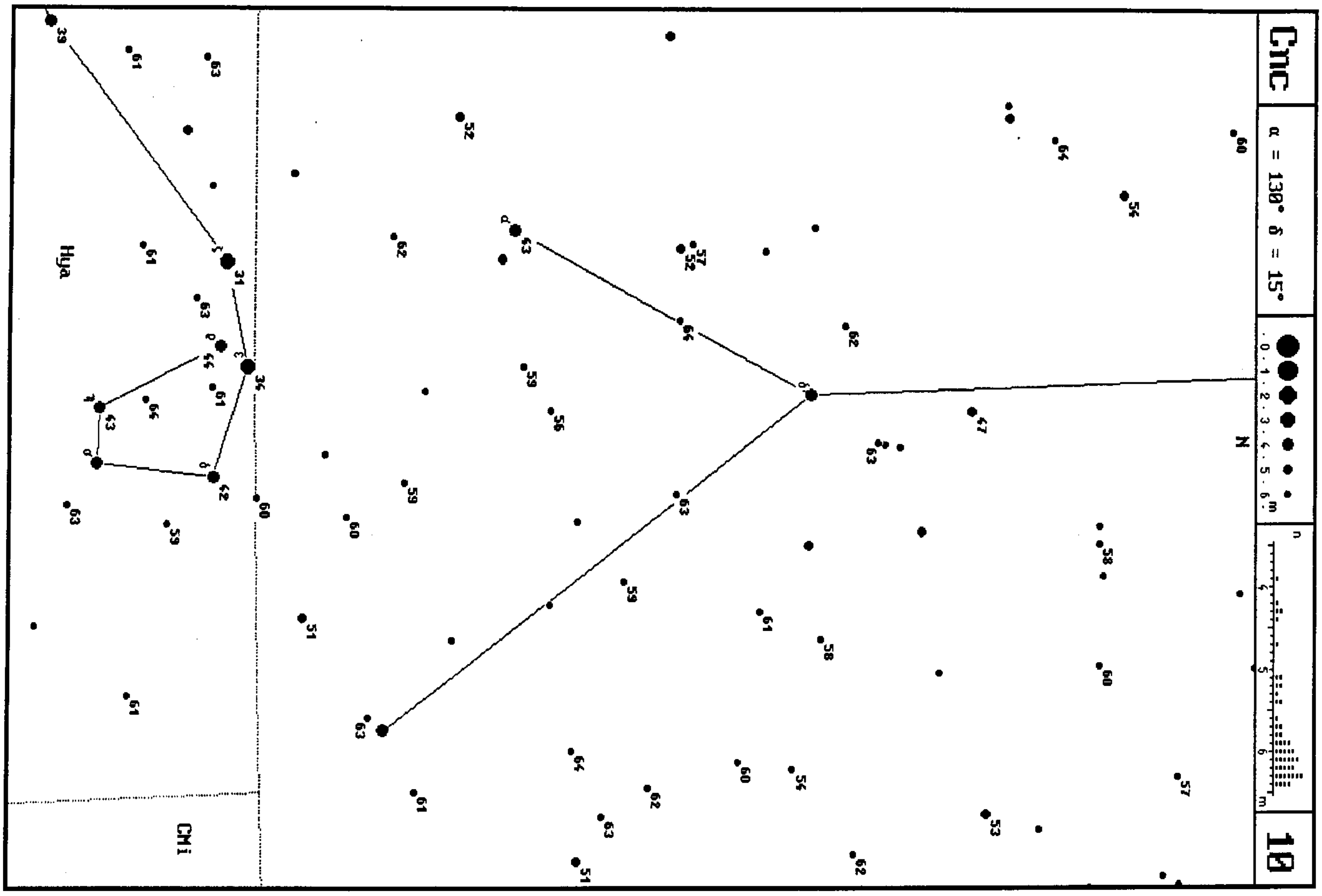

Aur
5
α = 82° δ = 40°
Per
Tau
Ori

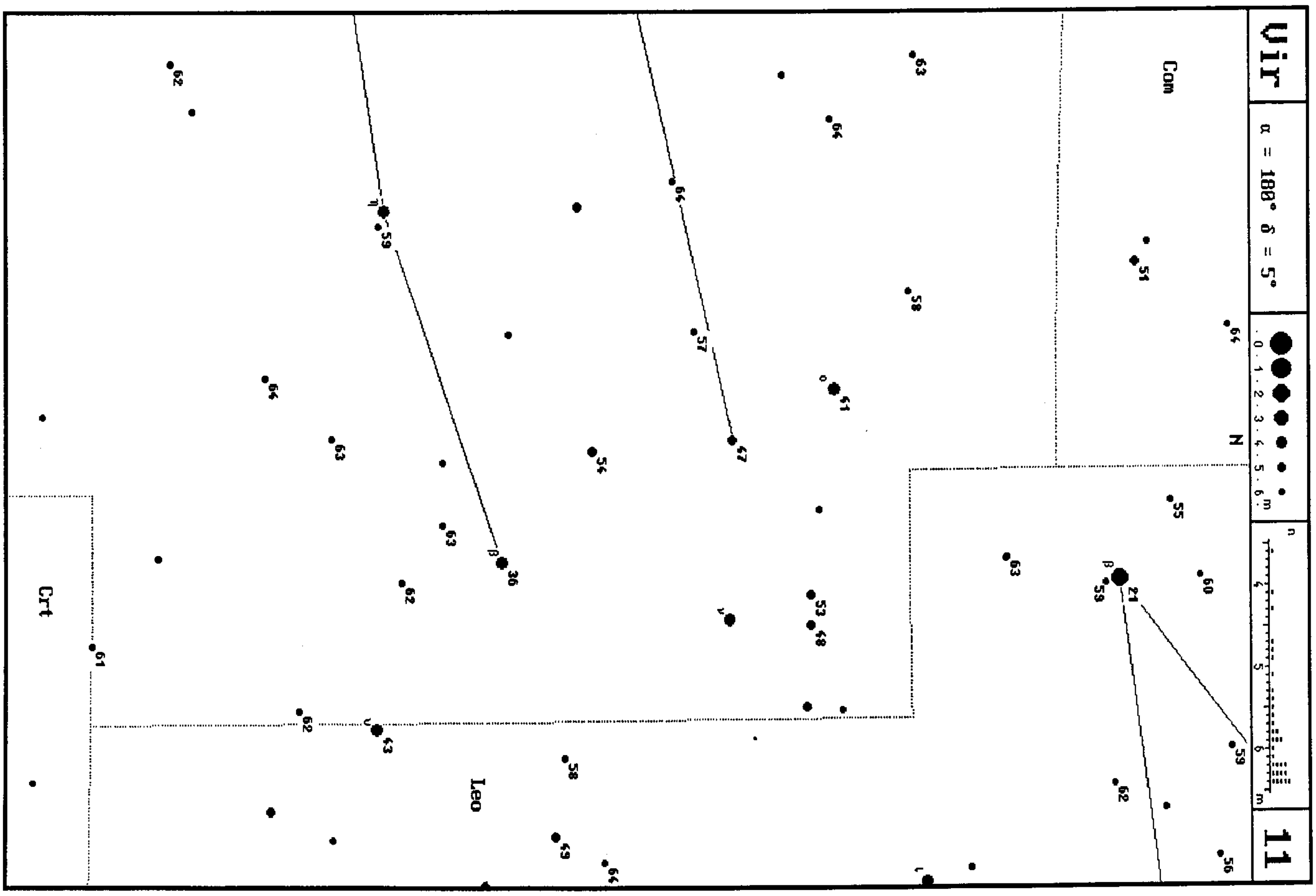

Boo
α = 225° δ = 30°
N
6
Ser
CrB

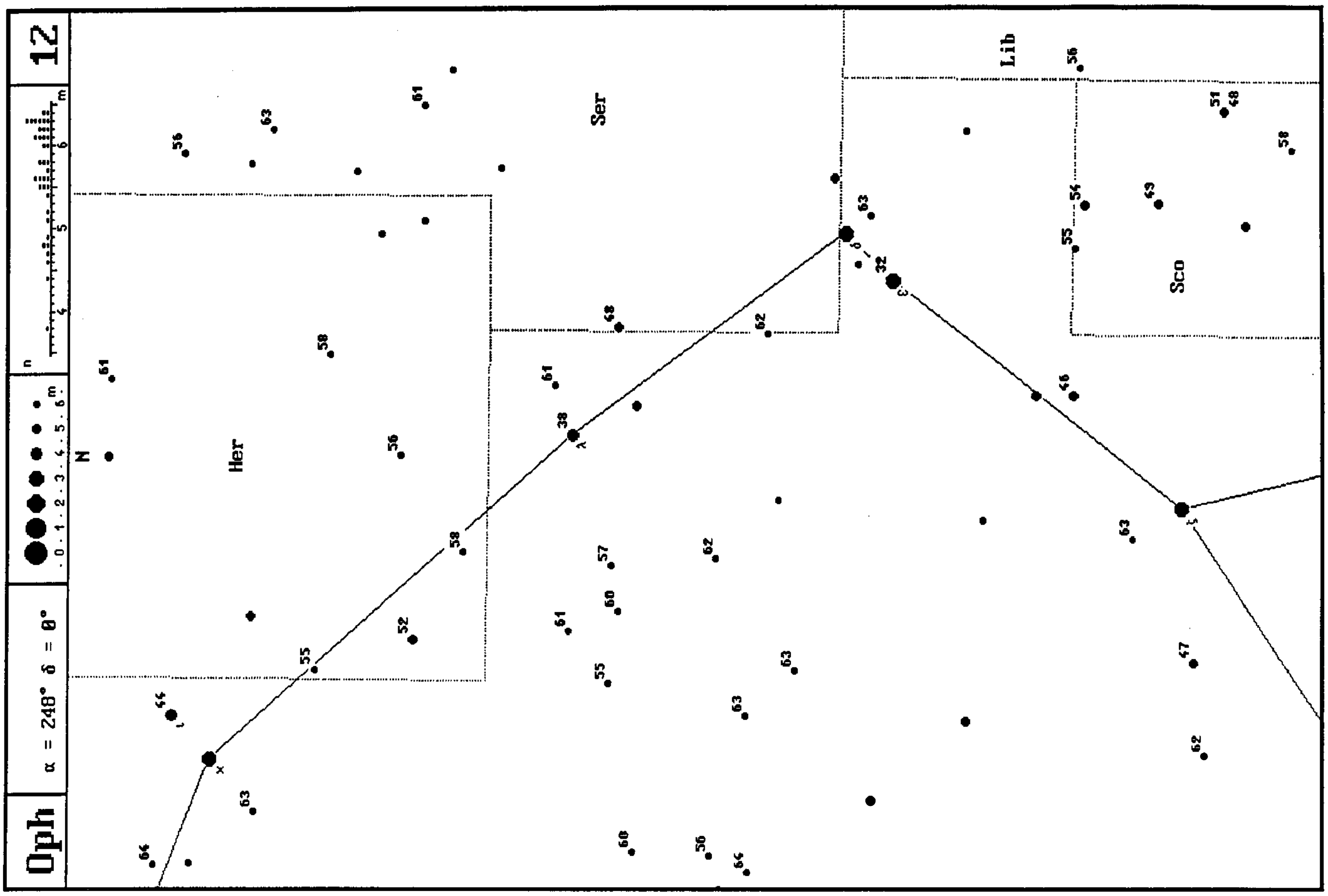

Lyr
α = 285° δ = 35°
N
7
Cyg
Vul
Her

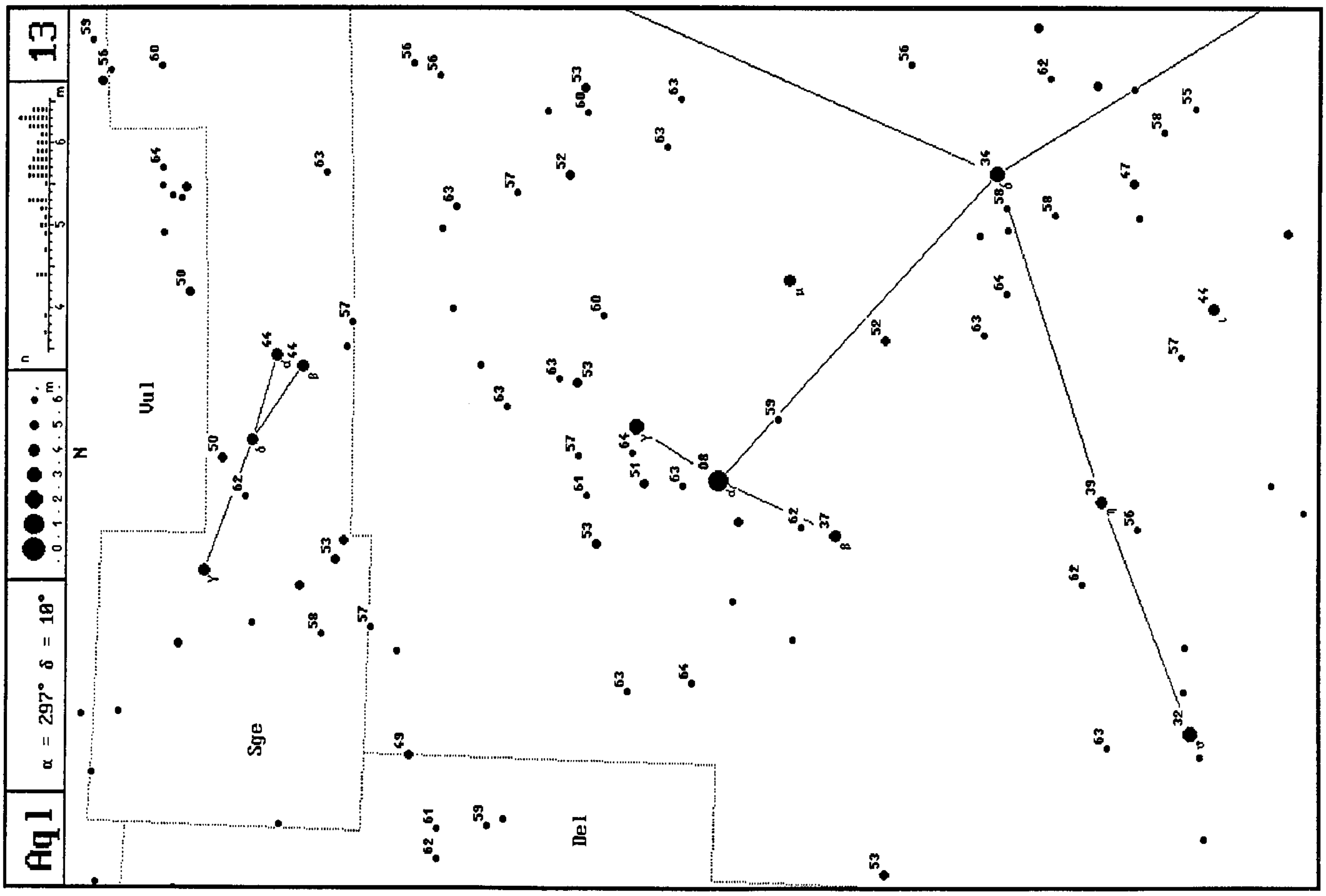

Ari
α = 35° δ = 25°
8
N
And
Tri
Psc
Per

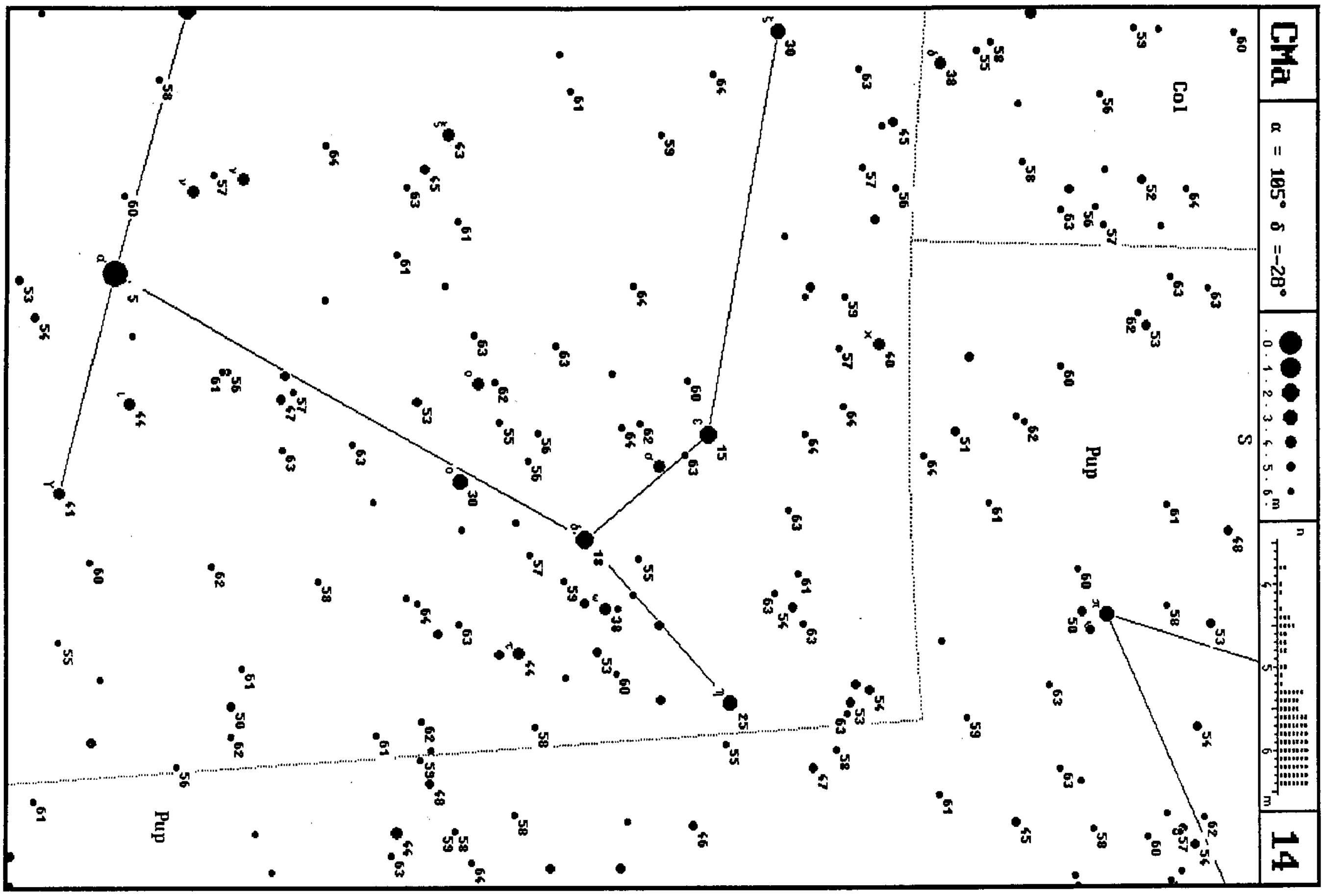

Ori
α = 85° δ = 3°
9
N
Tau
Eri
Mon

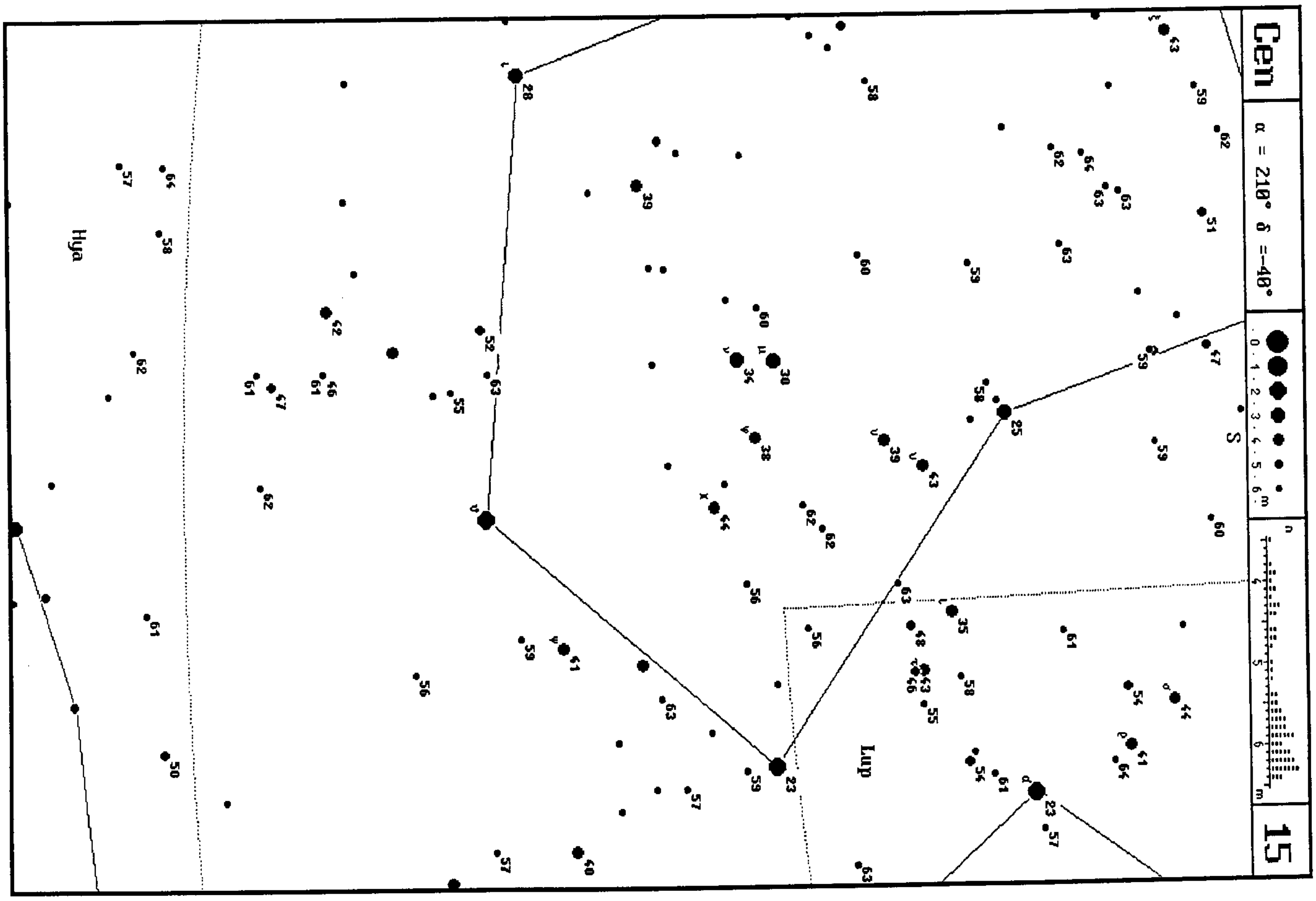

Cnc
α = 130° δ = 15°
10
N
Hya
CMi

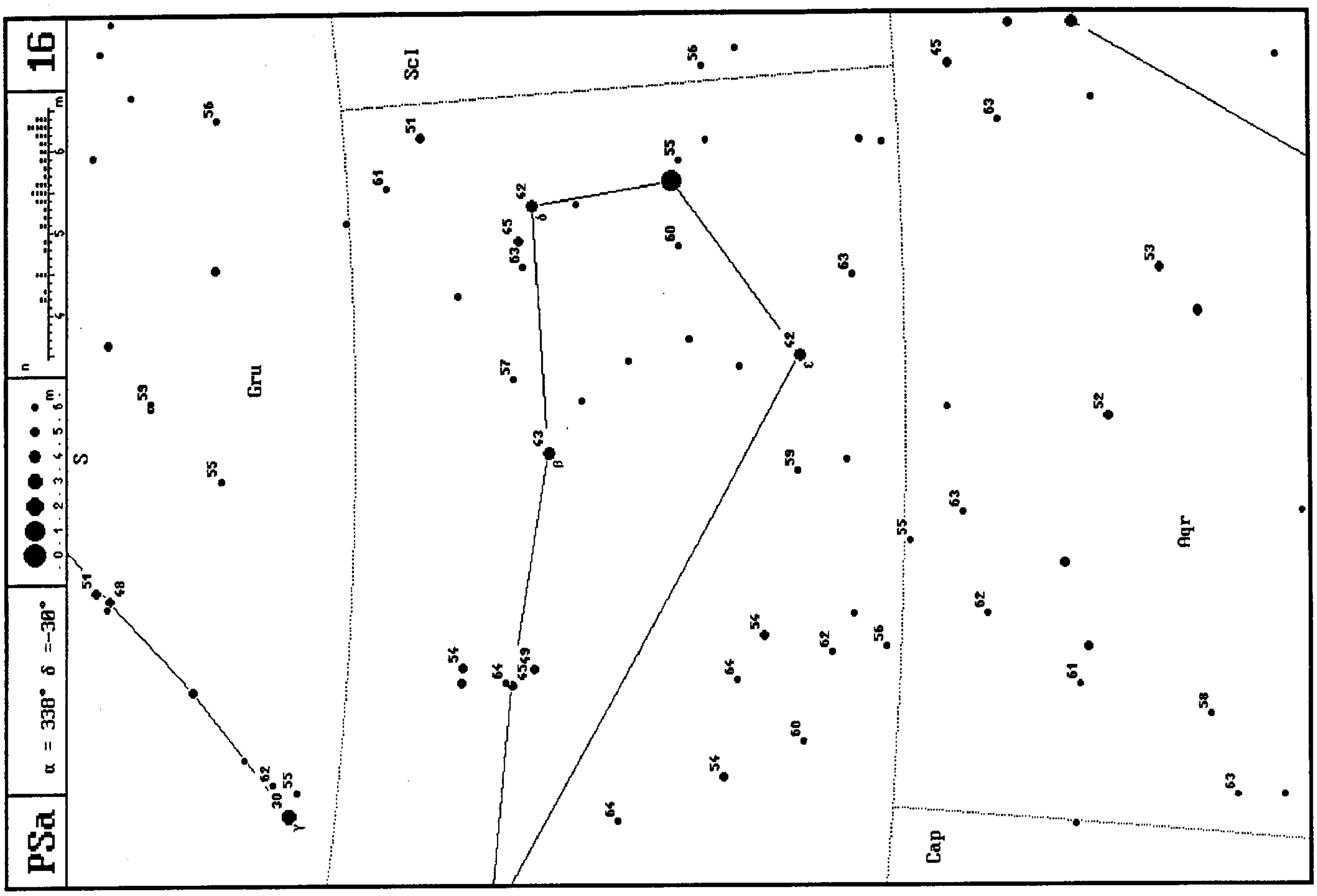

Vir
α = 180° δ = 5°
11
N
Com
Leo
Crt

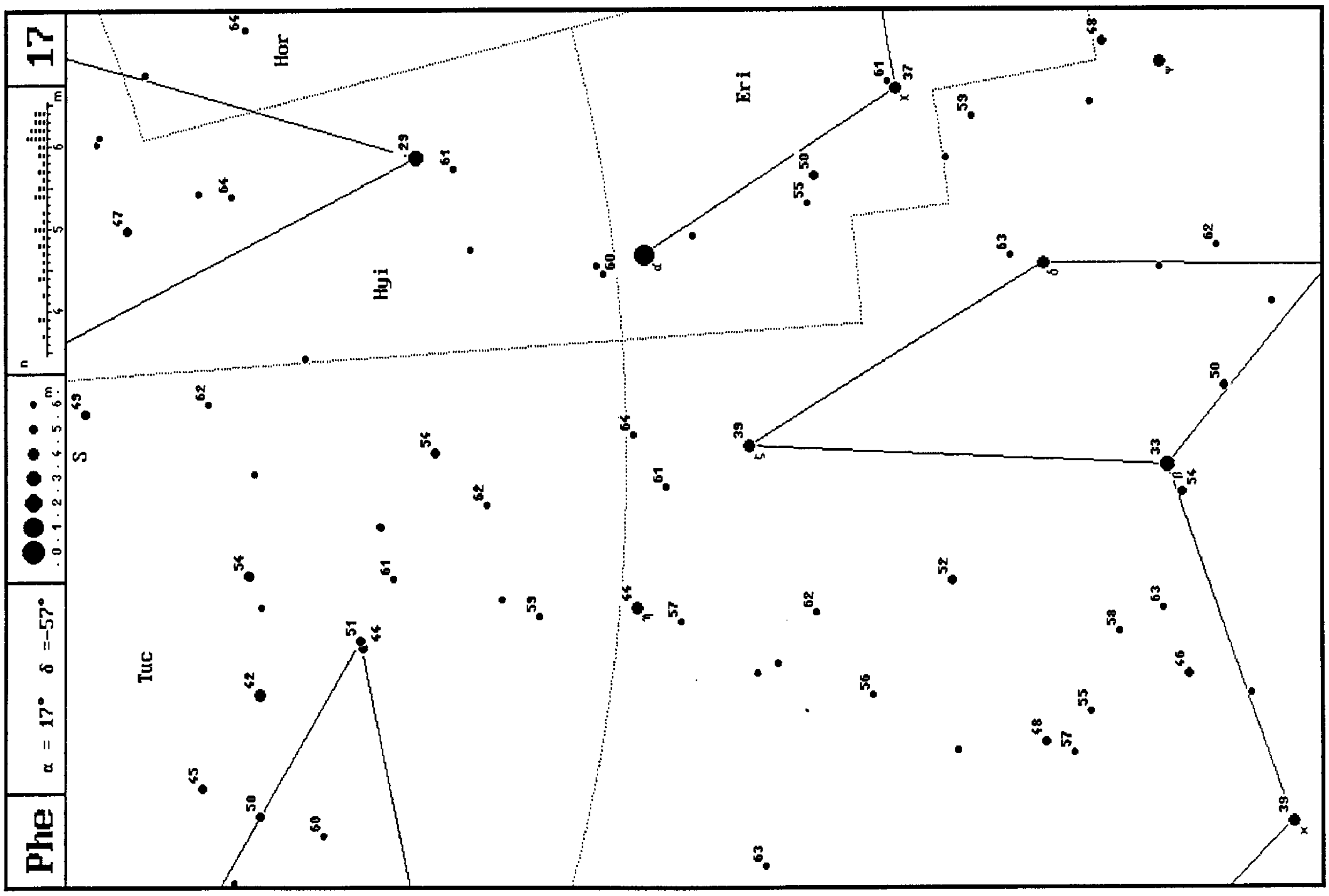

Oph
12
α = 248° δ = 0°
N
Her
Ser
Lib
Sco

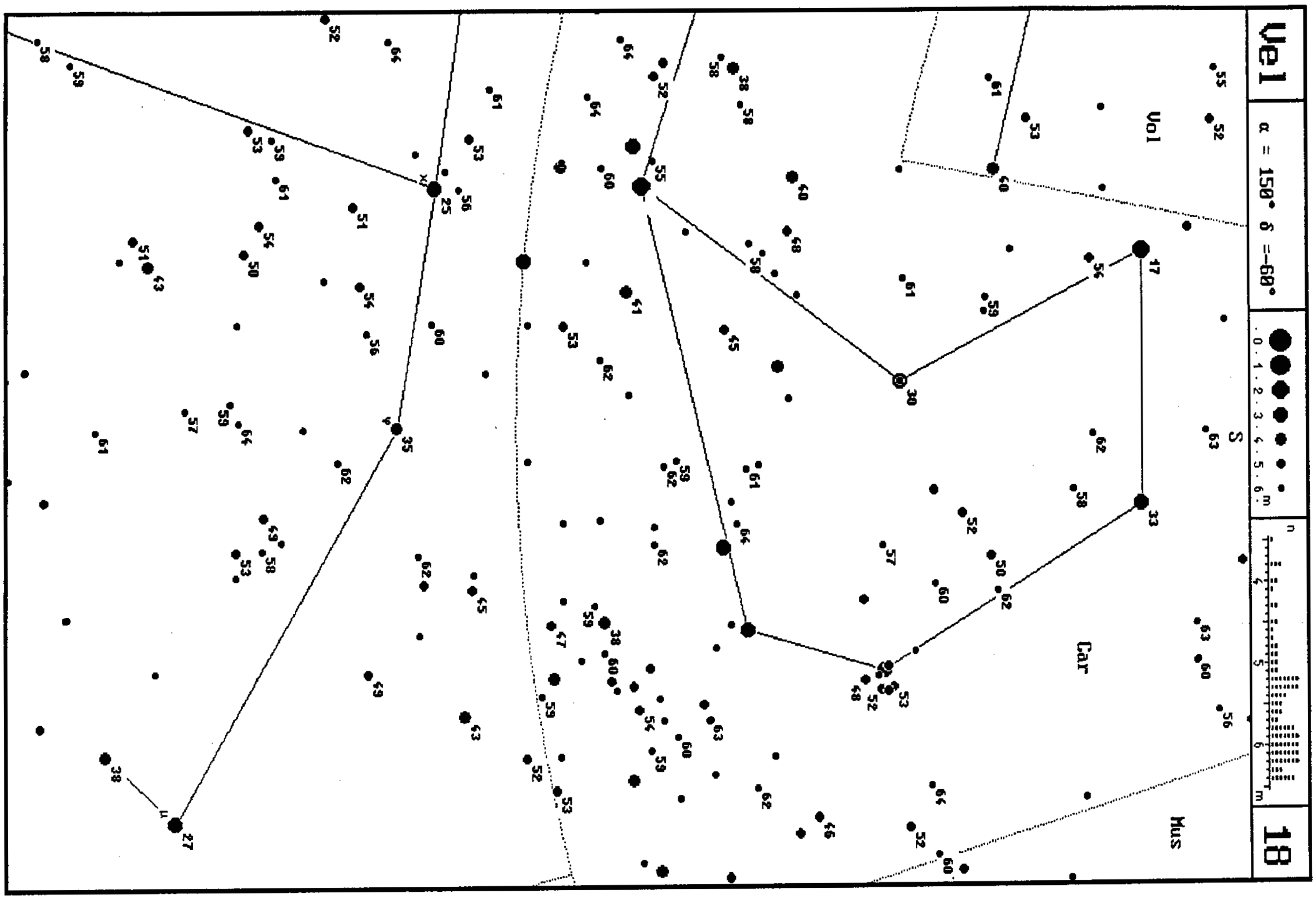

Aql
13
α = 297° δ = 10°
N
Vul
Sge
Del

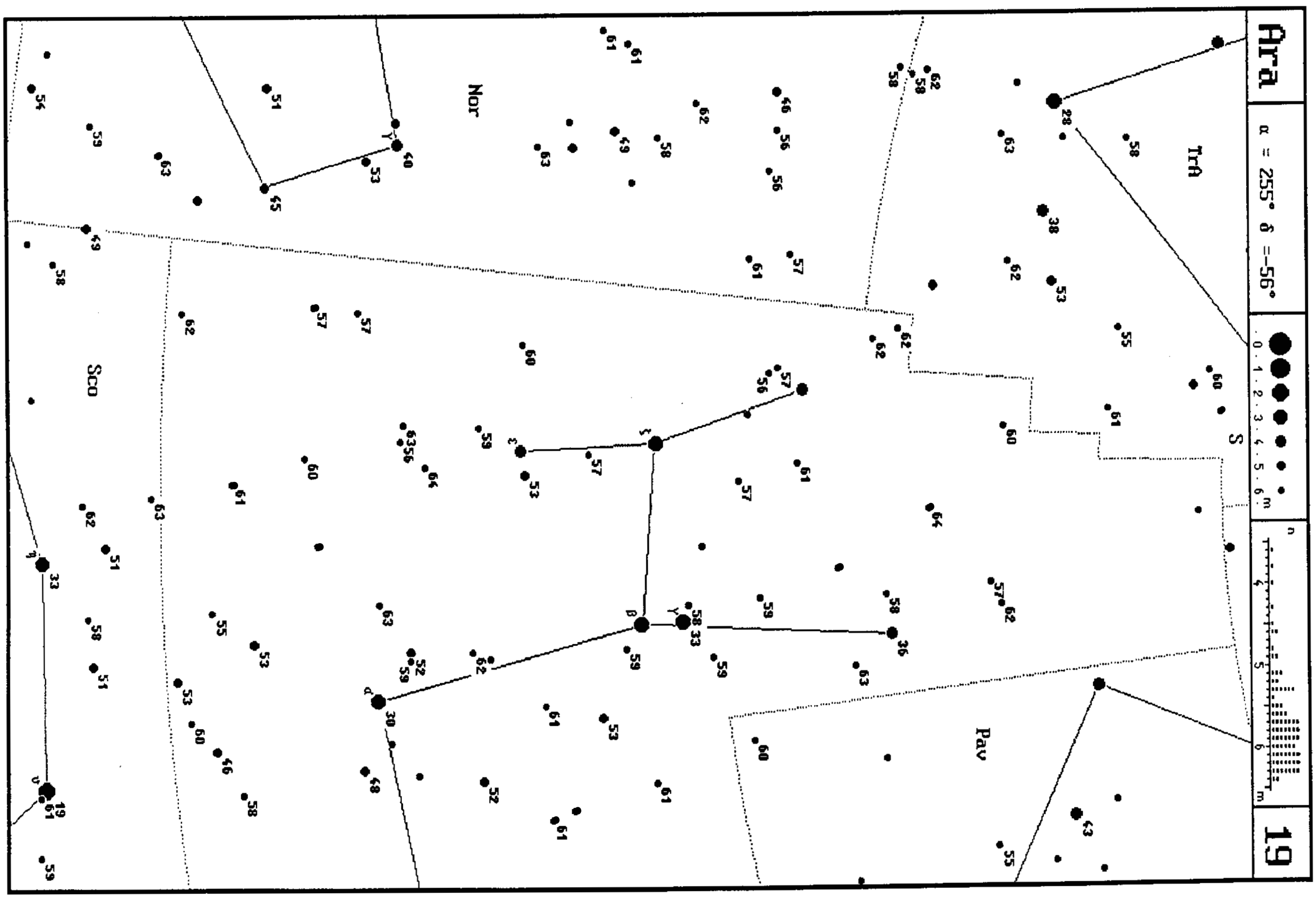

CMa
α = 105° δ = -28°
14
Col
Pup
Pup
S


Cen
α = 210° δ = -40°
15
Hya
Lup
S


16
PSa
α = 330° δ = −30°
Gru
Scl
Aqr
Cap


17
Phe
α = 17° δ = −57°
Hor
Eri
Hyi
Tuc


Vel
α = 150° δ = −60°
18
Vol
Car
Mus


Ara
α = 255° δ = −56°
19
Nor
Sco
TrA
Pav

Visibility of Leonid Showers in 1999–2006 and 2034

Robert H. McNaught, Siding Spring Observatory

We present geographical visibility maps for the predicted times of Leonid maxima in 1999–2006 and 2034 related to encounters of the Earth with dust trails generated during recent perihelion passages of 55P/Tempel-Tuttle. We also present a map of time adjustments which corrects for the offset of the observer from the Earth's center.

1. Introduction

The maps presented here, showing the geographical visibility of the upcoming Leonid showers, are based on the assumption that the time of peak activity can be accurately predicted from dust trail calculations [1,2][1]. Comparison of the dust trail predictions with the times of observed storms indicate that this assumption is well-founded and that the uncertainty is probably of the order of 10 minutes [3,4]. However, these original predictions were made for the center of the Earth. A time adjustment to correct for the offset of the observer from the center of the Earth is therefore plotted for use as an overlay on the presented maps. The derivation of this adjustment, which is a function of the inclination of the stream, is given by McNaught and Asher [5]. Application of the adjustment improves the time residual for previous storms, suggesting the uncertainty is of the order of 5 minutes [5]. It is thus reasonable to present maps showing the area of the Earth's surface that will experience the peak rates from these dust trails.

2. Choice of projection

As an illustration of the value of such a map, the circumstances for 1966 are presented in Figure 1 from the dust trail prediction in [4]. This orthographic projection shows a geometrically accurate view of the Earth as seen from the direction of the Leonid radiant and from an infinite distance. The presented hemisphere experiences the shower, but visibility is limited to the night-time region to the left. The day/night boundary (terminator) passes through Central America, Florida and southern Greenland and the various twilight boundaries (civil, nautical, and astronomical) appear to its left. Moon rise/set and "lunar civil twilight" appear as dashed lines just present in 1966 (they are more evident in the later figures) near the day/night boundary at the top and bottom of the map. Lunar conditions are not plotted in the daylight region. The lunar phase is shown (as seen from the northern hemisphere), and the intensity of the plotted coastlines is modified to indicate the extent of twilight and moonlight interference. Zenithally attracted (apparent) radiant elevations are presented as concentric circles at 10° intervals. This map, based on the time predicted from the dust trail (11^h53^m UT), can be compared to the map given by Guth [6] for the actual event. Guth used the peak time as 11^h55^m UT.

Orthographic projection gives a feel for the relative rates visible from different parts of the Earth. The compression of the map projection towards the Earth's limb is proportional to the sine of the radiant elevation, as are shower rates, hence it is very difficult to identify the geographical regions that have the radiant at low elevations. It also cannot display the extended zone caused by zenithal attraction. In the case of the Leonids, this amounts to an additional $0\overset{\circ}{.}7$. Observations from these limb regions are not without interest, as, from them, Leonids have longer paths and durations. Very close to the limb, Leonids would be true Earth grazers, moving parallel to the Earth's surface. During the 1966 Leonid peak, observers in the Russian Arctic described an impressive display of some 5–10 such long pathed Leonids per second [7], but it is very difficult to identify this limb region on the orthographic map. For the above reasons, a linear radial projection (zenithal equidistant) out to the zenithal attraction limit is a preferable projection to display information on radiant elevation. The data for Figure 1 are thus redisplayed with this projection in Figure 2. The Russian Arctic is now clearly visible, and comparison can be made with the maps of the Arctic research stations given by Bronšten [7]. This projection is used for all subsequent maps.

[1] Reference [2] is another important, but overlooked, study by Kondrat'eva and Reznikov.

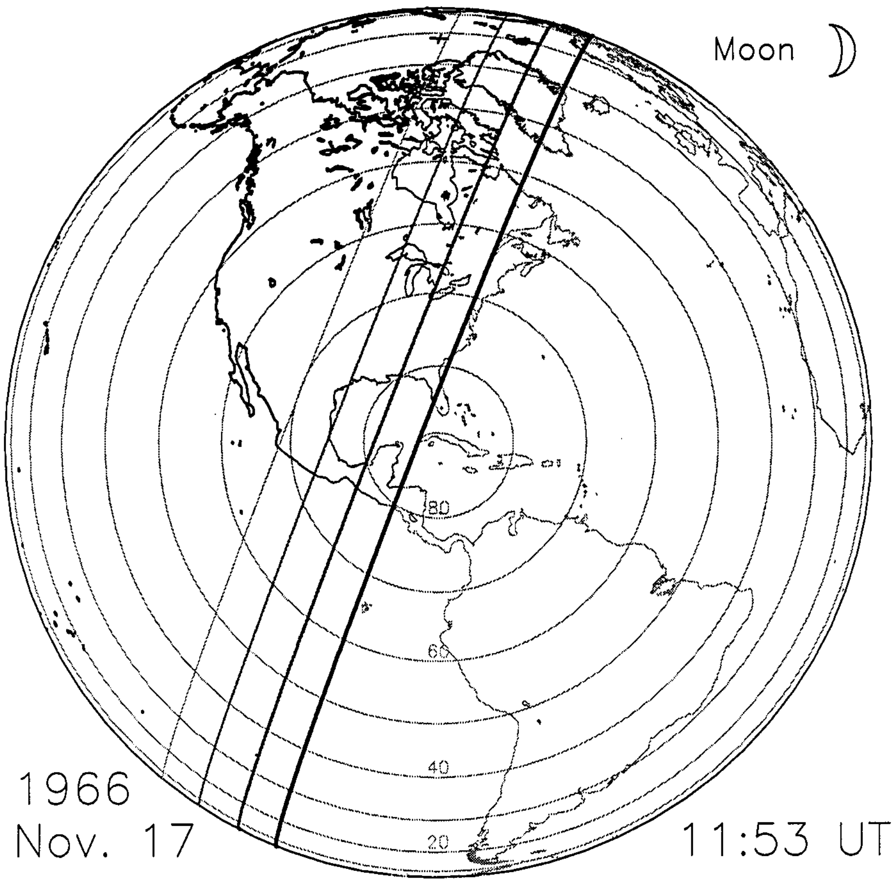


Figure 1.

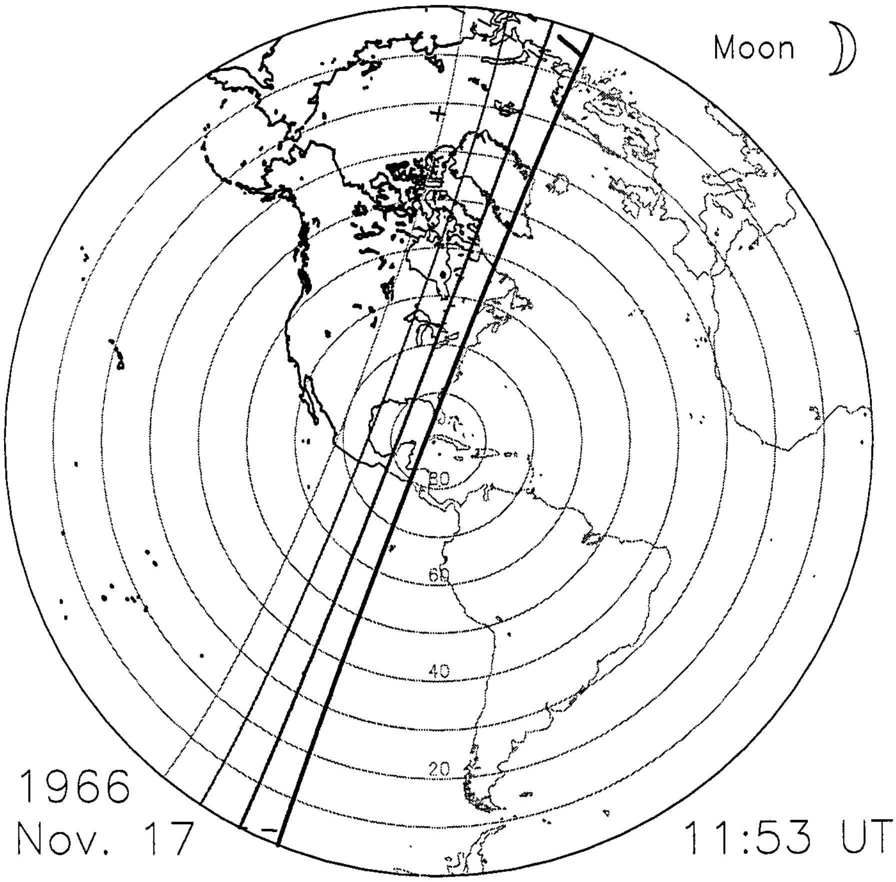


Figure 2.

3. Upcoming showers

Six potential showers/storms are predicted by Kondrat'eva, Murav'eva, and Reznikov [8] and McNaught and Asher [4] for 1999–2002. The respective observing circumstances are given in Figures 3–8. Figure 9 presents the circumstances for the predicted minor shower in 2006 and Figure 10 for the 2034 event [4]. The estimated ZHRs are substantially different from one trail encounter to another; see [4]. These maps modify slightly the regions of visibility given in [4]. In both 2000 and 2001, two potential storms are predicted to occur some 4.1 and 8.3 hours apart in the respective years. It would thus be possible for observers to locate in the overlap zone to observe both these events, or for an airborne observatory to remain within the observable zone during this period. The only continental night-time overlap zone in 2001 is in the Russian Arctic.

Over the course of a few hours, the Sun and Moon rise/set and twilight boundaries are effectively fixed while the continents rotate from left to right at a rate of 15° longitude per hour. Around the north pole, which is marked by a cross, the Earth will rotate anti-clockwise.

It must be noted that these maps are only for the specific dust trails considered in these years. Observations at other longitudes are important to cover possible activity from more distant dust trails and to monitor the background activity. Such background activity could itself be very high, and years with a ZHR approaching 500 are known which are not associated with young dust trails. Some such showers may be related to old, unconsidered, dust trails, and—until detailed calculations are done—some surprises may still occur.

4. Time adjustments

The calculations presented in [4] were based on the center of the Earth. The location of the observer, being offset from the Earth's center, will have a bearing on the observed time of maximum. The time adjustment can be calculated in one of two ways, by assuming that the dust trail is a flat sheet within the orbital plane, or a cylinder. In reality, a dust trail profile will lie between these two extremes or may even be tilted out of the orbital plane. The observational evidence is discussed in [5] and strongly favors a highly flattened profile within the orbital plane. In fact, application of these adjustments is shown to decrease the uncertainty in the time of maximum to the order of 5 minutes.

Figure 11 has been constructed [5] to give the time adjustment for passage of any location on the "Leonid" side of the Earth, through the plane of the dust trail orbit. A good example is the observed time of maximum for the 1966 Leonids from the Russian Arctic [7] mentioned earlier. They observed the peak at $12^{h}05^{m} \pm 10^{m}$ UT giving an O–C of $+12^{m}$. The correction for the Russian Arctic, measured from the overlay (cf. Figures 2 and 11), is 9 minutes after the Earth's center passes through the orbital plane ($11^{h}53^{m}$ UT). This gives an adjusted O–C of only $+3^{m}$.

To estimate the time adjustment, Figure 11 can be copied onto clear film and overlaid on any of the visibility maps. The twilight contours should be superimposed accurately. For 1999, the values for S. Africa, the Mediterranean, and N. Scandinavia are −11, 0, and +6 minutes, respectively. Thus, the predicted time of maximum in 1999 will vary from November 18, $1^{h}57^{m}$ UT in S. Africa through $2^{h}08^{m}$ UT in the Mediterranean to $2^{h}14^{m}$ UT in N. Scandinavia.

5. Other possibilities

Many observers will not observe from inside the night-time visibility zones presented here. Should the peak activity occur at these predicted times, however, they may still witness some activity. Firstly, fireball activity could be observed in daylight from the region to the right on the maps, something that has been reported in previous storms. Leonids could also be observed up to 6° (dependent on meteor height) beyond the zenithally attracted "limit," by looking at low elevation towards the azimuth of the radiant. Low observable rates and the increased distance to such meteors would require a high ZHR to have any reasonable chance of success.

Radio and radar observations of the Leonids are possible from any location on the maps at the predicted peak time.

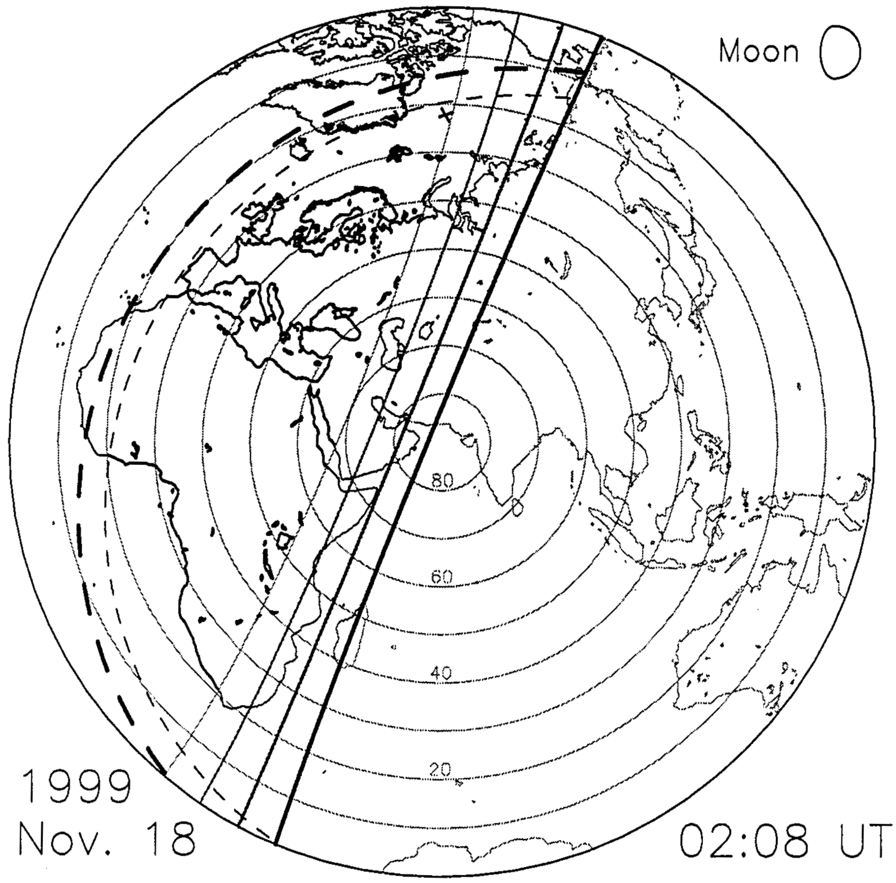


Figure 3.

Acknowledgments

I thank David Asher for helpful comments on this work and for pointing out the importance of reference [2].

Steve Lee and Gary Kitley of the Anglo-Australian Observatory helped in implementing the plotting routine. Brian Boyle and Fred Watson are to be thanked for access to the Anglo-Australian Observatory's facilities. Tony Beresford pointed me towards THE WORLD DIGITISED shareware database created by John B. Allison.

References

[1] D.J. Asher, "The Leonid meteor storms of 1833 and 1966", *MNRAS*, 1999, in press.

[2] E.D. Kondrat'eva, E.A. Reznikov, *Solar System Research* 19, 1985, pp. 96–101.

[3] R.H. McNaught, *The Astronomer* 35, 1999, pp. 279–283.

[4] R.H. McNaught, D.J. Asher, *WGN* 27, 1999, pp. 85–102.

[5] R.H. McNaught, D.J. Asher, "Variation of Leonid maximum times with location of observer", *Meteorit. Plan. Sci.*, 1999, submitted.

[6] V. Guth, in *IAU Symp.* 33, *Physics and Dynamics of Meteors*, Ľ. Kresák, P.M. Millman, eds., Reidel, Dordrecht, 1968, pp. 476–480.

[7] V.A. Bronšten, in *IAU Symp.* 33, *Physics and Dynamics of Meteors*, Ľ. Kresák, P.M. Millman, eds., Reidel, Dordrecht, 1968, pp. 440–445.

[8] E.D. Kondrat'eva, I.N. Murav'eva, E.A. Reznikov, *Solar System Research* 31, 1997, pp. 489–492.

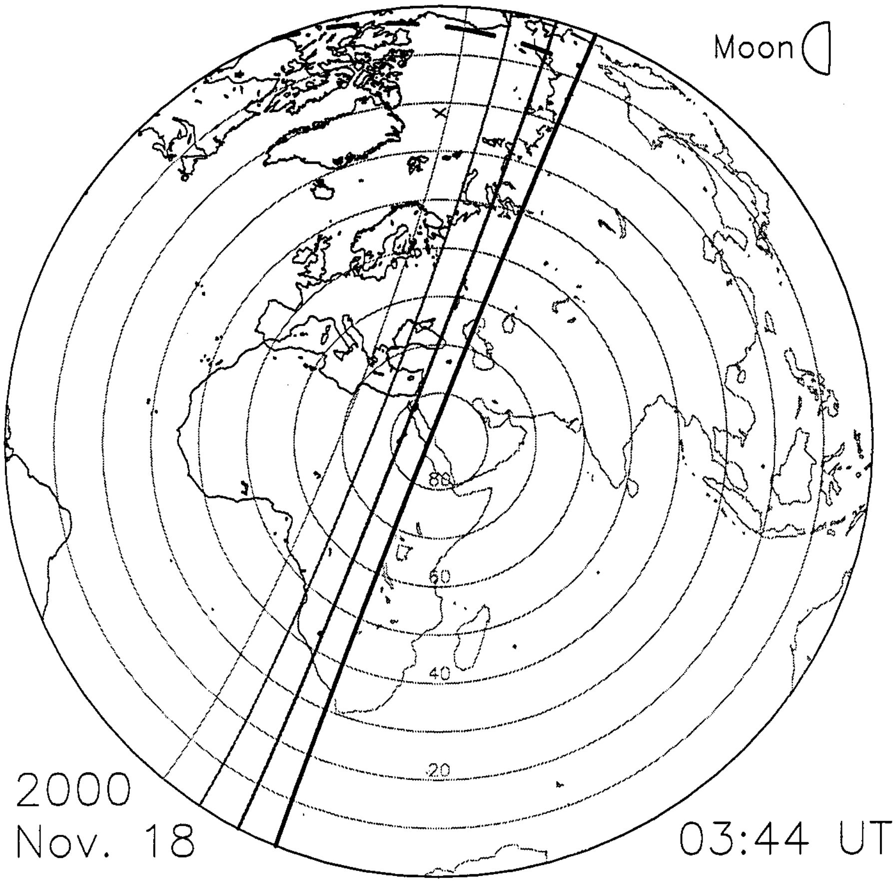


Figure 4.

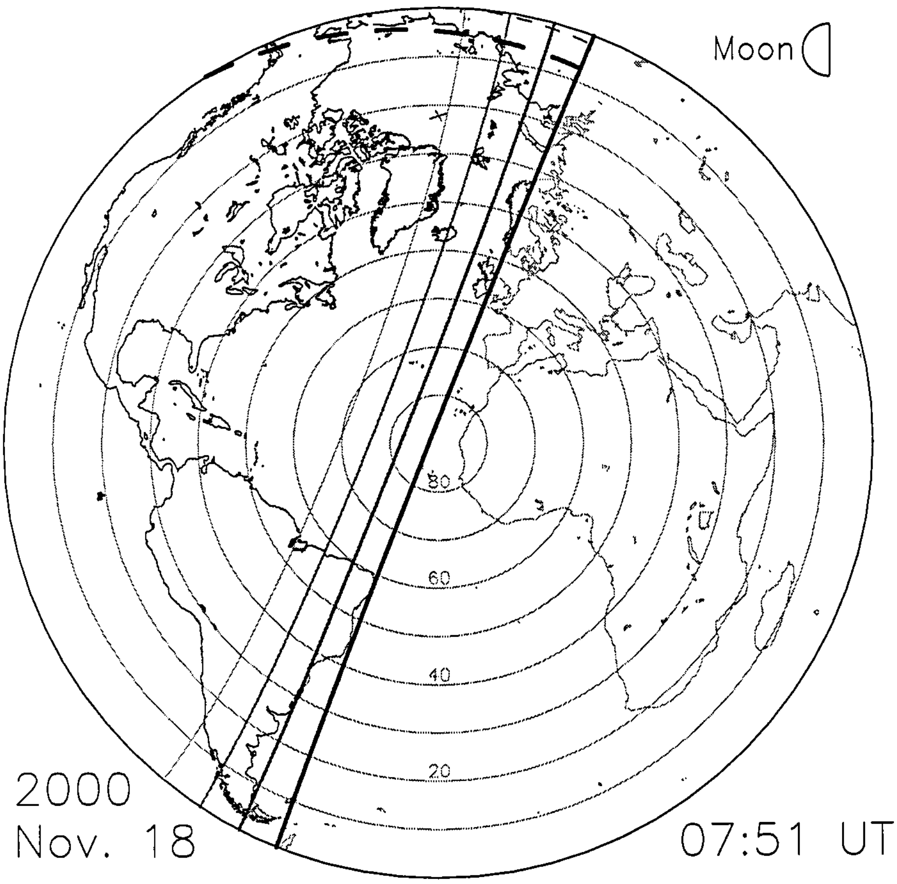


Figure 5.

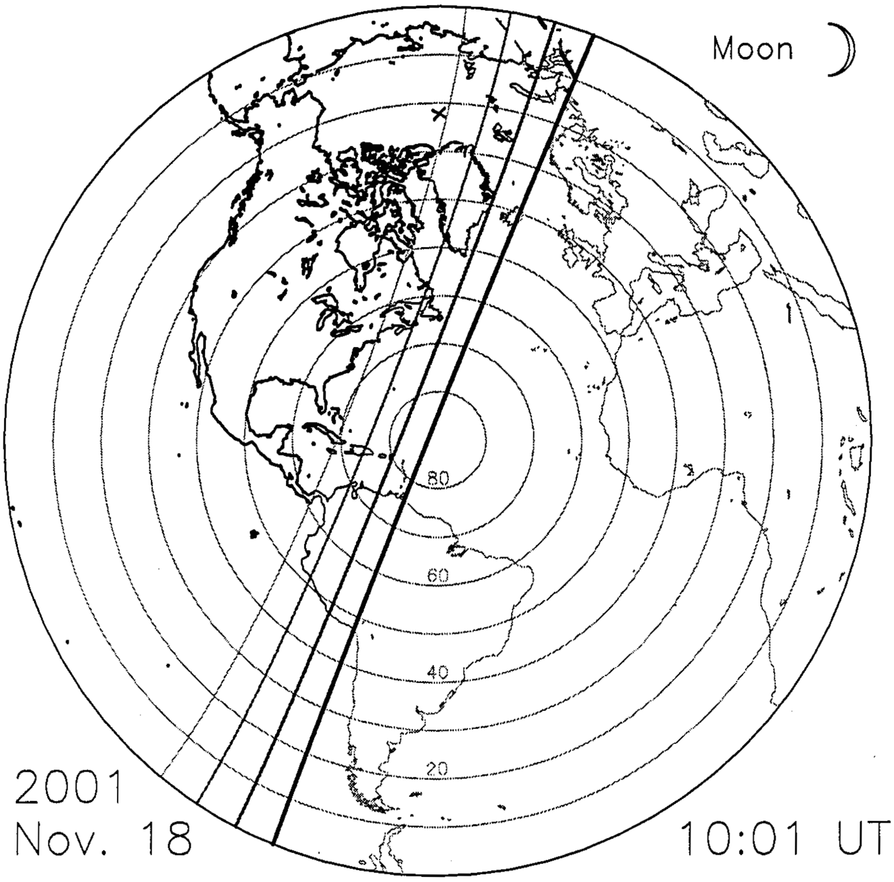


Figure 6.

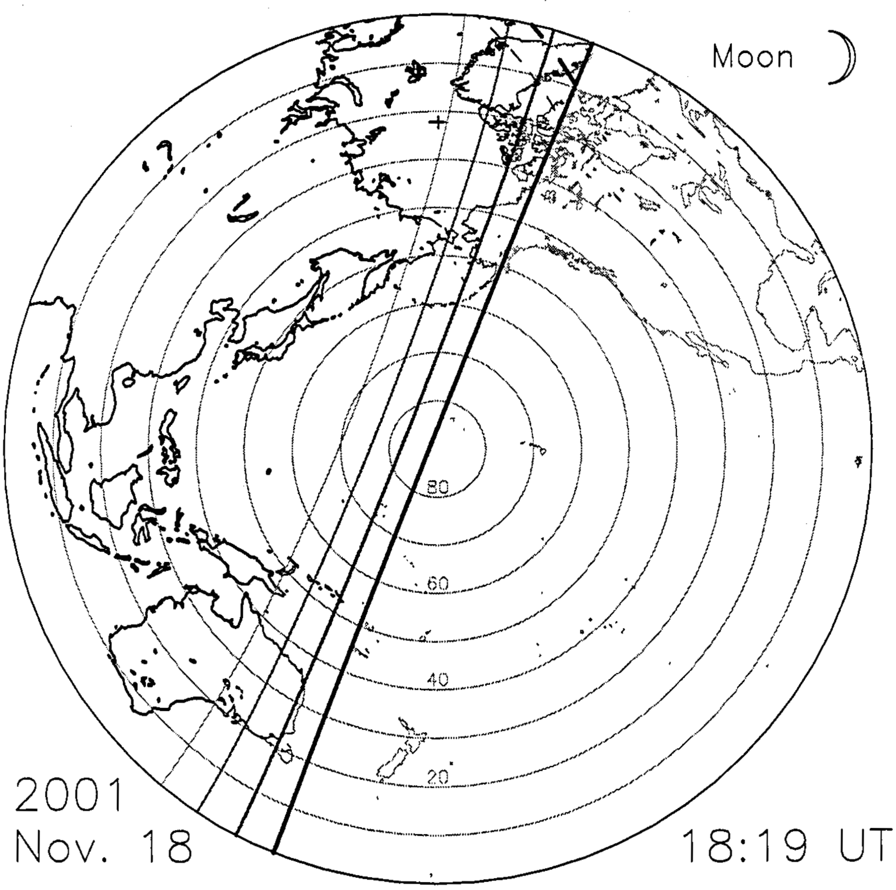


Figure 7.

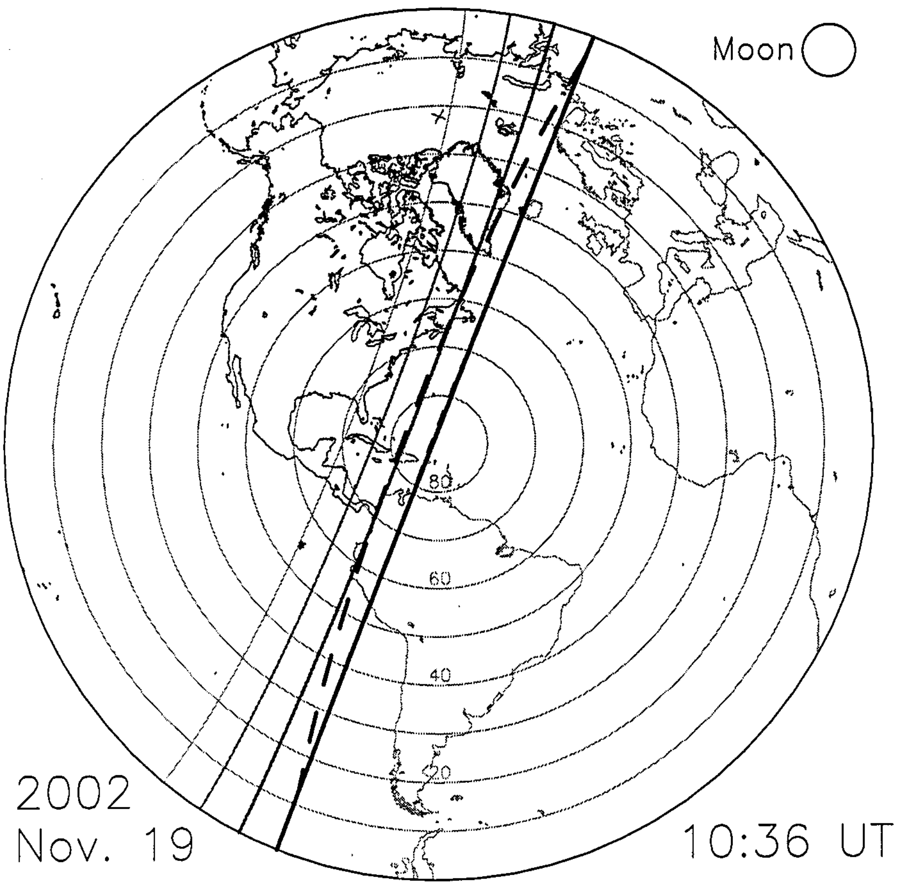


Figure 8.

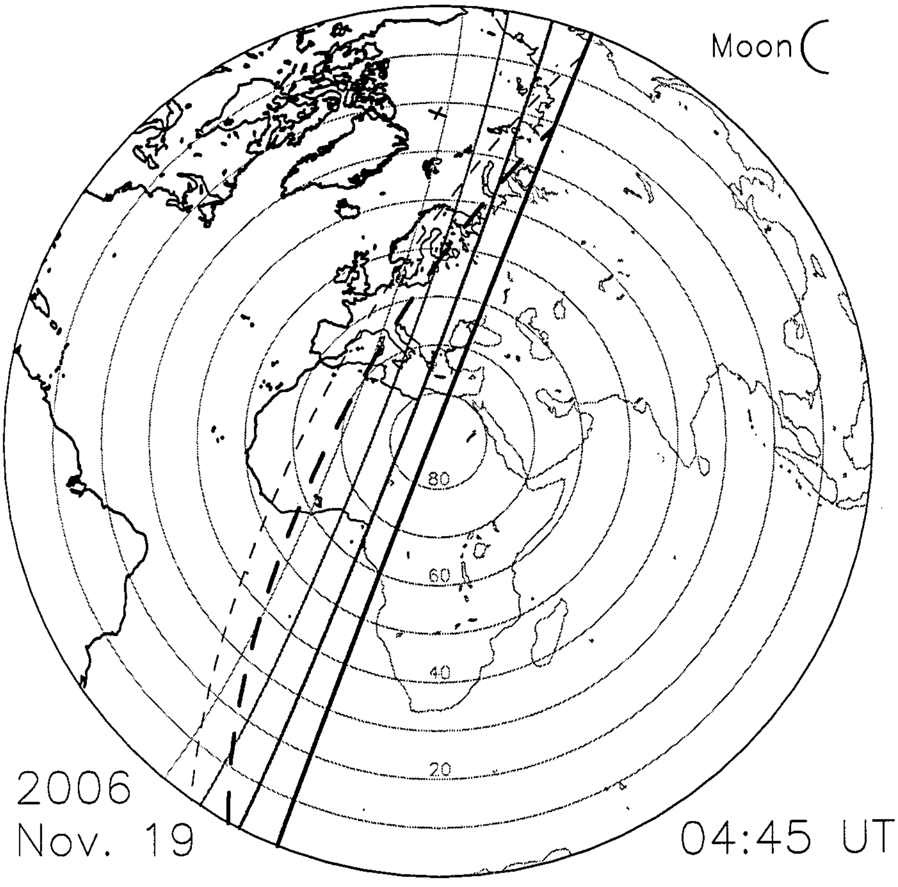


Figure 9.

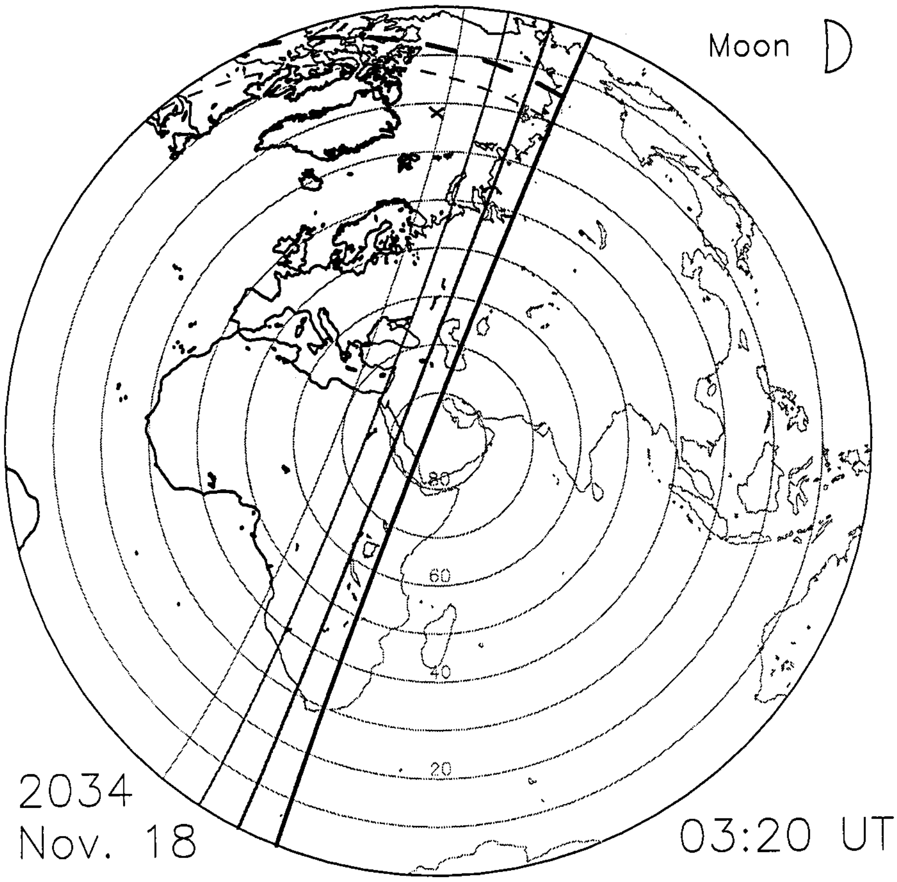


Figure 10.

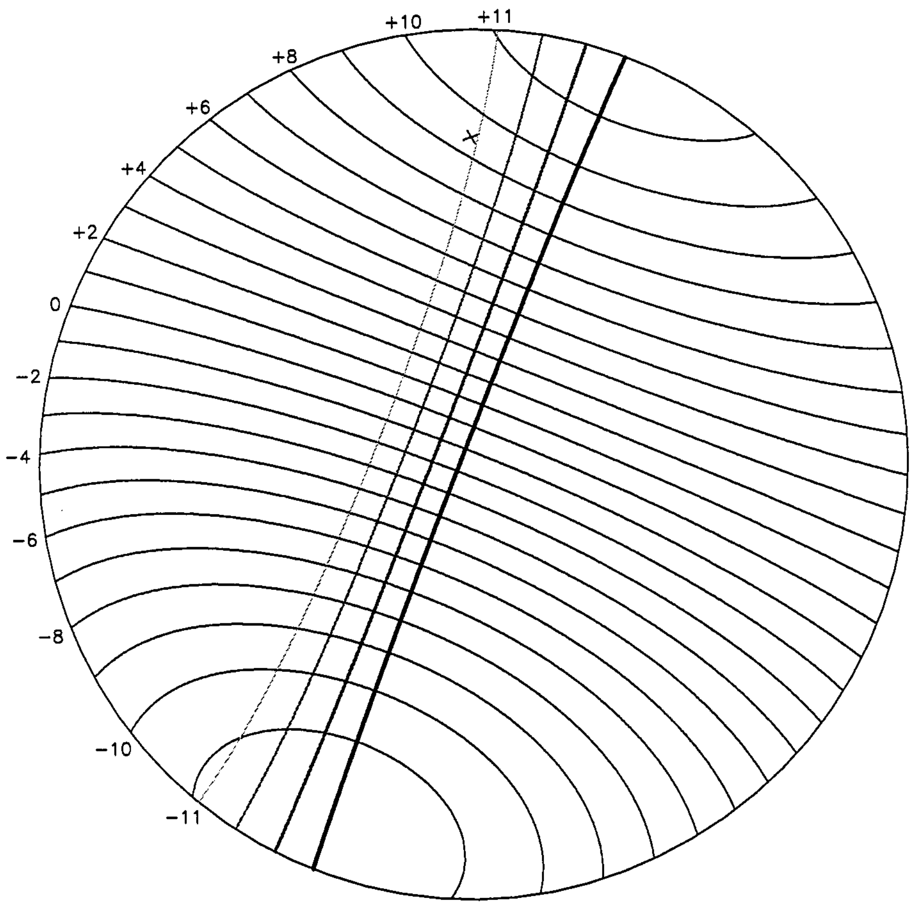


Figure 11.

Clustering Analysis for the 1998 Leonids

Eran O. Ofek, Tel-Aviv University

We analyzed visual and video observations of the 1998 Leonid fireball shower in order to check the hypothesis of clustering of meteors on small time scales. Three sets amounting to a total of 634 meteors brighter than magnitude +4.5 were inspected. We found a very small excess of clustering on 5-seconds intervals with a false alarm probability of about 2% at best.

1. Introduction

The internal structure of meteoroid streams could be investigated through the analysis of time-tagged observations from a single site.

The basic principle in the analysis is to compare the time distribution of meteors to the one expected from a completely random distribution. Porubčan [1] summarized three methods of analysis, which are the following:

1. comparing the number of events in a time bin to the number of events expected from a Poisson process;
2. comparing the distribution of successive time intervals between events to the exponential distribution;
3. Comparing the correlation between successive time intervals, to the correlation expected from a random distribution (0).

These methods could be used to prove the null hypothesis that the meteor distribution is random.

Past analyses

Millman [2] and Hoffleit [3] found, based on visual observations, some tendency towards grouping of meteors. Later, McCrosky [4] analyzed radar observations of the Perseid and Geminid annual showers and of sporadic meteors. From analysis of a total of 6980 meteors he found a probability of 0.0013 of their being random. However, he remarks that some of the observed pairs may be a single meteor, whose echo strength along its path varied above and below the noise level.

Porubčan [1] analyzed radar observations of more than 32 000 meteors in the Geminids, Lyrids, α-β Perseids, L Aurigids, and Orionids annual showers, and of sporadic meteors. He found that the events' time distribution is in excellent agreement with a random distribution. Molau [5] examined the clustering of the 1993 Perseids, using 228 Perseids from video observations, and did not find significant evidence (1.2σ) for clustering on 1–2-second intervals.

Leonids 1998

Young meteoroid streams are good subjects for clustering analysis, since if clustering exists in a meteoroid stream, it will be most pronounced in young streams where the Sun's radiation pressure and Poynting-Robertson effect did not affect the shower greatly.

For the 1998 Leonids, Arlt [6] reported a broad maximum with FWHM of 17 hours around 1998, November 17, $1^{\mathrm{h}}40^{\mathrm{m}}$ UT with ZHR $= 340 \pm 20$. This broad maximum was characterized by an extremely low population index ($r = 1.19 \pm 0.02$). Based on the width and low population index, Arlt [6] suggested that this broad maximum of very bright (and hence large) meteors is only few revolutions old. Asher et al. [7] suggested that the observed bright Leonid meteors are explained by trapping of meteoroids ejected into the 5/14 resonance with Jupiter by 55P/Tempel-Tuttle in 1333. This makes the 1998 Leonid shower a moderate-age stream.

2. Observations

In this work we used three data sets kindly supplied by Rainer Arlt of the *IMO*. The following table list these data sets. For all observers we used only events tagged as Leonids by the observers.

Table 1 – List of data sets used in this work.

Data set	Observer	Location	Equipment	Lm	Date (Nov 1998)	Leonids
I	Tamás Tordai	Budapest	Eye + tape recorder	+4.5	17.0175–17.1860	226
II	Sirko Molau	Mongolia	AVIS Camera	+4.5	17.7581–17.9286	304
III	Sirko Molau	Mongolia	AVIS Camera	+4.5	16.6677–16.8428	106

3. Analysis

We applied two methods for the analysis of time distribution, namely methods 2 and 3 mentioned in the Introduction.

Correlation

The correlation (ρ) between successive time intervals (t_i) was calculated using

$$\rho(k) = \frac{\sum_n t_n t_{n+k} - NT^2}{\sum_n t_n t_n - NT^2} \pm \frac{1}{\sqrt{N}}, \tag{1}$$

where N is the total number of intervals and T is the mean interval. There is one problem applying equation (1) to the observations: if there is a long-term change in the rate of meteors, this could give rise to a spurious correlation with k corresponding to a change in rate. In order to show this effect, we plot in Figure 1 the correlation coefficient as a function of k. A clear trend is seen, and this was removed by taking the mean interval T in equation (1) as the average of the mean intervals in the two correlated time sequences:

$$T = \frac{T_{1,N-k} + T_{k,N}}{2}. \tag{2}$$

As seen in Figure 2, this method corrects the problem of a changing rate. Figures 3 and 4 show that the correlation of both data sets is consistent with zero (up to 2σ). The correlation method for data set III shows similar results.

Exponential distribution

If the arrival times of meteors are randomly distributed, the time interval between successive meteors should be distributed exponentially, and the number of meteors in time interval $[t, t+\Delta t]$, denoted N_t, would be given by

$$N_t = \frac{N\Delta t}{T} e^{-t/T}, \tag{3}$$

where N is the total number of intervals, and T is the mean interval.

Porubčan [1] showed that in the case of rounded-off times, equation (3) is no longer valid, and one should take into account the round-off errors in times. This is true only in the case of very high meteors rate (hence low T), and, indeed, we checked this, and there is no difference between the result of Equation (3) and the result given by the corrected formula

$$N_t = \frac{NT\Delta t}{\tau}(e^{\tau/T} - 2 + e^{-\tau/T})e^{-t\tau/T}, \tag{4}$$

where τ is the round-off interval taken in this work as 1 second.

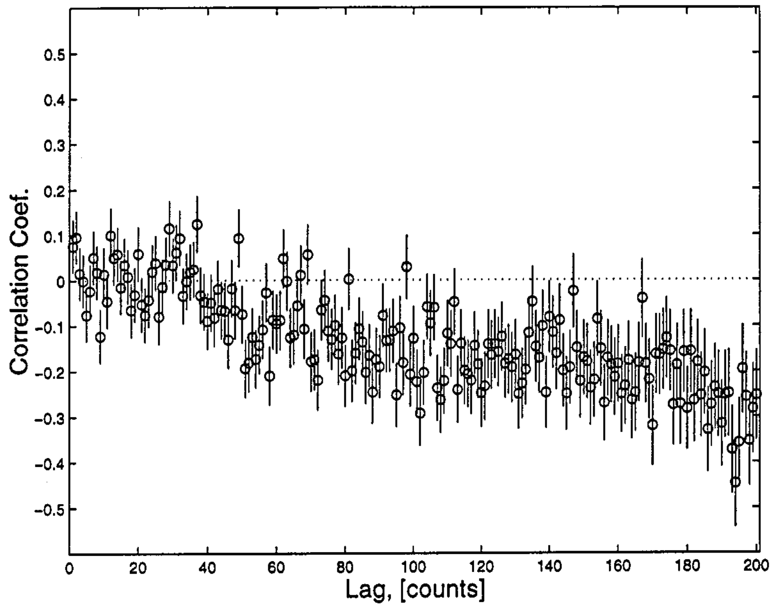


Figure 1 – Mongolian data set II, correlation between successive meteors as calculated using equation 2.

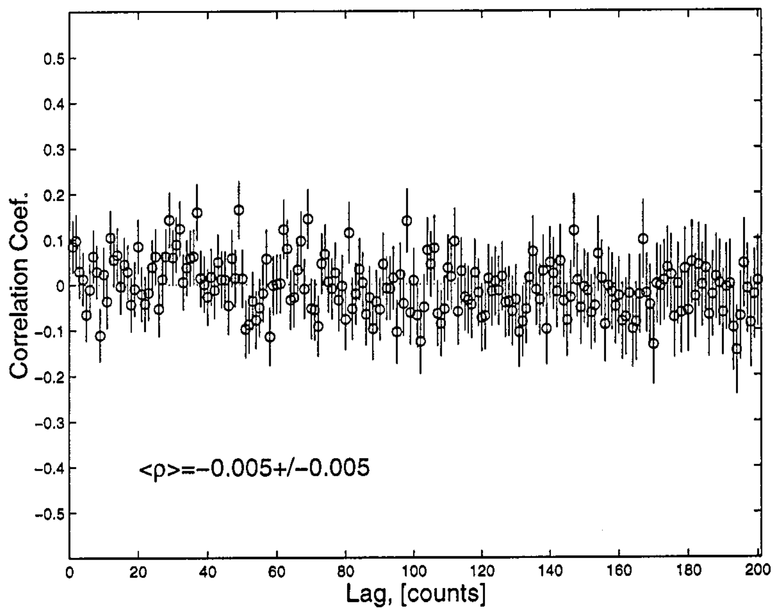


Figure 2 – Mongolian data set II, correlation between successive meteors, with mean interval calculated using equations 1 and 2.

The histogram of the time intervals with a 5-seconds bin for data set I is shown in Figure 5. The line represents the number distribution as expected from an exponential distribution. The excess of meteors in the first bin is at the 2.2σ level. In this method, we still have interference from the changing rate of meteors. In order to avoid this problem somewhat, we divided the data into subsets and noticed that the excess is lowered (1σ, 1.5σ) when only subsets (e.g., first half and second half) of the data is inspected.

Figure 6 shows the interval distribution with 5 seconds bins for data set II, and the line represents the expected distribution. Here the observed distribution is exactly as expected from a random distribution.

We also checked for excess of meteors in the November 16 Mongolian data set III, and found an excess at the 1.2σ level.

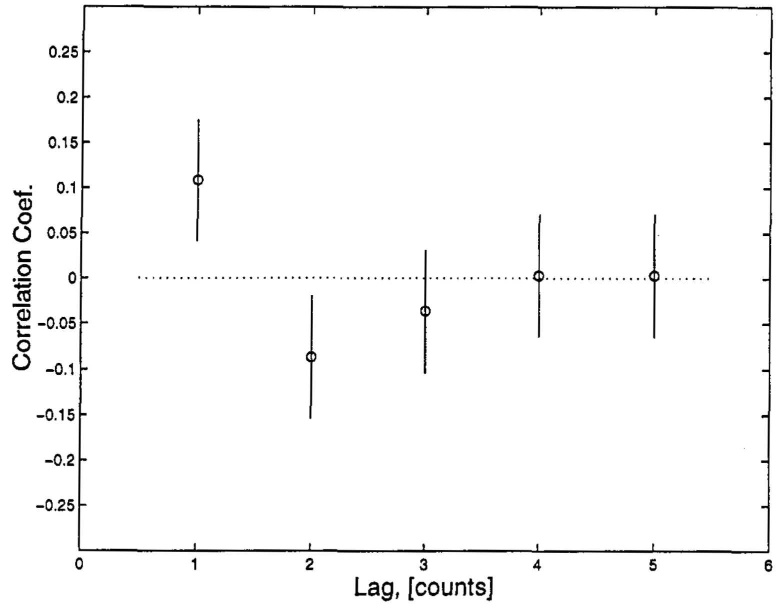


Figure 3 – Hungarian data set I, correlation between successive meteors

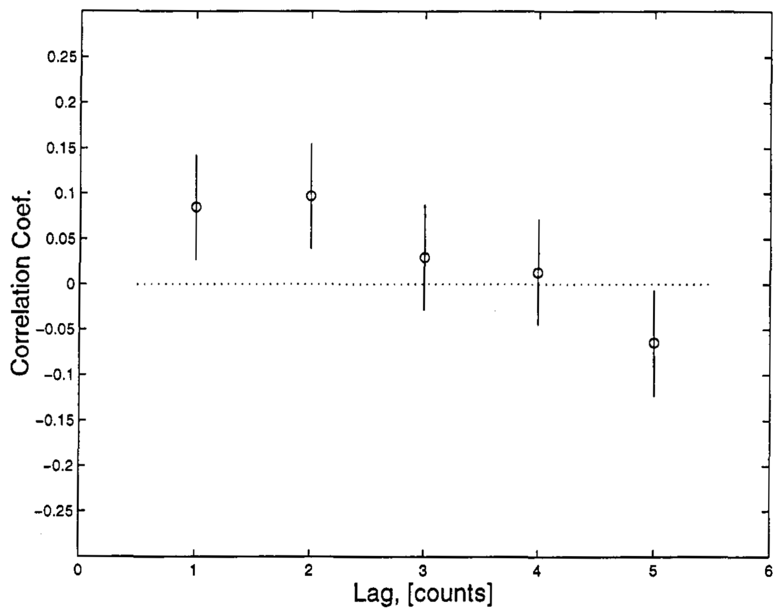


Figure 4 – Mongolian data set II, correlation between successive meteors

4. Summary

We presented clustering analysis of meteor times, from visual and video observations. We analyzed only data with meteors brighter than +4.5, while most of the radar analysis done by Porubčan [1] was for meteors up to magnitude +13. This is very important, since small meteors are much more sensitive to radiation pressure and the Poynting-Robertson effect. In part of the data, we find an excess of meteors in the time interval of 0–5 seconds, corresponding to a scale of up to 350 km ($= 5\ \mathrm{s} \times V_{\mathrm{Leo}}$). This result is not conclusive and has a false alarm probability of about 2% at best.

5. Acknowledgments

We are very grateful to all the observers who submitted their observations to the *IMO* database, especially to Sirko Molau and Tamás Tordai whose observations were used in this work. I would like to thank Rainer Arlt for his encouragement, data collection, and for supplying the observations.

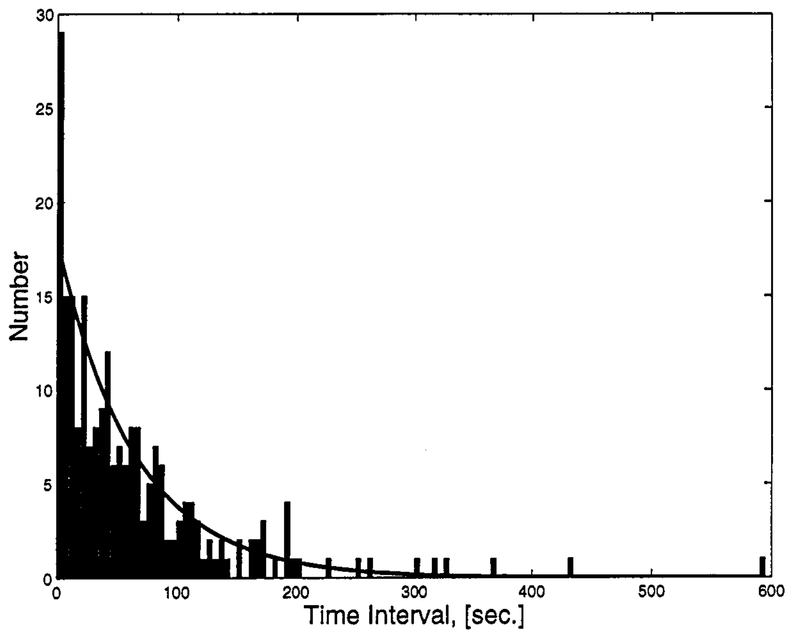


Figure 5 – Hungarian data set I, distribution of time intervals compared to the exponential distribution with mean time interval=65.00 s.

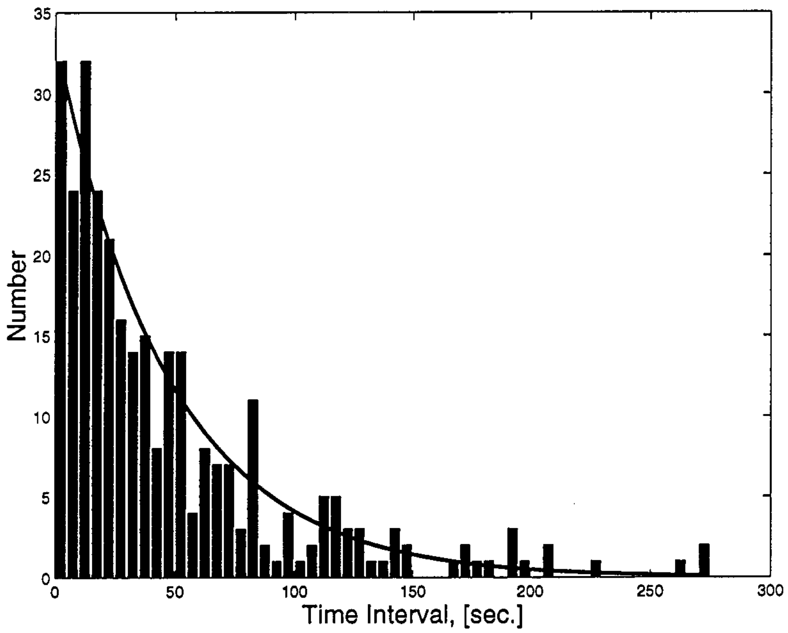


Figure 6 – Mongolian data set II, distribution of time intervals compared to the exponential distribution with mean time interval=47.76 s.

References

[1] V. Porubčan, *Bull. Astron. Inst. Czechoslov.* 19, 1968, p. 316.
[2] P.M. Millman, *J. Roy. Astron. Soc. Canada* 30, 1936, p. 338.
[3] D. Hoffleit, *Harvard College Obs. Circ.* 420, 1937, p. 1.
[4] R.E. McCrosky, *Bull. Astron. Inst. Czechoslov.* 8, 1957, p. 1.
[5] S. Molau, *WGN* 23, 1995, p. 217.
[6] R. Arlt, *WGN* 26, 1998, p. 239.
[7] D.J. Asher, M.E. Bailey, V.V. Emel'yanenko, *MNRAS* 304, 1999, p. L53.

Anticipation: The 1999 Leonid Meteors

Joe Rao

The prospects for a possible meteor storm generated by the Leonid meteor shower in 1999 are examined. Observed Leonid shower maxima from the seven most recent storms are investigated. The average values of these seven storms for ΔT (Earth at node) and C-E (the minimum distance between the orbit of Comet 55P/Tempel-Tuttle and the Earth) compare favorably with the upcoming 1999 values, suggesting that the odds for a storm occurring are now probably at their best for the current Leonid apparition. The production of meteor trails by the parent comet is discussed. It appears that the meteor storms of 1833 and 1966 were caused by meteor trails that were produced respectively in 1800 and 1899. Perturbation of the 1800 trail by Saturn and Jupiter apparently was responsible for the lack of any significant Leonid activity in 1899, while the meteor trail created in 1899 was not yet wide enough to interact with the Earth in 1933 (though a storm did occur on the second revolution of these particles in 1966). An attempt is made to integrate the 1899 meteoroids forward in time from 1966 in order to determine if it is capable of producing another storm in 1999. Through several orbital simulations, it is determined that the 1800 trail was more severely perturbed than was originally believed in 1899 and that the 1966 meteoroids likely underwent a perturbation by Uranus in May 1982, pushing them closer to the Earth's orbit for 1999. The distance between the meteoroids' orbit and that of Earth's (M-E) is found to be 0.0026 AU, which compares favorably with C-E values for the 1833 and 1966 storms. Two methods (extrapolation from past solar longitude values and a comparison between C-E distance and nodal crossing/max. activity times) are used to determine a peak time for the 1999 Leonids. It is found that the peak (on November 18) is most likely to come anywhere from 21 to 150 minutes after the time of Earth's 1^h47^m UT crossing of the comet node, placing Europe and North Africa in prime viewing position. The latter time might even allow the peak to be glimpsed from eastern North America. Although, in conclusion, it is noted that circumstances appear favorable for a strong and impressive Leonid showing in 1999, caution is still advised because of the inherent risks involved in meteor shower predictions.

1. Introduction

> *"There is one aspect of the 1998 Leonid campaign I feel less comfortable about... the press coverage. Unfortunately, the information given was not always that accurate. Several news sources ignored astronomers' cautioning remarks and failed to mention the possibility that no storm would materialize, thus causing disappointment among the general public, who blamed the astronomers for this rather than the media. The outburst of bright meteors in the night of November 16-17 was mistaken for the storm that did not occur, so the conclusion was predictable: the astronomers had 'miscalculated' the storm."*
>
> Marc Gyssens, editorial *WGN* 26:6, December 1998.

One could readily understand the level of Marc Gyssens's exasperation after watching television news reports on the Leonids this past November. In most cases, the general public was being told that come the night of November 17, Earth would be *"...passing through the* tail *of a comet."* ("Dirty trail" would have been far more accurate!). Moreover, the term "meteor storm" was passed-over by some newscasters in an effort to try and convey something even more dramatic. I myself winced when, upon watching the NBC Nightly News of November 17, anchorman Tom Brokaw compared the Leonid shower to *"... the cosmic equivalent of a hurricane in space."* Even worse, in virtually all media reports, it was constantly driven home to the unsuspecting general public that the Leonids were a *"... once in 33-year sky show,"* giving the distinct impression that 1998 would be the one-and-only year to truly see them at their best. These feelings were pretty much confirmed for me after clouds, fog, and drizzle ruined the view locally, as well as for much of the northeastern United States. The next day at the television station where I work as an on-camera meteorologist, several co-workers paid me condolence calls with comments such as *"better luck in 2031!"* or *"don't feel bad, Joe..., 33 years will pass before you know it!"*

Certainly, then, it is going to be most interesting to see how the media covers *this year's* Leonid shower, especially since, as this paper will outline, 1999 could be the "make-or-break year" for the long-awaited meteor storm.

2. History is on our side

Periodic comet 55P/Tempel-Tuttle has long been the recognized progenitor of the Leonid meteor shower. Much has been written about this association in two previous *WGN* papers. Only a brief summary will be provided here.

Like a truck spewing exhaust, 55P/Tempel-Tuttle leaves a "river of rubble" along its path, and like the comet itself, every particle in the stream orbits the Sun in a roughly 33-year period. Each November, Earth hurtles through this rubble river producing a meteor shower. Both the debris and Earth pursue separate orbits around the Sun, but the geometry of their meeting ensures that the meteors always come from the direction of the constellation Leo, the Lion, hence the name "Leonids." The meteors actually travel on parallel paths, but the illusion of perspective makes them appear as if they were fanning out from a single spot on the sky (within the "Sickle" of Leo at $\alpha = 10^{\rm h}12^{\rm m}$ and $\delta = +22°$), just as railroad tracks appear to diverge coming from a distance.

Figure 1 – Leonid storm of November 14, 1868, illustrated by astronomical artist Leopold Trouvelot, who observed the display from Massachusetts between midnight and dawn. This display was the third consecutive meteor storm observed in as many years and the second consecutive Leonid storm in as many years that was observable from the United States. The unusual curving and zigzag meteors depicted in his painting might have been artist's license on the part of Trouvelot, although such phenomena can also be classified as an optical illusion. This particular display reached its peak approximately two hours prior to the Earth's arrival at the descending node of Comet 55P/Tempel-Tuttle.

The tiny particles (called meteoroids) are not spread uniformly along the comet's orbit, but congregate in some sort of tremendous knot or densely packed cluster near and around their parent comet. It has been noted that spectacular "storms" of meteors (with hourly rates of over 1000—see Figure 1) seem to occur when the comet is passing through the inner part of the solar system. The comet most recently passed the perihelion of its orbit on February 28, 1998, and crossed the plane of the Earth's orbit several days later (on March 5). In a 1995 *WGN* paper, I had suggested that the years 1997 through 2000 would provide the best opportunities to experience another Leonid storm. So far, this has not happened in either 1997 or 1998. In order to help us anticipate the possibility of a meteor storm for 1999, we should carefully examine the circumstances of past historical Leonid displays. A summary of the seven most recent storms is provided below.

In Table 1, the first column provides the date of the observed Leonid maximum. In the second column, ΔT (Earth at node) is the number of days that the shower follows the parent comet. In the third column, C-E is the minimum distance between the orbit of Comet 55P/Tempel-Tuttle and the Earth measured in astronomical units, the minus sign in each case indicating that the comet had a smaller heliocentric distance than the Earth at closest approach. The fourth column provides hourly rates of meteors and a remark[1] concerning the shower in question.

Table 1 – Observed Leonid shower maxima.

Date	ΔT (days)	C-E (AU)	Hourly rate	Activity/Remarks
Nov 13, 1833	+ 307.9	−0.0013	~ 100 000	"Stars descend like snow" (US)
Nov 14, 1866	+ 299.4	−0.0065	5 000	Max. over Europe at 1^h20^m UT
Nov 13, 1867	+ 664.4	−0.0065	~ 3 600	Max. N. Amer./Bright Moon
Nov 13, 1868	+1029.9	−0.0065	~ 1 500	Illustrated by L. Trouvelot
Nov 16, 1900	+ 495.8	−0.0117	> 1 000	Created panic at Hudson Bay
Nov 15, 1901	+ 861.4	−0.0117	~ 1 200	"Too thick to count" (Mexico)
Nov 17, 1966	+ 561.0	−0.0033	< 150 000	"A rain of shooting stars" (US)

Were one to average the seven values for "Earth at node" as well as the seven C-E values, the figures would come out to be 602.8 days and −0.0068 AU, respectively. The fact that, in 1999, these figures work out to be 622.3 days and −0.0080 AU readily demonstrates that if one has hopes to observe a possible Leonid meteor storm, 1999 seemingly is the most likely year to expect it. In 1998, Earth trailed the parent comet by 257.0 days. With no Leonid storm during the previous six 33-year cycles having been recorded with the Earth less than 299.4 days from the node (in 1866), I had commented prior to last year's shower that the chances for a storm in 1998 were, at best, "*...iffy.*" In contrast, 1999 most closely matches the two averaged values for the previous seven Leonid storms.[2]

Fortunately, the situation regarding the Moon is marginally good: although ten days old and 67% waxing, it will set by roughly 1^h a.m. local time for mid-northern latitudes on the morning of November 18, leaving the balance of the night dark for meteor viewers.

[1] Concerning the 1867 display, we notice that the Moon was 98% waxing, suggesting that, had there not been lunar interference, this display may have rivaled the previous year's display.

[2] In separate lists of past Leonid storms compiled by Donald K. Yeomans and John W. Mason, eleven post-perihelion storms were concurrently identified dating back to AD 902 (902, 1002, 1202, 1238, 1533, 1601, 1833, 1866, 1867, 1868, and 1966). In one case—1533—did a storm occur with the Earth trailing the parent comet by less than 299 days, the value in this particular case being 229.7 days. The C-E for 1533 was −0.0065 AU. For these eleven storms, the average "Earth at node" value works out to 623.4 days and the average C-E is −0.0067 AU. Not included here are the 1965 Leonids, which were identified by Yeomans and Mason as a storm, but since have been shown to have been merely a shower.

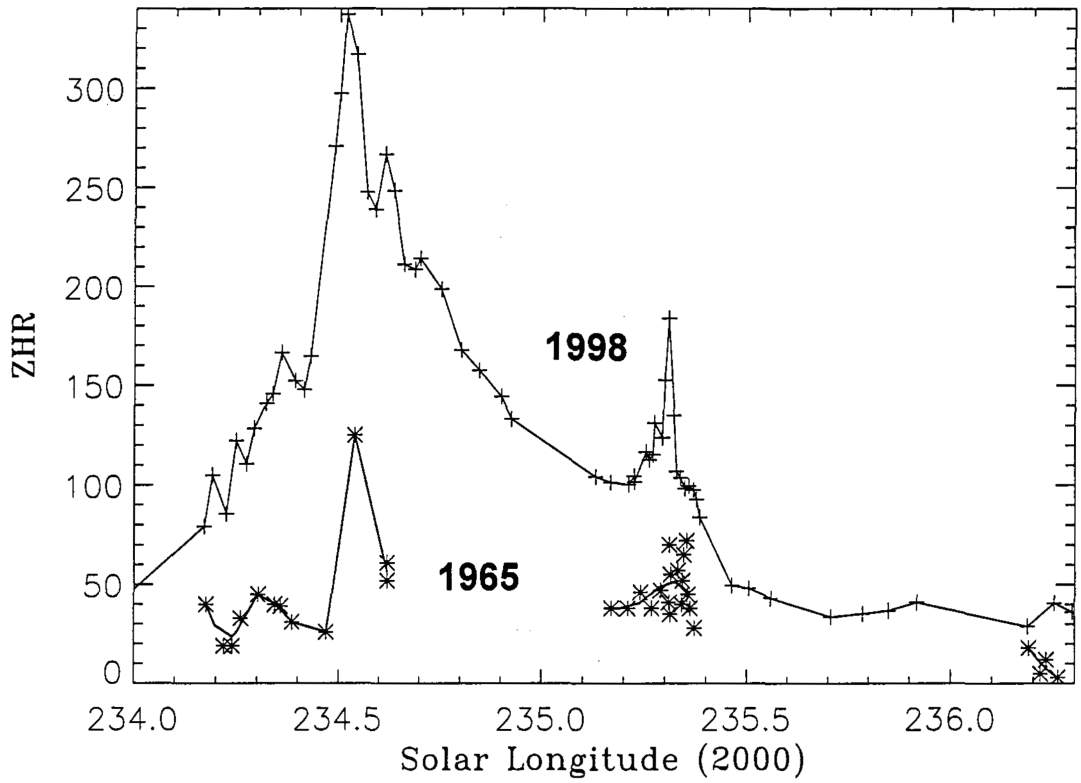


Figure 2 – Comparison between the 1965 and 1998 Leonids from visual observations. Note the similarities between the very high rate observed for the background components, which came roughly 1/2 to 3/4 of a day prior to the lower secondary maximum of the storm component. The number of observational data is very small for 1965; they are, in fact, individual values as there was no global coverage of the profile (such as in 1998). The 1965 ZHR value of 125 was derived from the records of a Baker-Nunn satellite tracking camera. Nevertheless, the radar, visual, and photographic records of the 1965 Leonids indicate an activity profile which resembles the 1998 Leonids. (From R. Arlt, *WGN* 26, 1998, p. 247.)

One might also take note of the similarities between the Leonids of 1965 and 1998 (Figure 2), in that they both displayed a broad peak of very bright meteors—the so-called "background component"—roughly 12 to 18 hours prior to the Earth's arrival at the comet's descending node. This was later juxtaposed on a peak of fainter meteors—the "storm component"—rather close to the time of the Earth's arrival at the node. Might this all imply that perhaps the 1999 Leonids might approach or at least somehow resemble the spectacular display of 1966?

How do storm prospects look for the year 2000? Could a Leonid storm occur in that year as well? In theory, it is not out of the question, although the odds are nowhere near as good. The Earth will be following 55P/Tempel-Tuttle to the node by 988.6 days. Going back to 1833, only one other occasion—1868—saw a Leonid storm occur with the Earth at a greater distance (1029.9 days). As an added handicap next year, the Moon will be 20 days old and 64% waning, shining brightly just a couple of degrees east of the Praesepe Cluster in Cancer and not very far from the Leonid radiant.

3. Particle peregrinations

There have been a couple of occasions where astronomers must have felt as if they were "led down the beaten path" by the Leonids. In the years leading up to 1899 and again as we approached 1933—the two prime examples when it was hoped that the Leonids would storm—the shower displayed increasing activity, suggesting that the hoped-for grand displays would indeed soon materialize. The Leonids of 1898 produced 50 to 100 meteors per hour across parts of the United States, and again showed great strength in 1930 and 1931. In those two latter years, they actually produced rates as high as 190 per hour along with reports of "*... many brilliant* *meteors with long enduring trains."*[3] Surely, it was thought, these Leonid showers supposedly presaged the coming of far-greater displays. Yet, no such grandiose meteor showers materialized. So, just why, after such promising performances did the Leonid meteor trail suddenly "go cold" in 1899 and again in 1933? As we will soon see, part of the problem involved a close encounter of 55P/Tempel-Tuttle with two planets during the latter part of the 19th century. Still, to more fully understand the "on-again, off-again" antics of the Leonids, we should take a closer look at how a comet can give rise to a meteor shower.

A disintegrating comet is accompanied by not just one meteor trail but by several, each trail consisting of the solid debris that broke away during the vaporization of the ices at one perihelion passage. It is generally accepted that the particles capable of producing the so-called "storm component" of the Leonid meteors are caused by narrow, high-density trails of meteoroids in close proximity of the parent comet, 55P/Tempel-Tuttle. Such meteoroids have not yet had time to disperse along the orbit. This is buttressed by the fact that the Leonids produce only about 10 meteors per hour when the parent comet is far from perihelion. Because major Leonid displays have only occurred in those few years before and/or after the comet's return to perihelion, the associated meteoroids are relatively young. Each perihelion creates a new trail: new clumps of debris that break away and multiply. These trails rapidly become separated by distances of up to several hundred thousand miles, caused chiefly by the gravitational action of Jupiter and Saturn on their orbits. This meteor trail production does not increase indefinitely, however, for they all become dispersed and eventually fade into the overall "background component" of the stream. Perhaps a good rule-of-thumb is to assume that the grandest of Leonid displays are produced by meteor trails that are no more than 4 to 6 revolutions old.[4] For anything older, the trails likely become too dispersed to produce storm-level activity. A large meteoroid particle's position relative to the parent comet depends upon the spin position of its nucleus and the location of its outgassing region. However, the smaller (dust grain) particles are immediately pushed away from the Sun by radiation pressure—independent of what direction they leave the nucleus. These latter particles will, sooner or later, wind up outside of and behind the parent comet and hence loan themselves to the evolution of the developing storm component of the Leonid stream.

Conversely, because they are relatively unaffected by radiation pressure, the larger pebble-to-marble-sized particles (those that cause brilliant fireballs and bolides) tend to linger for a much longer time around the nucleus. They also predominate in this region, because they leave the nucleus with less velocity than their smaller brethren do. Since it is likely that the orbital dispersion of the larger versus smaller particles takes place over a span of many revolutions, this background component is not sharply defined, but relatively broad. In 1998, Earth arrived at the nodal crossing point less than 300 days behind the parent comet, and it is likely that this fact—in part—explains the large number of fireball observations made worldwide (Figure 3).

4. A Jovian connection to the 1998 fireballs

This past April, David J. Asher and Mark E. Bailey of Armagh Observatory and Vacheslav Emel'yanenko of South Ural University, Chelyabinsk, Russia demonstrated that the 1998 outburst occurred when the Earth passed through a dense arc-shaped cloud of particles shed from 55P/Tempel-Tuttle in the year 1333 (20 revolutions ago!). By matching theory and observation, they proved for the first time that meteoroid streams associated with Halley-type short-period comets have braid-like structures within them.

---

[3] Charles P. Olivier, *Flower Observatory Reprint* 8, 1931, p. 35.

[4] From the short-duration meteor outbursts of 1966 and 1969, B.A. McIntosh estimated that the associated particles had made only 5–6 orbital revolutions after separating from the comet (From "Origin and evolution of recent Leonid meteor showers," published in *Evolutionary and Physical Properties of Meteoroids*, NASA SP-319, pp. 193–197.)

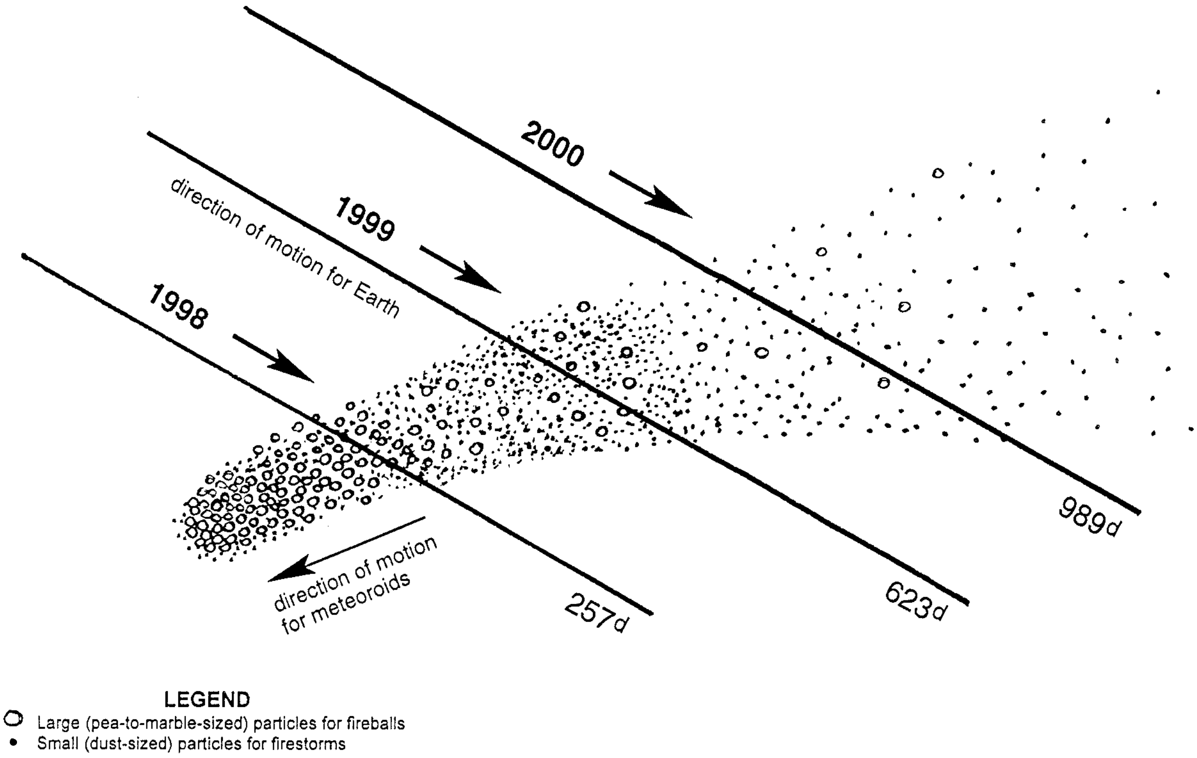


Figure 3 – Earth's passage through meteoroid trails shed by 55P/Tempel-Tuttle at the nodal crossing point in 1998, 1999, and 2000. Over the past six Leonid cycles, there has never been a Leonid storm with the comet less than 299 days from its descending node. On no fewer than seven occasions beyond this point—even as far as 1030 days from the node—Leonid hourly rates of over 1000 have been observed. Yet on three occasions—1932, 1965, and 1998—the comet was less than 299 days from the node, yet only modest Leonid showers were observed, accompanied by copious fireball activity. The author theorizes that when the comet is roughly 300 days from the node and beyond, there is more in the way of smaller dust particles encountered, while within roughly 300 days behind the comet there is less dust but a greater proportion of larger meteoroids. In 1998, the Earth was 257 days behind the comet and as a consequence witnessed a display with a peak hourly rate of 340 along with a proliferation of brilliant fireballs. In 1999, Earth will be 623 days behind the comet and crossing through a region where there is more in the way of smaller dust particles, and it is here where—historically—the Leonid storms of the past two centuries have taken place. While a storm is also a possibility in 2000, it is assumed that both the larger and smaller particles will be more widely dispersed as compared to the two previous years and hence is less likely. Depiction of the aerial coverage of the two particle sizes has been greatly exaggerated for the sake of clarity. (Diagram by J. Rao.)

Such particles were postulated to be locked in a special 5/14 mean-resonance motion with the planet Jupiter. In other words, for every fourteen revolutions of Jupiter, the largest particles released by the comet (as well as the comet itself) makes five. These particles did not spread out in space because of a dynamical process known as resonance. A similar process gives rise to the fine structure seen in the rings of Saturn. The largest meteoroids therefore have kept average orbital periods very close to the comet itself, and are kept in step by the influence of Jupiter. As a result, rather than spreading uniformly around the comet orbit, these resonant meteoroids have the ability over time to build up into a dense strand of large particles and, despite their extreme age, produce a localized concentration within the Leonid meteoroid stream.

Looking ahead to 1999, Earth will be more than 600 days removed from the comet and passing through a sector in which smaller (dust) likely proliferates and where a number of past meteor storms have occurred.[5] So, whereas last year we sampled a branch of the Leonid stream which

[5] Comet expert John E. Bortle on examining why the annual sequence of Leonid showers immediately trailing 55P/Tempel-Tuttle are almost always the same (fireballs/storm/faint display) comments, "*. . . such observations could suggest that a defunct secondary nucleus and associated debris stream, traveling about 300 days behind Tempel-Tuttle, might be a better choice as the causative agent for the Leonids. This possibility is strongly suggested*

produced a display of brilliant meteors thanks to a proliferation of larger particles, this year, for a meteor storm to occur we would have to sample a different branch consisting of smaller particles. In essence, what happened in 1998 with its brilliant array of meteors is merely history—the unusual concentration of the large fireball-producing particles is now well past the Earth—and should have no bearing on what will inevitably happen in 1999 (just as, with the benefit of hindsight, 1898 had no bearing on 1899, and 1930 or 1931 had no bearing on 1933; Figure 4).

Put simply: if 1998 was the year of the fireballs, then 1999 *could* be the year of the storm.


presented to an appropriate institution where it could be displayed and safeguarded.

ASSERT JUPITER LED THE LEONIDS ASTRAY

Astronomers Lay Sparseness of 33-Year Shower to Attraction of the Great Planet.

BRILLIANT ONES OBSERVED

Dr. Olivier at Philadelphia Reports That Some Were Brighter Than a First-Magnitude Star.

By JAMES STOKELY.

PHILADELPHIA, Nov. 16.—Again the Leonid meteors disappointed astronomers who watched for them, expecting possibly a return of the brilliant shower of shooting stars of November, 1866. A careful watch, in a beautifully clear sky, at two observatories near Philadelphia, revealed a very sparse display, far inferior to that of last year.

In the opinion of Dr. Charles P. Olivier, director of the Flower Observatory of the University of Pennsylvania, and president of the Meteor Commission of the International Astronomical Union, the 1899 experience is being repeated. After fine showers in 1833, when the entire sky was covered with shooting stars, and in 1866, a repetition was confidently expected in 1899. The warning of two English astronomers that the planet Jupiter

Figure 4 – Coverage of the Leonids as presented in the November 17, 1932 issue of *The New York Times*. It was noted that activity was rather poor as seen from the northeastern United States, with noted meteor astronomer Charles Olivier attributing this to perturbations by the planet Jupiter in 1898. Actually, a brief outburst of over 200 Leonids per hour was noted in parts of Europe some hours earlier. In the article, Olivier suggested that much better Leonid showers might be expected in 1933 and especially 1934 (when he hoped for high activity similar to the 1901 display), but they did not materialize.

---

to me, and there may be a counterpart in the December Ursids, since its outbursts occur half a revolution behind the parent comet's (Tuttle) perihelion dates. This is all rather hard to explain by originating from simple ejection debris (i.e., the long duration necessary to get left half a revolution behind, yet remain concentrated enough for a good display)."

5. A voice from the Leonid past

Thirty-three years ago during the last Leonid cycle, there were very few people who held out hope that a meteor storm—or even a significant shower—could occur. Most experts said nothing would happen—the Leonids were considered to be all but dead, since the meteor stream had apparently shifted in space so that Earth no longer ran into its dense core. Several years earlier (in 1961), Donald W.R. McKinley wrote in *Meteor Science and Engineering* that it *"... is highly improbable that we shall ever again witness the full fury of the Leonid storm."* Amidst all this gloom and doom however, there were two sanguine Leonid predictions issued. Both were published in the lead article appearing in the November 1966 issue of *Sky and Telescope* under the title "A Good Leonid Year?"

The first prediction was by Harold B. Ridley of the *British Astronomical Association*, who noted that *"... a strong maximum may be confidently expected... when the hourly rate is unlikely to be less than 100."*[6] The other prediction came from Kenneth Linn Franklin, astronomer and later Chairman of the *American Museum/Hayden Planetarium* in New York City. Franklin is perhaps best known in astronomy circles as the discoverer of radio emissions from Jupiter in 1955. But prior to the 1966 Leonids, he had made a study of past Leonid apparitions and decided that based on the geometry of the Earth relative to 55P/Tempel-Tuttle, that the Leonids for that year could put on *"... an interesting display."* On November 16, 1966, a major story on the Leonids appeared in *The New York Times*, also making a reference to Franklin's optimistic assessment that *"... a dramatic shower, like the one in 1833, may be in the offing."*[7]

Based on Franklin's confident outlook, New York Park's Commissioner Thomas P.F. Hoving invited the public to view the Leonids from Central Park's vast Sheep Meadow. Despite inclement weather, over 10 000 New Yorkers turned out. Meanwhile, Franklin himself was on board a special flight sponsored jointly by Trans World Airlines and the Hayden Planetarium to carry reporters above the clouds. Unfortunately, the Leonids had only begun to build toward the kind of display that Franklin was hoping for when sunrise put an end to observations in the eastern United States.[8] Over the western United States, where it was still dark, it indeed was a dramatic shower!

It was shortly after last year's Leonid performance that I received an e-mail from Franklin who discussed some of the pros and cons concerning a possible Leonid storm in 1999. It was obvious that the Leonids still piqued his interest and in his message he made the following observation and a suggestion:

> *"I see that the Leonid stream is very ropy and stringy, so why not a "gout" of meteoroids as well? If such a meteor cloud can be identified, its perturbations should be studied as well as those of the comet. In fact, I think variations in the comet's path can have very little effect on the cloud, because they are so far apart. In other words, whether we pass inside or outside of the currently osculating comet path may have no bearing on whether we encounter the cloud or not. Perhaps you might consider attempting a simulation of the orbital trajectory of the cloud itself. Such a cloud of meteoroids should*

[6] As was later pointed out in *Sky and Telescope* 33:1, January 1967, p. 4, it turned out that Ridley's prediction was *"... about 1000 times too small!"*

[7] In the summer of 1992, I wrote to Franklin—who was by then retired and living in Florida—and asked what he based his prediction on. On August 17, 1992, he wrote back the following: *"I investigated the value of the mean anomaly of the comet for the possible storms in 1833, 1866, 1899, and 1933. The value for 1966, around* 135°, *as I recall, was close to the values for 1833 and 1866, but not for the years with poor displays. My prediction of a good shower was published in an editorial by Charlie Federer in* Sky and Telescope *in 1966, but Brian Marsden still says he did not understand what I did."*

[8] Along the immediate seaboard of the United States, the 1966 Leonid hourly rate climbed rapidly to roughly between 150 and 300 before the onset of bright morning twilight. From Tallahassee, Florida, Norman McLeod saw rates increase to 30 per minute (1800 per hour) before dawn intervened. In addition, there were reports of a sudden increase of brilliant fireballs including one easily seen from Norriston, Pennsylvania, only 13 minutes before local sunrise (*Sky and Telescope*, 33:1, January 1967, p. 9).

be much larger than the comet body, so perturbations would not be so stringent on it for shower purposes. Consider making the center of mass the "particle sampling" that suffers the perturbations. Back in 1966 I was only working with the linear aspect of the meteoroid stream trailing the comet, not with the three dimensions of our encounter with the actual path. Of course, this is all interesting and important, but I had no way of handling the work at the time, even if I had thought of it."

6. Been there... done that

The idea that Franklin proposed—to track the cloud of meteoric debris responsible for the Leonids, rather than the parent comet itself—is not a new one. A century ago, two British astronomers, G. Johnstone Stoney and Arthur M.W. Downing attempted just such a prediction, utilizing an orbit not for 55P/Tempel-Tuttle, but for the Leonids themselves.[9] John Couch Adams did the original computation in February 1867.

According to their calculations, Stoney and Downing demonstrated that the swarm of particles passed sufficiently near to Saturn in 1870 and to within 0.90 AU of Jupiter in 1898 to be deflected into a different orbit. Indeed, by 1899, the orbit of the particles had apparently been given such a severe shift that Stoney himself addressed the *Royal Astronomical Society of London* five days before the peak of the 1899 Leonids. He announced that, unless the particle stream radius extended at least 0.0141 AU from the central orbit path, the expected meteor display might not be seen. To make matters worse, a 98% waxing Moon would prove to be a tremendous nuisance for all prospective observers. Yet, despite all these negative aspects, both astronomers still felt compelled to predict a good Leonid showing! In an article in the November 9, 1899 issue of the British journal *Nature*, they are actually quoted as stating that *"... the Earth is likely to receive one of the great showers this year."*[10] Unfortunately, the 1899 Leonids completely fell flat with hourly rates no better than a range of 20–40. The potential "great shower" turned instead into a great disappointment!

7. On the trail of the missing trails

A recent independent study by David Asher points out that for the Leonid storms of 1833 and 1966 respectively, the Earth likely passed through meteoroid trails generated at the 1800 and 1899 returns of 55P/Tempel-Tuttle. This was proven through an evaluation of differential gravitational perturbations, comparing the parent comet with its accompanying meteoroids. This is an interesting concept, in that it may provide a clue to the reason for the lack of any meteor storm activity in both 1899 and 1933. One could assume, for instance, that the meteoroid trail ejected at the 1800 perihelion was responsible for not only the 1833 storm, but perhaps loaned itself to the production of the 1866 storm as well.

In Table 2, those years which spawned a meteor trail can be found in the first column, while the years in a which a potential storm might have been seen are located across the top row. If a storm occurred in a selected year, "Yes" is given along with the C-E distance in astronomical units for that particular apparition. If a storm failed to occur, a "No" is given.[11] We can see that, in order for the Earth to interact with the 1800 ejecta after only one revolution in 1833, the C-E distance was unusually small—a mere 0.0013 AU (about half the average distance of the

[9] "Perturbations of the Leonids," *Proceedings of the Royal Society of London*, 64, March 2, 1899, pp. 403–409.

[10] We cannot help but note the similarities between this episode and the ill-fated Comet Kohoutek in 1973-74. Initially ballyhooed as potentially "The Comet of the Century," it soon became painfully clear that Kohoutek was going to fall far short of these original expectations. Nonetheless, there were very few announcements indicating this to the general public—perhaps because many astronomy outlets were in so deep thanks to their initial pronouncements for a stunning display, that quietly they might have been hoping against hope that somehow, in the end, everything would turn right. Stoney and Downing might have felt the same way with the 1899 Leonids.

[11] In a 1996 study ("Dynamics of the Leonid Meteoroid Stream: a Numerical Approach"), Peter Brown and Jim Jones indicate that, in the case of potential storm activity for 1998–2000, the material causing these (possible) storms were *"... ejected during the 1932 and 1898 passage of the comet."*

Earth to the Moon). For the trail's second revolution in 1866, enough material in this branch of the Leonid stream presumably had spread out from the comet's orbit to reach as far as 0.0065 AU to Earth, thus creating another—albeit weaker—storm opportunity. As Table 2 also implies, the 1866 C-E separation was likely too wide for any interaction from any 1833 particle ejection.

Table 2 – Potential "storm years."

Ejection years	1833	1866	1899	1933	1966	1999
1800	Yes (0.0013)	Yes (0.0065)	No	No	No	No
1833	–	No	No	No	No	No
1866	–	–	No	No	No	No
1899	–	–	–	No	Yes (0.0033)	? (0.0080)
1932	–	–	–	–	No	No
1965	–	–	–	–	–	No
1998	–	–	–	–	–	–

But then came the aforementioned perturbations induced by Saturn and Jupiter, which likely threw the 1800 trail far off-course. Such perturbations probably also adversely affected any meteoroid trails subsequently generated in 1833 and 1866 as well. However, disappointing as the 1899 Leonid apparition was, there ironically would be a bright side: the meteoroid ejection that occurred at the comet's perihelion that year would ultimately allow for a renewal of meteor storm activity. That activity, however, was not observed in 1933, since the C-E distance for that apparition was 0.0062 AU—probably far too wide for any interaction with the freshly ejected (one-revolution) particles of 1899.[12]

In 1966, however, the C-E distance was nearly halved, and, if we assume that the 1899 particles had dispersed after two revolutions as much as the ejected particles of 1800 apparently had spread out by 1866, the prospects for a meteor storm in 1966 suddenly became a very distinct possibility! As Table 1 indicated, the Leonids indeed produced a tremendous meteor storm on the morning of November 17, 1966, with observations suggesting a rate briefly attaining an incredible 40 per second![13] In an 1981 Leonid article in the journal *Icarus*, Donald K. Yeomans of NASA's *Jet Propulsion Laboratory* suggested that the cause of nonshower events (1933, for instance) lay in the fact that *"...the particle distribution surrounding the comet is far from uniform in density."* But from examining Table 2, we might ascertain another reason as to why the Leonids failed in 1899 and 1933. Looking down the respective columns for these years reveals that *Earth was apparently in a "void" between meteor trails*! Interaction with the 1800 trail had ended by 1899 and the 1899 trail would not cross paths with Earth until 1966.

[12] In the strictest sense, were we to go by our general rule of no possible storm while the Earth was less than 299 days removed from the comet node, then the year to anticipate a storm would *not* have been 1899 (Earth at node of +130.4 days), but rather 1900 (Earth at node of +495.8 days). As it turns out, there is indeed a report of a Leonid storm in that latter year. Kazimircak-Polonskaja et al. state that a major display occurred in 1900 over Hudson Bay with observed hourly rates of 1000 early on November 16. Also, in the October 1934 issue of *The Telescope*, Willard J. Fisher has an article about the historical Leonids and says that the *"... apparition of 1900 was also disappointing, except about Hudson's Bay."* He attributed this observation to *"... very sharp gradations in density"* in the swarm. Unfortunately, reports from elsewhere in North America conflict with this. Conversely, the Leonids of 1901 produced a very significant display for a wide variety of locations. In a paper by Peter Jenniskens on meteor outbursts in *Astronomy and Astrophysics*, 295, 1995, an activity curve is given for the 1901 shower on p. 217 which suggests a peak rate above 1000 per hour. So, in the absence of confirmatory data that the 1900 Hudson Bay storm actually occurred, we would like to suggest that this 1900 display has been misdated and might actually have taken place in *1901*.

[13] It should be noted here that many other observers of the Novêmber 1966 Leonid storm noted lower rates of 10 to 30 per second. It also seems that the peak activity was not constant, but actually came "in waves" and "surges." Wrote Dana K. Bailey of Boulder, Colorado, *"...I decided that no fewer than 10 new meteors were appearing each second, for many minutes. Sometimes the rate was double or triple that..."* (*Sky and Telescope*, 33:1, January 1967, p. 7).

So now the burning question is—can the Earth once again interact with the 1899 trail to produce another meteor storm in 1999?

8. Let's dance!

Can a viable prediction on the intensity of the Leonids be made by tracking the future movements of the meteor trails themselves rather than their parent comet? Says orbit expert Brian G. Marsden of the *Minor Planet Center*, Cambridge, Massachusetts, *"I agree that in order to judge what is happening it is necessary to integrate the orbits of Leonids rather than Comet Tempel-Tuttle, but one has to have the right revolution period (of the meteoroids). And even then, there is no guarantee."* Still, ... nothing ventured, nothing gained. To be sure, the determination of such a revolution period is far from straightforward. An iterative method must be used.

For the task of providing adequate orbital simulations for the existing Leonid particles, the computer program DANCE OF THE PLANETS[14] was chosen to do the job. Orbital simulation is what makes DANCE so fascinating and instructive. When a date and time is specified, the instantaneous positions and velocities of the orbiting bodies are calculated—and, then, "gravitation" takes over. The incremental movement of each body due to the gravitational influence of all others is continuously calculated, closely approximating the action of gravitation. As a testimony to its accuracy, when it was determined that the fragments of the Comet Shoemaker-Levy 9 (discovered in March 1993) were en route to a July 1995 collision with Jupiter, DANCE was used by many principal investigators to visualize the circumstances of the impending collisions: it had the capacity and flexibility to simulate the collisions as viewed from any angle, complete with impact site locations.[15]

Acting on Franklin's suggestion, DANCE OF THE PLANETS was initially used to determine the orbital movements not of 55P/Tempel-Tuttle, but rather, that part of the Leonid stream responsible for past storms. Only the 1800 and 1899 meteoroid trails were analyzed for this study, especially with the idea that the latter trail would probably have significant impact on what might happen in 1999.

9. Just how close?

An attempt was made to determine how closely storm-related meteoroids approached Earth at two past apparitions and how closely they would approach in 1999. Franklin had noted that such a cloud of meteoroids would likely be larger than a typical comet, so, dutifully, three comets were generated in DANCE to represent the known positions of Leonid meteoroids for three different storm occasions: 1833, 1866, and 1966. This was achieved by the utilization of osculating orbital elements for 55P/Tempel-Tuttle for the years 1833, 1866, and 1965 (the orbital data taken from an updated 1996 study on the Leonids by Yeomans, Kevin K. Yau and Paul R. Weissman[16]). For the representation of the respective meteoroid clouds, 55P/Tempel-Tuttle's orbital elements were copied onto the program's "`.CMT`" files. The only alteration made were in the dates of perihelion: each of the three simulations for a given year were initialized with perihelion passage times that placed a meteoroid cloud at or very near the descending node at the time that the Earth crossed the plane of the comet's orbit. Because of the constraints of the program, I could not always exactly match the initialization time with the exact time of the observed maximum of a selected storm, but was always able to come to within less than 30 minutes.

[14] DANCE OF THE PLANETS, Version 2.71, Arc Inc. Science Simulation Software, Loveland, Colorado, 1994.

[15] By July 18, 1994, after the first five comet fragments had fragmented, it became apparent from the position of the fragment that the predicted times of impact were early by about 5 to 10 minutes. These discrepancies were later attributed to systematic errors in the *Hubble Guide Star Catalog*. Yet, as it turned out, small errors in DANCE's simulator cancelled some of this discrepancy making DANCE's predicted impact times *closer to the real ones*!

[16] These calculations proved so accurate that the predicted time of the 1998 perihelion passage of 55/Tempel-Tuttle needed to be corrected by only 31 minutes.

To simulate the 1833 Leonids (all UT), T = November 7.1; for 1866, T = November 7.8; and, for 1966, T = November 12.4.

During a simulation, the screen also displays the Earth-particle distance in Earth radii. (One Earth radius equals 4.26352×10^{-5} AU). The results are given below in Table 3. Along with the date and time of initialization, the initial C-E (given in AU) is given, as well as the UT date that the Earth would arrive at the node in the subsequent 33-year Leonid cycle. Finally, the next cycle's projected values for the meteoroid/Earth orbit separation (labeled M-E) as well as the new C-E are provided. All M-E and C-E values are negative, indicating the respective orbits are inside Earth's.

Table 3 – Forward integration of Leonid meteoroids.

Initial Date/Time (UT)	Initial C-E (AU)	Earth at node for next cycle	M-E (AU)	C-E (AU)
Nov 13, 1833, 10^h42^m	−0.0013	Nov 14.01, 1866	−0.0069	−0.0065
Nov 14, 1866, 01^h06^m	−0.0065	Nov 15.40, 1899	−0.0206	−0.0117
Nov 17, 1966, 12^h12^m	−0.0031	Nov 18.08, 1999	−0.0026	−0.0080

While the projected M-E value for 1866 (−0.0069 AU) seems to agree quite well with the initial C-E value used for that same year (−0.0065 AU), there is a large discrepancy concerning the M-E and C-E values for 1899. As had been previously noted, Stoney and Downing indicated that the Leonids of 1866 passed to within 0.90 AU of Jupiter in 1898. In contrast, we found a closer Jupiter approach for the supposed meteor cloud of 0.80 AU (September 1898). As a result, while Stoney and Downing suggested that Leonid particles would be separated from the Earth's orbit by as much as 0.0141 AU in 1899, Table 3 suggests that the separation distance was an even greater 0.0206 AU!

In an attempt to verify the accuracy of DANCE for this particular situation, it was decided to run the 1866 osculating orbital elements for 55P/Tempel-Tuttle forward in time to 1899. For the initialization. The 1866 orbit data for the comet were taken from Yeomans et al.'s 1996 study (J2000.0, epoch December 30, 1865). The predicted osculating orbital elements for the comet that were derived by DANCE for 1899 were then compared to Yeomans's 1899 data. These are summarized in Table 4.

Table 4 – 1899 osculating orbital elements for 55P/Tempel-Tuttle.

Element	Predicted	Actual
q	0.9726997 AU	0.9725873 AU
e	0.9063497	0.9063604
i	162°85595	162°85228
Ω	234°14682	234°59349
ω	172°22679	172°20627
T (UT)	Jul 1.4122, 1899	Jul 1.9853, 1899
P	33.47 years	33.47 years

Considering that the Yeomans calculations attempt to account for nongravitational acceleration parameters (the rocket-like thrusts of the outgassing cometary nucleus) while DANCE provides a purely gravitational solution, the DANCE 1899 values were nonetheless still very close to Yeomans's 1899 values.[17] This gave great confidence in the accuracy for what was obtained for

[17] Notes Yeomans, *"Since the transverse nongravitational parameter (A2) that we determined for comet Tempel-Tuttle was positive, the 'actual' orbital period would be somewhat longer than an orbit for which no nongravitational accelerations were assumed. Hence, much of the difference between the 'predicted' and 'actual' times of perihelion passage would be due to nongravitation effects."*

the 1866 forward integration. Thus, it would appear that the Leonid meteoroids might have indeed actually missed the Earth by a distance 0.0065 AU greater than what was originally indicated for that year by Stoney and Downing.

More interesting is the situation regarding the 1966 integration. It suggests that the same concentration of particles that produced the great Leonid storm of that year will pass at a distance just 0.0026 AU inside of the Earth's orbit in 1999. This M-E value is just over three times closer than the C-E value of 0.0080 AU. In his 1996 Leonid study, Yeomans suggests that the varying C-E values for 55P/Tempel-Tuttle that have been observed since the early 19th century may help serve to anticipate the intensity of the upcoming 1999 Leonids:

> *"In 1998–99, the Earth will pass nearly three times as far from the comet's orbital path as it did in 1966 and more than six times further than it did during the great storm of 1833. The 1998–99 circumstances are most like those for the 1866–68 and 1931–32 returns. For the former period, hourly rates of up to 5000 were reported while in the latter period, about 200 was the maximum reported rate."*

As has been previously noted, we would attribute the reason for the lack of any storm activity in the early 1930s to the Earth's failure to interact with a fresh trail of meteoroids, while the Leonids of the 1860s might be an artifact of the trail that was shed in 1800. Were we to accept Yeomans's logic and additionally assume that the 1866–68 circumstances are the best for possibly representing the intensity of the 1999 display, we might suggest a rate of roughly 2000 meteors per hour. However—as Yeomans himself points out—this logic is based solely on Leonid stream particles moving along in the same orbit as the parent comet and only displaced in time along the orbit path. In contrast, our alternative solution is an attempt to track those Leonid stream particles that are moving independent of the motions of the comet.

10. Uranus: the apparent culprit

The most likely reason that the Leonid particles are pushed closer to the Earth's orbit for 1999, appears to stem from a perturbation by the planet Uranus.[18] The assumed center of the 1966 particle cloud was closely approaching the aphelion point of its orbit when it appears to have swept to within 0.59 AU of Uranus in May 1982 (Figure 5). The cloud apparently reached aphelion either near the very end of 1982, or the very beginning of 1983. Interestingly, in his 1996 study, Yeomans provided a listing for the minimum separation distances for those approaches of 55P/Tempel-Tuttle to within 1 AU of Jupiter, Saturn, and Uranus. Yet, during the 1965–1998 interval, there is no notation concerning Uranus, suggesting that—in contrast to the meteoroids—the parent comet suffered little or no effect from perturbations by this planet.

A meteoroid-Earth orbital separation of 0.0026 AU in 1999 would certainly seem to imply a more enhanced/intense form of meteor activity. Indeed, such a distance is slightly less than the 1966 C-E value of 0.0031 AU and just twice the 1833 C-E value of 0.0013 AU. Following along these lines, one might even be tempted to consider a meteor rate on the order of tens of thousands per hour. Unfortunately, we know very little about whether this presumed perturbation will have either an advantageous or adverse effect on the distribution of the individual particles: they might have a tendency to "clump" closer together, perhaps resulting in a very intense, albeit very short-lived display. In the great meteor storm of 1966, single-observer meteor rates rose from roughly 40 per hour to perhaps 40 per second over a span of about 2½ hours. Could the 1999 Leonids produce an even faster rise to their maximum? On the other hand, although the entire particle mass has apparently been moved closer to Earth, is it possible that the individual particles themselves have somehow ended up becoming more widely dispersed?

[18] On January 21, 1867, Urbain J.J. Le Verrier published a report in the French journal *Comptes Rendus* suggesting that the swarm of particles responsible for the Leonids entered the Solar System for the very first time in AD 126. They supposedly arrived at a point near to where the planet Uranus was then situated, and that it was this planet which transformed the original parabolic orbit into an elliptical one. In the Yeomans et al. paper, the motion of 55P/Tempel-Tuttle was integrated back to before AD 126 demonstrating that there was no unusually close approach to Uranus.

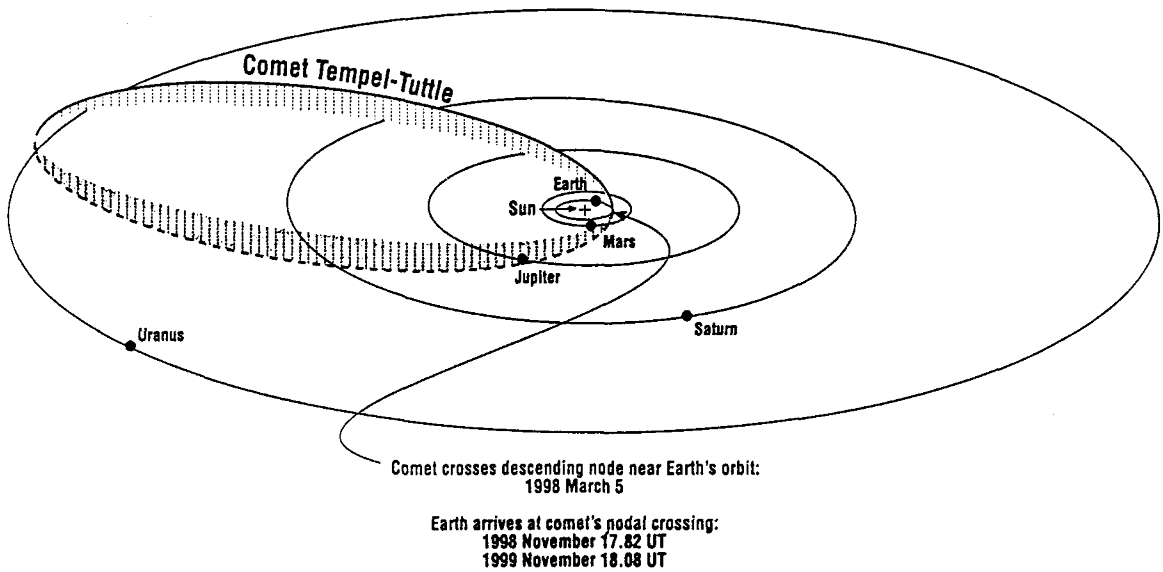


Figure 5 – The orbit of Comet 55P/Tempel-Tuttle. The orbit of the comet is tilted roughly 17° with respect to Earth's orbit. The comet passes closest to the Earth's orbit as it descends through the Earth's orbital plane just inside (sunward) to the Earth's orbit. Annually, when the Earth reaches this position closest to the comet's descending node, a Leonid shower usually is observed. The time of day when the Earth reaches that nodal crossing point can help to determine in what region on Earth the Leonids at their peak might be visible. Diagram from *The Heavens on Fire—The Great Leonid Meteor Storms* by Mark Littmann (Cambridge University Press, 1998).

11. This show(er) may be later than we think!

Another important question that needs to be answered is "When might the 1999 Leonids reach their peak?" According to Rainer Arlt, the "background component" of the 1998 Leonids apparently reached a maximum of 340 meteors per hour on November 17 at 1^h40^m UT. This was a full 18 hours prior to the time when the Earth crossed the node of 55P/Tempel-Tuttle. The "storm component" of the shower was later detected as having peaked at 180 meteors per hour on November 17 at 20^h30^m UT, or just 50 minutes after Earth crossed the comet node. Since we are most interested in the situation regarding the storm component in 1999, two methods were used in an attempt to anticipate when the most likely time of its maximum activity will be achieved. A fresh ejection of meteoroids from 55P/Tempel-Tuttle is most likely to be found—at least during its first several revolutions around the Sun—interacting with Earth rather near to the comet's nodal crossing point. With the passage of time and after many more revolutions, particle dispersion and planetary perturbations begin to take their toll, causing the particles to merge into the background component as well as causing Earth to encounter the meteoroids many hours earlier or later from the scheduled nodal crossing time. The background component of the 1998 Leonids provided an excellent example of this.

The first method that was employed to determine the time of the Leonid maximum was to refer to its solar longitude. Our calendar month and day do not specify the Earth's position in its orbit unambiguously, but the celestial longitude of the Sun ($\lambda_\odot$) does. Hence, meteor astronomers habitually use this (referred to the equinox of 2000.0) instead of dates, when they are computing meteor rates observed in different years. So far as the Leonids are concerned, the longitude of the storm component peak has gradually shifted from 1996 with $\lambda_\odot = 235\overset{\circ}{.}17$[19] and 1997 with $\lambda_\odot = 235\overset{\circ}{.}22$ to 1998 with $\lambda_\odot = 235\overset{\circ}{.}31$. Using simple extrapolation from these three locations,

[19] In a 1996 study ("Dynamics of the Leonid Meteoroid Stream: a Numerical Approach"), Peter Brown and Jim Jones simulated the evolution of the Leonid stream via numerical integration of 3 million test particles ejected

seems to indicate that in 1999 the storm component might peak near $\lambda_\odot = 235.^\circ38$. This would correspond to November 18 at 4^h17^m UT or 2 hours and 30 minutes after the Earth crosses the comet node. There also seems to be a distinct relationship concerning the C-E distance and the occurrence of past maximum activity of the Leonids, at least in the case of meteor trails only one or two revolutions old. Table 5 lists pertinent data concerning C-E distances along with the dates and times of nodal crossings of three previous storm scenarios (1833, 1866, and 1966).

Table 5 – C-E distance versus nodal crossing and maximum activity times.

Nodal crossing date	C-E	Node crossing	Max. activity	Time difference
Nov 13, 1833	0.0013 AU	10^h20^m UT	10^h20^m UT	0 minutes
Nov 14, 1866	0.0065 AU	00^h20^m UT	01^h20^m UT	+60 minutes
Nov 17, 1966	0.0033 AU	06^h20^m UT	06^h55^m UT	+35 minutes
Nov 18, 1999	0.0080 AU	01^h50^m UT	03^h00^m UT?	+70 minutes?

The year 1999 would mark the third revolution around the Sun and the second Earth encounter for the 1899 ejecta. The 1999 C-E value is 0.0080 AU, which, if following along the same lines of 1833, 1866, and 1966, suggests peak Leonid activity will be attained roughly 70 minutes after the nodal crossing. However, as noted earlier, Uranus may have perturbed the particles that produced the 1966 Leonids to bring them much closer to the Earth's orbit, with an M-E distance of 0.0026 AU. Acting on a suggestion from Donald Yeomans, I performed a forward integration for the observed storm component from the year 1965 and found that those meteoroids passed to within 1.25 AU of Uranus in March 1982. The M-E value for 1998 was determined to be 0.0057 AU, having peaked 47 minutes after the Earth arrived at the comet node. If we follow along this same distance/time relationship for 1999, an M-E of 0.0026 AU indicates peak activity will come 21 minutes after the nodal crossing at 2^h08^m UT on November 18. Interestingly, from his own independent study of past Leonid meteor trails, David Asher has come up with the exact same time for the peak of the 1999 storm component! ($\lambda_\odot = 235.^\circ29$). Combining these two solutions suggests that the 1999 Leonids will be somewhat late in attaining their maximum activity—late at least relative to the Earth's scheduled arrival at the comet nodal crossing point (November 18, 1^h47^m UT). The "window" for this year's peak seems destined to fall in a 129-minute interval between 2^h08^m and 4^h17^m UT on November 18, or 21 to 150 minutes after the time of nodal crossing.

12. A glancing blow for eastern North America?

Interestingly, if the shower does indeed peak near 4^h17^m UT, there is a possibility that those living near and along the east coast of North America could see some enhanced Leonid activity (Figure 7). This would be by virtue of visibility of so-called Earth-grazing meteoroids. These are meteoroids which skim through our atmosphere along a path nearly tangential to that of the Earth. They are seen when the shower radiant is either very near to, or just below the local horizon. Such meteors appear to take much-longer paths across the sky compared to when the radiant is much higher up. In this particular case, viewers might see a number of very long streaks clearly emanating from out of the east-northeast horizon. George Zay notes that that the eastern United States *"... would have a fighting chance to see a good number of Earth skimmers. I would expect a few to show up... both bright and dim meteors traveling a long way..."* Echoing Zay's sentiments is Robert Lunsford, who says, *"If I were staying in North America, I would certainly recommend that you observe from a location as far east as possible, with a good history*

from 55P/Tempel-Tuttle during five perihelion passages of that comet. Their model suggested that the material causing enhanced activity for 1998–2000 would be most concentrated about nodal longitude $235.^\circ16 \pm 0.^\circ04$. While this certainly seemed true for 1996, it appears from analysis of the 1997 and 1998 showers that the location of the storm component has shifted forward in time since 1996 by approximately $0.^\circ07$ per year.

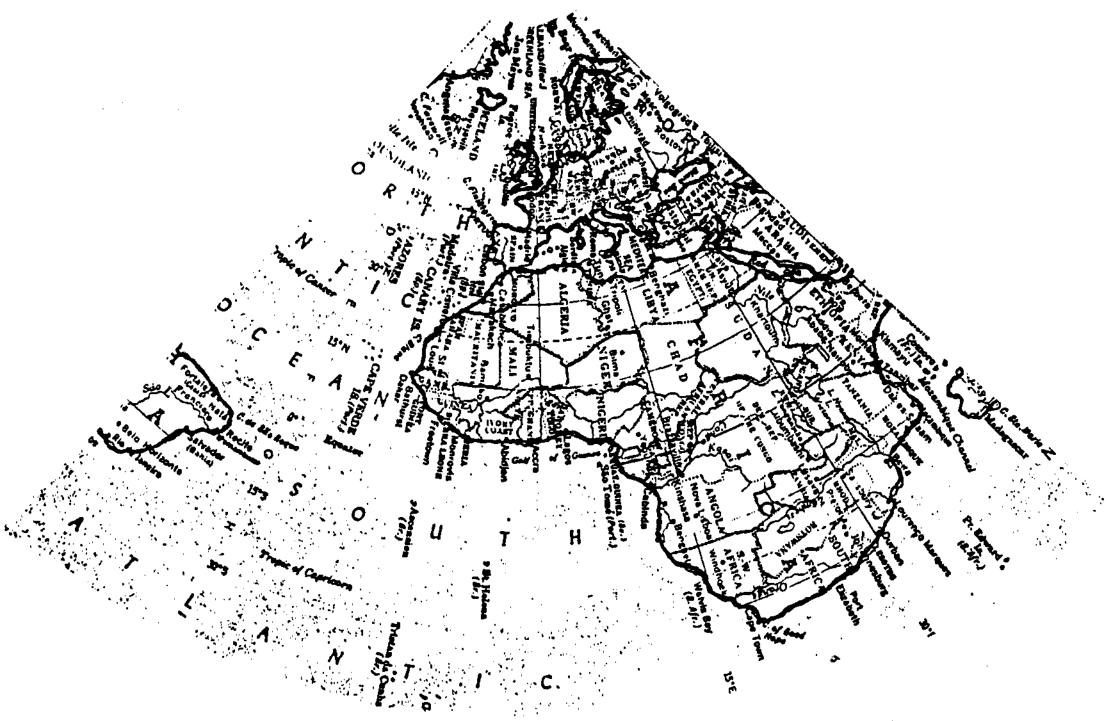


Figure 6 – Assumed regions of visibility for the maximum of the 1999 Leonid Meteors. Quadrants are based on times of 2^h08^m UT on November 18, 1999 (this figure) and 4^h17^m UT (Figure 7). Much of Europe, as well as northern Africa seem to be in the prime viewing zone, although an error of several hours either side of the anticipated time could easily bring parts of Asia or North America into position for good viewing. Should the latter time verify, there would also be a *chance* that people in parts of eastern North America could glimpse a number of meteors sporting unusually long trails (Earth-grazers) emanating from the Leonid radiant at or near the east-northeast horizon late on the corresponding evening of November 17. Map taken from *Hammond World Atlas*, New Perspective Edition, 1967, Maplewood, N.J.

of clear skies." Norman McLeod (*American Meteor Society*) notes that, should peak activity be appreciably delayed, *"... the sky ought to have a continuous show of Earth-grazing Leonids in view from the eastern states. Considering that each Earth-grazer typically lasts 3 to 6 seconds, there ought to be more than one visible at any instant for a while."* Prospective East Coast residents who are hoping to catch a part of the Leonid peak should take special note that the radiant would be rising out of the east-northeast at around 23^h (11^h p.m.) EST on the late evening of November *17* as opposed to the morning hours of November *18* for Europe. Also, the bright waxing Moon will still be well above the west-southwest horizon.

13. Conclusion

> *"A projection of these calculations into the future gives cheering results... on the 18th of November, 1999, we should run smack into the middle of the same stream that produced the great shower of 1966."*
>
> Edward K.L. Upton, UCLA, May 1977 *Griffith Observer*

Based upon all circumstantial and empirical evidence, it would appear at first glance that the Leonids should be unusually active in 1999. However, the actual level of this activity is still open to debate. There are those like Peter Brown and Jim Jones of the University of Western Ontario who are suggesting a heavy Leonid shower for this year. Peter Jenniskens of NASA's *Ames Research Center* says, *"I am optimistic... we may get rates as high as 7000 per hour or so."* David Asher's study of meteor trails for three-revolution ejected particles from 55P/Tempel-Tuttle demonstrates that 1999 compares quite favorably to the one-revolution storm of 1833 and two-revolution storm of 1966. Meanwhile, there are others, like Zidian Wu and Iwan P. Williams in Great Britain, who are standing by their prediction that *"only a few Leonids will be seen."*

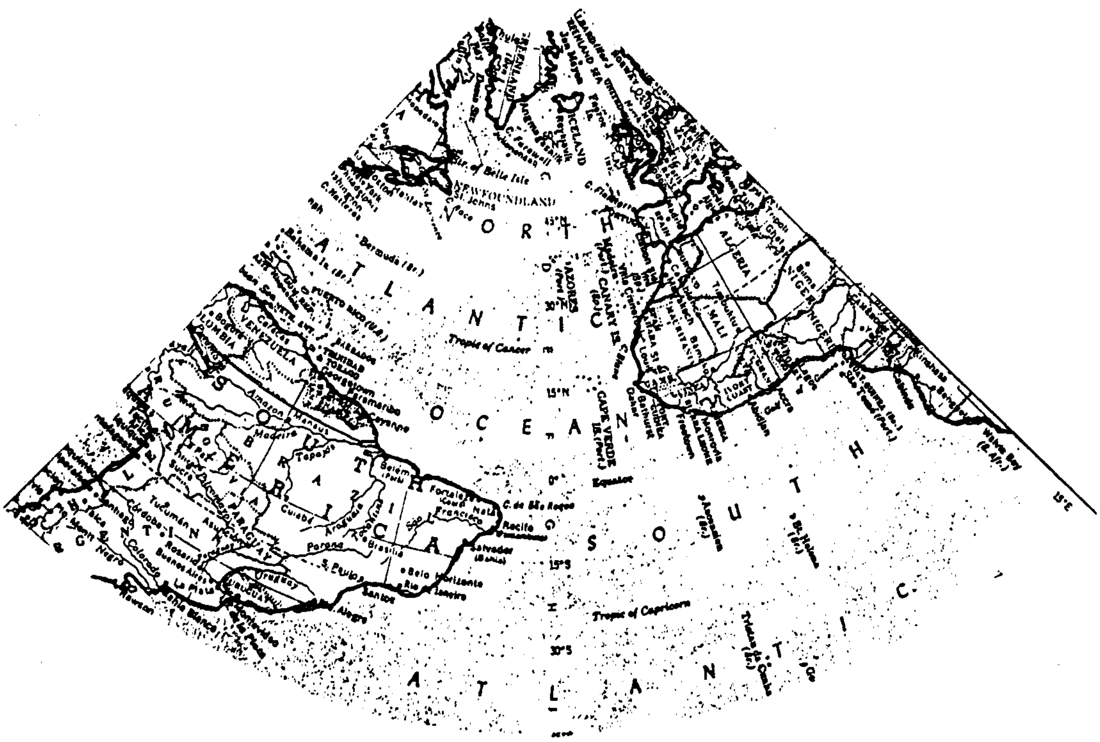


Figure 7 – Assumed regions of visibility for the maximum of the 1999 Leonid Meteors (cf. Figure 6). The shown is based on the time of November 18, 1999, 4^h17^m UT.

Echoing Franklin's thoughts from 1966, I personally will only go so far as to say—with guarded optimism—that the 1999 Leonids certainly have the potential to put on an "interesting display." If so, much of Europe and Northern Africa apparently will have ringside seats for it (see Figure 6). However, ...so far as my other comment made in the March 1999 *Sky and Telescope* about observers worldwide being entered in a 1999 "Leonid Lottery," there is still some merit in that as well. Another famous periodic shower, the Giacobinids, surprised one and all in 1998 by arriving at their maximum some 4 to 8 hours earlier than the most reliable projections had indicated.[20] Were this to happen with this year's Leonids, it would mean that the best show would shift toward eastern Asia and Australia. If they are to peak 4 to 8 hours late, then much of North America would get a shot at them. On paper, the odds are weighed against either of these scenarios actually happening, but meteor displays do not occur on paper! Indeed, it is always risky business to come out and make any definite predictions concerning any meteor shower, especially one with a history of being so unpredictable as the Leonids. As Donald Yeomans noted several years ago:

> *"That's the way it usually is with the Leonids... you can say 'probably,' but if you say 'definitely,' they'll get you every time!"*

Good luck and clear skies to you all!

Acknowledgments

I would like to thank the following individuals for reading the original manuscript and making very helpful comments and suggestions: David J. Asher, Armagh Observatory, Armagh, Northern Ireland; John E. Bortle, W.R. Brooks Observatory, Stormville, NY; Edward M. Brooks, Boston College, Boston, MA; Peter Jenniskens, NASA/Ames Research Center, Moffett Field, CA; and Donald E. Yeomans, NASA/Jet Propulsion Laboratory, Pasadena, CA.

[20] Earth was predicted to cross the descending node of 21P/Giacobini-Zinner at 20^h53^m UT on October 8, 1998. Factoring in a correction based on observations of the Giacobinids in 1985 suggested the peak would perhaps occur closer to 17^h15^m UT. In actuality, the peak was observed to occur at 13^h10^m UT. It should be noted, however, that a last-minute prediction by E.A. Reznikov of Russia, apparently issued over the Internet less than a month prior to the occurrence of the Giacobinids, was on target in suggesting a peak on October 8.55 (13^h12^m UT).

References

[1] R. Arlt, "Bulletin 13 of the International Leonid Watch: The 1998 Leonid Meteor Shower", *WGN* 26:6, December 1998, pp. 239–248.

[2] D.J. Asher, "The Leonid meteor storms of 1833 and 1966", *Mon. Not. R. Astron. Soc.*, 1999, in press.

[3] D.J. Asher, M.E. Bailey, V.V. Emel'yanenko, "Resonant meteoroids from Comet Tempel-Tuttle in 1333: the cause of the unexpected Leonid outburst in 1998", *Mon. Not. R. Astron. Soc.* 304, 1999, pp. L53–L56.

[4] P. Brown, J. Jones, "Evolution of the Leonid Meteor Stream", University of Western Ontario, London, Ontario, 1992.

[5] P. Brown, J. Jones, "Dynamics of the Leonid Meteoroid Stream: a Numerical Approach", in *Physics, Chemistry, and Dynamics of Interplanetary Dust*, ASP Conference Series, Vol. 104, 1996.

[6] K.L. Franklin, *personal communications*, 1998, 1999.

[7] Kresák, Ľ., "Meteor Storms", in *Meteoroids and Their Parent Bodies*, J. Štohl and I.P. Williams, eds., Astronomical Institute of the Slovak Academy of Sciences, Bratislava, 1993, pp. 147–156.

[8] G.W. Kronk, "Comets—A Descriptive Catalog", Enslow Publishers, Hillside, N.J., 1984.

[9] G.W. Kronk, "Meteor Showers—A Descriptive Catalog", Enslow Publishers, Hillside, N.J., 1988.

[10] M. Littmann, "The Heavens on Fire—The Great Leonid Meteor Storms", Cambridge University Press, 1998.

[11] A.C.B. Lovell, "Meteor Astronomy", Oxford University Press (Clarendon), London, 1954.

[12] R. Lunsford, *personal communications*, 1999.

[13] B.G. Marsden, *personal communications*, 1999.

[14] N.W. McLeod, *personal communications*, 1999.

[15] J. Rao, "The Leonids: King of the Meteor Showers", *Sky and Telescope* 90:5, October 1995, pp. 24–31; see also *WGN* 23:4, August 1995, pp. 120–135.

[16] J. Rao, "The Leonids' Last Hurrah?", *Sky and Telescope* 92:5, October 1996, p. 76.

[17] J. Rao, "The Return of the Leonid Meteors", *Sky and Telescope* 96:5, October 1998, pp. 38–44.

[18] J. Rao, "Prospects for Two Upcoming Period Meteor Showers", *WGN* 26:5, October 1998, pp. 192–216.

[19] J. Rao, "Awaiting the Storm", *Sky and Telescope* 97:3, March 1999, pp. 48–50.

[20] P. Roggemans, "Handbook for Visual Meteor Observations", Sky Publishing Corporation, Cambridge, Massachusetts, 1989.

[21] E.K.L. Upton, "The Leonids Were Dead, They Said", *Griffith Observer* 41:5, 1977, pp. 5–9.

[22] Z. Wu, I.P. Williams, "Leonid Meteor Storms", *Mon. Not. R. Astron. Soc.* 280, 1996, pp. 1210–1218.

[23] D.K. Yeomans, "Comet Tempel-Tuttle and the Leonid Meteors", *Icarus* 47, 1981, pp. 492–499.

[24] D.K. Yeomans, "Comets—A Chronological History of Observation, Science, Myth, and Folklore", John Wiley and Sons, 1991.

[25] D.K. Yeomans, K.K. Yau, P.R. Weissman, "The Impending Appearance of Comet Tempel-Tuttle and the Leonid Meteors", *Icarus* 124, 1996, pp. 407–413.

[26] G. Zay, *personal communications*, 1999.

A Double-Station Video Look on the October Meteor Showers

Marc de Lignie and Hans Betlem

Double-station video observations in the Netherlands on October 21-22, 1995, resulted in 67 orbits, among which 32 Orionids, 4 Southern Taurids, and 3 Leo Minorids. For the Orionid radiant, new values for the radiant motion are derived that are argued to be more plausible than the existing literature values. Little structure is present in the Orionid radiant, although its width is shown to increase for small particles. As in other video samples around October, the ε-Geminids are not present, and it is concluded that the activity of this shower must be lower than currently believed from visual observations. On the other hand, the Leo Minorids were clearly present, and new values for their radiant position and motion are proposed.

1. Introduction

After the successful video observations of the 1993 Orionids [1], people from the *Dutch Meteor Society* were eager to further extend the coverage of this stream. Their next chance occurred in the night of October 21-22, 1995, when Klaas Jobse set up his video equipment under a clear sky in Oostkapelle ($\lambda = 3°33'$ E, $\varphi = 51°34'$ N, $h = 0$ m), Jaap van 't Leven in Bosschenhoofd ($\lambda = 4°33'$ N, $\varphi = 51°34'$, $h = 4$ m), and Hans Betlem in Ratum ($\lambda = 6°48'$, $\varphi = 51°58'$, $h = 41$ m). During 7 hours of observing, they recorded 67 meteors in such a way that orbital elements could be determined.

Below, the results of these observations are presented and the consequences for the "general facts" of the Orionid, ε-Geminid, and Leo Minorid streams are indicated. The Taurids are left for a later analysis.

2. Observations and data reduction

The three cameras that were used consist of second-generation type image intensifiers, $f/1.2$, 55 mm or 85 mm photo objectives and Hi-8 camcorders. The field of view of these cameras is about 25°, and the limiting magnitude for stars is about +8, and for double-station meteors about +6. The three cameras were pointed at a common point in the atmosphere, about 100 km above the Earth's surface.

The data reduction was done with the AstroRecord measuring program and with the Ondřejov software for calculating trajectories and orbital elements. The exact procedure is described in more detail in [2].

The results are listed in Table 1 and Table 2. In Table 3, estimates for the video ZHR are given, according to

$$\mathrm{VZHR} = \frac{N}{N_{\mathrm{Spor}}} \frac{3.4^{\Delta m}}{\sin h_{\mathrm{rad}}} \mathrm{HR}; \tag{1}$$

$$\mathrm{HR} = 10 + 1.5\cos(230° - \lambda_{\odot}); \tag{2}$$

$$\Delta m = \left(1 - \frac{\log r}{\log 3.4}\right) (\overline{m}_{\mathrm{Spor}} - 3.24). \tag{3}$$

These equations assume that the visual sporadic HR is given by equation (2), and that the sporadic background at a limiting magnitude of +6.5 is characterized by an average visual magnitude of +3.24 and a population index of 3.4. Equation (3) corrects for the effect that, for limiting magnitudes higher than +6.5, the number of sporadic meteors increases faster than the number of shower members.

Table 1 – Orbital elements (J2000.0) of 32 Orionid, 4 Southern Taurid, 3 Leo Minorid, and 28 sporadic meteoroids. The header `node` is short for the longitude of the ascending node and `w` indicates the argument of the perihelion. The data are available in electronic form on `http://home.wxs.nl/~dms-web/` and `http://www.imo.net/video`.

code	day	str	Mv	q	tol	a	1/a	tol	e	tol	i	tol	w	tol	node	pi	tol
95352	21.9339	Ori	3	0.558	0.014	7.2	0.139	0.06	0.923	0.032	164.2	0.8	85.2	2.6	28.1	113.3	2.6
95354	21.9571	Ori	3	0.562	0.014	7.5	0.133	0.06	0.925	0.032	164.7	0.5	84.6	2.5	28.1	112.7	2.5
95355	21.9839	Ori	3	0.574	0.013	18.6	0.054	0.06	0.969	0.035	165.0	0.6	82.0	2.4	28.2	110.1	2.4
95356	21.9873	Ori	3	0.582	0.014	57.3	0.017	0.07	0.990	0.042	165.4	0.6	80.5	2.7	28.2	108.7	2.7
95358	21.9898	Ori	3	0.578	0.015	9.6	0.104	0.07	0.940	0.038	165.2	1.6	82.3	2.8	28.2	110.5	2.8
95361	22.0104	Ori	4	0.521	0.019	9.5	0.105	0.08	0.945	0.042	172.1	1.1	88.9	3.5	28.2	117.1	3.5
95363	22.0129	Ori	3	0.579	0.015	13.9	0.072	0.06	0.958	0.036	164.9	1.0	81.6	2.6	28.2	109.8	2.6
95389	22.0646	Ori	5	0.542	0.017	4.9	0.203	0.07	0.890	0.034	165.6	0.6	88.2	3.1	28.2	116.4	3.1
95393	22.0756	Ori	3	0.581	0.013	19.2	0.052	0.06	0.970	0.036	163.8	0.6	81.1	2.4	28.2	109.3	2.4
95397	22.0844	Ori	4	0.555	0.014	7.7	0.130	0.06	0.928	0.031	163.2	0.7	85.4	2.5	28.3	113.7	2.5
95399	22.0912	Ori	3	0.525	0.016	5.5	0.180	0.06	0.905	0.031	161.7	0.7	89.6	2.9	28.3	117.9	2.9
95404	22.0960	Ori	2	0.593	0.013	-82.2	-0.012	0.06	1.007	0.038	164.7	0.5	78.8	2.3	28.3	107.1	2.3
95406	22.0973	Ori	4	0.591	0.014	14.3	0.070	0.07	0.959	0.039	164.5	0.6	80.2	2.6	28.3	108.4	2.6
95407	22.0985	Ori	4	0.614	0.012	14.8	0.068	0.06	0.958	0.037	165.8	0.2	77.5	2.4	28.3	105.7	2.4
95410	22.1001	Ori	4	0.675	0.022	9.4	0.106	0.07	0.928	0.045	160.5	1.0	70.6	3.1	28.3	98.9	3.1
95413	22.1061	Ori	4	0.588	0.013	12.1	0.082	0.06	0.952	0.035	163.9	0.3	80.8	2.4	28.3	109.1	2.4
95419	22.1190	Ori	4	0.626	0.011	-7.7	-0.130	0.07	1.081	0.043	166.1	0.9	73.4	2.1	28.3	101.7	2.1
95426	22.1270	Ori	4	0.556	0.016	9.2	0.108	0.06	0.940	0.034	163.6	0.6	84.9	2.7	28.3	113.2	2.7
95434	22.1397	Ori	3	0.594	0.012	-35.9	-0.028	0.06	1.017	0.038	163.7	0.6	78.5	2.3	28.3	106.8	2.3
95435	22.1428	Ori	4	0.555	0.015	4.9	0.204	0.06	0.887	0.030	163.3	0.5	86.6	2.7	28.3	114.9	2.7
95441	22.1527	Ori	3	0.594	0.013	17.1	0.058	0.06	0.965	0.036	164.6	0.6	79.7	2.4	28.3	108.0	2.4
95444	22.1598	Ori	5	0.553	0.033	20.2	0.049	0.15	0.973	0.079	163.3	1.7	84.4	5.7	28.3	112.7	5.7
95445	22.1611	Ori	1	0.604	0.012	-13.8	-0.072	0.06	1.044	0.040	163.9	0.6	76.7	2.2	28.3	105.0	2.2
95446	22.1617	Ori	5	0.569	0.013	7.4	0.136	0.06	0.923	0.032	163.9	0.6	83.8	2.5	28.3	112.2	2.5
95448	22.1656	Ori	4	0.599	0.022	9.1	0.110	0.11	0.934	0.062	163.4	0.3	79.9	4.3	28.3	108.2	4.3
95452	22.1716	Ori	4	0.581	0.015	27.5	0.036	0.07	0.979	0.042	163.1	0.6	80.9	2.8	28.3	109.2	2.8
95455	22.1731	Ori	6	0.668	0.018	5.7	0.174	0.09	0.884	0.055	168.3	0.6	72.6	3.6	28.3	100.9	3.6
95459	22.1790	Ori	4	0.572	0.013	17.3	0.058	0.06	0.967	0.034	162.8	0.6	82.2	2.4	28.4	110.6	2.4
95461	22.1800	Ori	2	0.614	0.012	25.7	0.039	0.06	0.976	0.038	164.7	0.3	77.0	2.3	28.4	105.4	2.3
95464	22.1871	Ori	2	0.570	0.014	8.0	0.125	0.06	0.929	0.033	163.9	0.5	83.5	2.5	28.4	111.9	2.5
95467	22.1905	Ori	0	0.618	0.017	-25.5	-0.039	0.09	1.024	0.058	164.5	0.6	75.5	3.2	28.4	103.9	3.2
95478	22.2073	Ori	3	0.617	0.013	8.0	0.125	0.06	0.923	0.036	165.6	0.6	78.0	2.5	28.4	106.4	2.5
95370	22.0296	S-Tau	5	0.411	0.011	1.6	0.635	0.03	0.739	0.020	4.6	0.5	112.5	0.6	28.2	140.7	0.6
95381	22.0478	S-Tau	5	0.409	0.005	1.5	0.686	0.01	0.719	0.009	3.5	0.3	114.1	0.3	28.2	142.3	0.3
95385	22.0556	S-Tau	3	0.286	0.005	1.5	0.660	0.02	0.811	0.007	6.4	0.5	126.2	0.4	28.2	154.4	0.4
95411	22.1006	S-Tau	5	0.503	0.005	3.4	0.292	0.02	0.853	0.011	5.7	0.3	94.2	0.6	28.3	122.5	0.6
95414	22.1077	LMi	5	0.621	0.010	-365.9	-0.003	0.06	1.002	0.035	125.7	0.5	104.4	1.9	208.3	312.7	1.9
95465	22.1887	LMi	0	0.586	0.017	219.0	0.005	0.06	0.997	0.033	126.1	0.9	100.1	2.6	208.4	308.5	2.6
95476	22.1991	LMi	5	0.614	0.028	20.1	0.050	0.06	0.969	0.034	126.0	1.5	102.8	3.9	208.4	311.1	3.9
95357	21.9880	Spo	4	0.741	0.049	3.4	0.296	0.25	0.781	0.174	142.7	2.0	65.3	11.6	28.2	93.5	11.6
95367	22.0219	Spo	4	0.856	0.004	2.5	0.408	0.02	0.651	0.020	6.7	0.5	229.8	0.7	208.2	78.0	0.7
95372	22.0325	Spo	4	0.917	0.012	3.0	0.335	0.10	0.693	0.090	113.9	1.1	216.2	3.9	208.2	64.4	3.9
95383	22.0517	Spo	4	0.993	0.000	6.5	0.154	0.07	0.847	0.066	171.9	0.3	174.3	0.5	208.2	22.6	0.5
95384	22.0547	Spo	3	0.974	0.002	2.5	0.394	0.05	0.616	0.053	78.8	0.9	199.5	1.2	208.2	47.7	1.2
95400	22.0919	Spo	3	0.649	0.006	2.8	0.352	0.02	0.771	0.014	12.5	0.5	258.4	0.9	208.3	106.7	0.9
95401	22.0922	Spo	5	0.953	0.007	17.8	0.056	0.10	0.946	0.093	128.5	1.4	24.1	2.4	28.3	52.3	2.4
95402	22.0925	Spo	4	0.963	0.004	4.3	0.231	0.03	0.778	0.033	30.7	0.6	157.7	1.4	208.3	5.9	1.4
95405	22.0964	Spo	4	0.389	0.033	-6.1	-0.164	0.17	1.064	0.073	161.5	1.3	280.5	5.9	208.3	128.7	5.9
95409	22.0995	Spo	4	0.901	0.002	5.2	0.191	0.02	0.828	0.019	17.7	0.3	217.8	0.4	208.3	66.1	0.4
95412	22.1054	Spo	3	0.791	0.009	3.4	0.296	0.06	0.766	0.041	144.6	0.3	58.3	2.4	28.3	86.6	2.4
95416	22.1137	Spo	4	0.901	0.010	2.9	0.348	0.09	0.687	0.081	148.0	0.9	39.9	3.5	28.3	68.2	3.5
95420	22.1195	Spo	4	0.154	0.005	4.4	0.226	0.04	0.965	0.008	38.4	1.6	316.1	0.7	208.3	164.4	0.7
95422	22.1204	Spo	3	0.551	0.006	9.7	0.103	0.03	0.943	0.019	70.1	0.6	94.6	1.1	208.3	302.9	1.1
95424	22.1266	Spo	2	0.936	0.004	288.5	0.003	0.06	0.997	0.058	130.8	0.6	151.7	1.3	208.3	0.0	1.3
95425	22.1267	Spo	4	0.767	0.018	6.8	0.148	0.12	0.887	0.089	149.2	0.6	239.2	4.3	208.3	87.5	4.3
95428	22.1298	Spo	2	0.989	0.001	-85.7	-0.012	0.07	1.012	0.070	176.2	0.4	189.3	0.7	208.3	37.6	0.7
95429	22.1314	Spo	3	0.850	0.020	3.5	0.284	0.15	0.758	0.121	139.2	1.1	131.5	5.8	208.3	339.8	5.8
95430	22.1316	Spo	4	0.628	0.012	-20.1	-0.050	0.07	1.031	0.042	147.9	0.5	74.2	2.2	28.3	102.5	2.2
95438	22.1509	Spo	3	0.991	0.001	6.5	0.154	0.06	0.848	0.059	138.7	0.5	352.3	0.8	28.3	20.6	0.8
95450	22.1659	Spo	3	0.957	0.662	1.0	1.012	0.30	0.032	0.376	0.2	5.0	285.4	60.0	208.4	133.8	60.0
95457	22.1755	Spo	4	0.878	0.017	2.4	0.415	0.12	0.636	0.102	144.1	1.0	45.8	5.8	28.3	74.2	5.8
95466	22.1894	Spo	-1	0.923	0.004	6.6	0.151	0.07	0.861	0.060	169.5	0.5	147.4	1.6	208.4	355.7	1.6
95472	22.1955	Spo	4	0.833	0.007	-243.9	-0.004	0.07	1.003	0.057	177.7	0.1	47.6	1.8	28.4	76.0	1.8
95473	22.1959	Spo	1	0.993	0.000	-23.9	-0.042	0.07	1.042	0.073	147.2	0.3	174.3	0.4	208.4	22.7	0.4
95475	22.1984	Spo	4	0.982	0.006	1.3	0.742	0.13	0.272	0.122	158.9	1.7	20.5	8.4	28.4	48.9	8.4
95477	22.2066	Spo	1	0.373	0.010	-110.3	-0.009	0.05	1.003	0.019	122.2	0.8	104.4	1.9	28.4	132.8	1.9
95479	22.2087	Spo	4	0.370	0.032	0.9	1.078	0.05	0.601	0.021	97.6	2.0	47.7	4.4	208.4	256.1	4.4

Table 2 – Trajectory data (J2000.0) of 32 Orionid, 4 Southern Taurid, 3 Leo Minorid, and 28 sporadic meteoroids. Here, Nst is the number of stations that recorded the meteor, Z is the zenith distance of the radiant, and Qmax is the largest intersection angle between the meteor trails.

code	VG	VH	VINF	<V>	tol	Hb	Hmax	He	RA	tol	DE	tol	RAG	DEG	Nst	cos Z	Qmax
95352	65.7	40.7	66.9	66.7	0.7	119.1	111.6	103.2	94.39	0.28	16.36	0.35	94.77	15.97	2	0.278	12
95354	65.8	40.8	67.0	66.9	0.7	113.1	104.3	94.7	94.63	0.18	16.56	0.24	94.93	16.21	2	0.368	32
95355	66.7	41.7	67.8	67.7	0.7	118.5	104.1	94.0	94.58	0.13	16.56	0.27	94.79	16.26	2	0.459	40
95356	67.1	42.0	68.3	68.1	0.8	115.7	110.4	99.2	94.63	0.09	16.70	0.29	94.82	16.41	2	0.473	45
95358	66.3	41.1	67.5	67.3	0.8	116.1	112.4	105.3	95.12	0.11	16.65	0.77	95.32	16.35	2	0.475	13
95361	65.9	41.1	67.1	66.9	0.9	117.9	108.8	103.6	93.57	0.08	20.04	0.49	93.69	19.80	2	0.595	18
95363	66.6	41.5	67.7	67.6	0.7	114.5	106.0	95.6	95.01	0.40	16.47	0.48	95.14	16.20	3	0.550	46
95389	65.0	40.0	66.1	66.0	0.8	112.5	105.4	96.5	94.98	0.16	16.95	0.26	94.96	16.70	2	0.698	79
95393	66.7	41.7	67.8	67.6	0.7	129.1	105.5	94.9	95.10	0.24	15.90	0.27	95.05	15.66	3	0.706	59
95397	65.7	40.8	66.7	66.6	0.7	114.0	106.0	100.8	94.75	0.14	15.81	0.33	94.67	15.56	2	0.726	32
95399	64.8	40.3	65.8	65.7	0.7	114.4	110.6	101.2	94.05	0.16	15.31	0.32	93.96	15.05	2	0.734	58
95404	67.4	42.3	68.5	68.3	0.7	116.0	99.7	94.4	95.18	0.18	16.23	0.25	95.07	16.00	2	0.750	87
95406	66.7	41.5	67.7	67.6	0.7	114.9	105.9	96.6	95.72	0.10	16.17	0.29	95.61	15.93	2	0.750	38
95407	67.1	41.5	68.1	67.9	0.7	115.5	106.0	99.0	96.60	0.06	16.63	0.07	96.50	16.40	3	0.750	70
95410	67.0	41.1	68.1	67.9	0.7	98.7	94.4	90.3	98.67	0.88	13.67	0.49	98.58	13.41	2	0.715	46
95413	66.5	41.3	67.5	67.4	0.7	115.9	105.3	99.2	95.67	0.10	15.92	0.13	95.54	15.68	3	0.757	69
95419	68.9	43.6	69.9	69.8	0.7	110.6	104.8	99.5	95.80	0.13	16.74	0.43	95.64	16.52	2	0.784	33
95426	65.9	41.1	66.9	66.7	0.7	116.0	108.5	98.6	94.81	0.41	15.96	0.24	94.63	15.71	2	0.790	56
95434	67.5	42.5	68.5	68.3	0.7	112.1	103.2	94.9	95.17	0.11	15.76	0.28	94.97	15.52	2	0.797	79
95435	65.0	40.0	66.0	65.8	0.7	112.9	104.7	97.2	95.57	0.23	15.81	0.20	95.36	15.55	2	0.801	79
95441	66.8	41.6	67.8	67.6	0.7	115.1	103.9	93.6	95.91	0.14	16.20	0.27	95.68	15.95	2	0.809	85
95444	66.3	41.7	67.3	67.1	1.6	116.3	109.6	101.3	94.31	0.61	15.87	0.79	94.06	15.62	3	0.807	87
95445	68.0	43.0	69.0	68.8	0.7	123.0	100.5	96.6	95.32	0.09	15.80	0.29	95.08	15.56	2	0.805	34
95446	65.8	40.8	66.8	66.6	0.7	117.0	106.5	97.7	95.59	0.09	16.02	0.29	95.35	15.77	2	0.808	36
95448	66.4	41.0	67.3	67.1	1.2	118.8	112.8	95.4	96.42	0.01	15.59	0.02	96.17	15.33	3	0.804	85
95452	66.8	41.8	67.7	67.5	0.8	115.6	104.4	95.7	95.23	0.15	15.59	0.26	94.97	15.34	2	0.807	89
95455	66.9	40.4	67.8	67.6	1.0	118.1	111.9	99.0	99.75	0.11	17.55	0.28	99.50	17.32	2	0.824	43
95459	66.5	41.6	67.4	67.2	0.7	117.0	109.3	97.8	95.07	0.10	15.51	0.28	94.79	15.25	2	0.803	39
95461	67.3	41.8	68.2	68.0	0.7	116.3	105.1	94.5	96.57	0.11	16.13	0.12	96.30	15.88	3	0.812	75
95464	65.9	40.9	66.8	66.7	0.7	116.2	106.2	94.7	95.63	0.19	16.03	0.24	95.34	15.77	2	0.809	81
95467	68.0	42.6	68.8	68.7	1.0	121.4	101.2	93.1	96.17	0.23	16.00	0.30	95.88	15.75	3	0.804	84
95478	66.6	40.9	67.5	67.3	0.7	115.7	107.4	98.5	97.43	0.10	16.53	0.28	97.12	16.26	2	0.804	43
95370	24.1	34.9	26.5	26.2	0.7	97.2	94.0	90.7	39.51	0.20	12.13	0.48	38.65	10.13	2	0.766	44
95381	23.4	34.3	25.9	25.5	0.3	100.0	91.7	89.1	40.17	0.12	13.37	0.30	39.09	11.30	2	0.772	46
95385	28.0	34.6	30.1	29.8	0.3	101.7	93.1	85.3	45.77	0.10	13.37	0.43	44.98	11.88	2	0.774	38
95411	25.9	39.0	28.0	27.7	0.3	100.8	93.5	89.7	32.61	0.23	8.03	0.38	30.98	5.82	2	0.591	48
95414	62.2	42.2	63.4	63.2	0.6	118.0	108.1	98.8	158.83	0.10	36.93	0.20	159.27	36.73	3	0.504	9
95465	62.0	42.2	63.2	63.0	0.6	128.4	115.3	90.8	159.96	0.29	35.54	0.66	160.12	35.44	3	0.723	39
95476	61.8	41.7	62.9	62.8	0.6	121.7	109.3	102.5	158.88	0.23	36.57	1.23	159.00	36.49	2	0.764	16
95357	63.5	39.0	64.8	64.6	3.0	114.1	111.0	107.1	99.89	0.33	4.41	0.72	100.21	3.91	2	0.264	37
95367	13.8	37.7	17.5	17.1	0.3	86.3	82.9	80.2	0.74	0.38	22.57	1.18	356.38	17.71	2	0.730	34
95372	57.2	38.5	58.4	58.2	1.3	115.0	106.1	100.4	115.46	1.28	58.42	0.34	115.93	58.52	2	0.781	28
95383	70.3	40.6	71.4	71.3	0.7	120.4	107.8	99.9	123.17	0.10	24.86	0.18	123.38	24.66	3	0.515	29
95384	43.4	37.9	44.9	44.6	0.8	104.6	98.5	92.2	137.95	1.02	78.08	0.21	140.87	78.33	2	0.763	48
95400	21.7	38.3	24.2	23.8	0.3	97.3	87.0	82.5	17.59	0.51	28.84	0.64	15.03	26.64	3	0.730	90
95401	64.3	41.6	65.5	65.3	1.1	123.0	113.3	99.5	107.43	0.57	-6.98	0.84	107.48	-7.51	3	0.366	60
95402	21.6	39.7	24.2	23.9	0.3	101.8	96.8	95.0	251.29	1.58	51.92	1.18	252.00	46.58	3	0.236	81
95405	65.7	43.9	66.7	66.5	1.9	113.0	105.4	101.2	86.14	0.16	30.97	0.50	85.95	30.85	2	0.908	34
95409	17.6	40.2	20.6	20.2	0.3	97.8	92.5	88.5	343.61	0.34	41.01	0.44	338.70	36.81	2	0.545	18
95412	64.2	39.0	65.3	65.2	0.7	100.6	95.1	89.6	102.49	0.04	4.66	0.06	102.43	4.28	3	0.592	76
95416	65.1	38.4	66.2	66.0	1.1	111.9	105.4	102.5	108.06	0.12	5.17	0.49	108.02	4.80	2	0.584	28
95420	40.9	39.8	42.2	41.9	0.6	91.3	89.5	83.8	47.95	0.26	33.22	0.58	47.14	32.72	2	0.883	76
95422	44.5	41.1	46.1	45.8	0.5	107.3	102.9	98.8	192.09	0.13	40.31	0.28	193.25	39.52	2	0.311	22
95424	65.5	42.2	66.6	66.4	0.7	115.8	101.6	92.3	141.43	0.28	44.92	0.36	141.61	44.92	3	0.763	45
95425	66.2	40.6	67.2	67.0	1.3	112.4	101.0	95.2	104.42	0.22	39.10	0.20	104.26	39.07	3	0.931	89
95428	72.2	42.3	73.2	73.0	0.7	114.8	99.2	93.0	118.42	0.17	23.28	0.25	118.37	23.14	2	0.761	63
95429	64.0	39.1	65.2	65.0	1.8	114.1	102.4	97.5	142.16	0.32	38.08	0.42	142.34	38.01	2	0.723	23
95430	66.4	42.7	67.4	67.2	0.7	117.4	98.6	97.2	94.67	0.21	7.99	0.22	94.49	7.67	2	0.702	81
95438	66.1	40.6	67.1	67.0	0.7	111.4	100.5	96.7	118.34	0.19	-2.99	0.23	118.28	-3.43	2	0.494	82
95450	0.5	29.7	11.0	10.6	0.4	75.0	73.6	71.2	67.74	0.46	43.69	0.41	47.49	31.06	2	0.944	85
95457	63.6	37.6	64.6	64.4	1.5	97.4	94.0	90.5	107.10	0.22	3.47	0.45	106.90	3.09	2	0.655	70
95466	69.7	40.6	70.7	70.6	0.7	119.4	102.0	94.2	131.65	0.11	24.22	0.28	131.55	24.08	2	0.813	62
95472	70.6	42.3	71.4	71.3	0.7	118.8	100.5	89.2	106.12	0.04	21.57	0.04	105.87	21.39	3	0.864	71
95473	69.7	42.7	70.7	70.6	0.8	124.4	98.5	92.1	128.29	0.11	38.81	0.10	128.13	38.78	3	0.934	90
95475	62.3	33.5	63.4	63.2	1.7	110.4	107.9	100.8	116.53	0.16	10.26	0.88	116.33	9.93	2	0.733	31
95477	59.0	42.3	59.9	59.7	0.6	110.3	93.7	91.3	82.36	0.10	1.89	0.28	81.93	1.41	2	0.579	36
95479	43.8	28.7	45.4	45.1	1.1	105.6	101.9	98.0	162.15	0.32	41.82	0.94	162.50	41.68	2	0.802	20

Table 3 – Activity of the showers by comparing the number of shower members to the number of sporadic meteors.

Shower	Ori	S Tau	N Tau	ε-Gem	LMi
N	32	4	0	0	3
VZHR	16	2.0	0	0	1.1

3. Orionids

Although abundant observations of the Orionid stream are present in the literature, some controversies exist about the basic characteristics of the stream. Regarding the activity profile, Jenniskens claims a single-exponential distribution [3], while the *IMO Visual Handbook* rather finds an activity plateau as a many-year average, somewhat supported by the underlying mass-index profile [4]. In addition, enhancements in activity of the shower that just last for a day have been reported in both visual and radar observations.

Regarding the radiant position, a number of sources speak of a weaker second radiant just 3° north of the Orionid radiant [5]. For the radiant motion, the literature values vary wildly from $+0^\circ\!.65$ to $+1^\circ\!.23$ in right ascension per degree of solar longitude, and from $+0^\circ\!.06$ to $+0^\circ\!.22$ in declination [6], the most widely accepted values being $\Delta\alpha = +0^\circ\!.65$ and $\Delta\delta = +0^\circ\!.11$ based on the *IAU* photographic database.

The present observations say little about the activity profile, but can shed some light on the radiant area and motion, especially when the current sample is combined with the Orionid observations of 1993 around solar longitude $\lambda_\odot = 206^\circ$ [1]. Table 4 shows the average Orionid orbits of 1993 and 1995 as well as the orbit from photographic orbits of the *IAU* database. Although the differences are not significant in the statistical sense, there is a tendency for the 1995 video data to agree more with the photographic data, most probably because of the closer match in average ascending node.

In calculating the geocentric radiant motion from the two video samples, the independent sample of 12 Orionids in the *DMS* photographic database was used [7]. The latter data did not alter much the resulting values, but improved the overall accuracy. In the regression, 4 video meteors were removed which had radiant coordinates more than three times the standard deviation from the average. The results for equinox J2000.0 are as follows:

$$\begin{aligned} \alpha_g &= 94^\circ\!.99 + (+0^\circ\!.90 \pm 0^\circ\!.07) \times (\lambda_\odot - 208^\circ\!.00); \\ \delta_g &= +15^\circ\!.80 + (+0^\circ\!.10 \pm 0^\circ\!.04) \times (\lambda_\odot - 208^\circ\!.00). \end{aligned}$$

The specified plus and minus values follow directly from the regression analysis and assume a normal distribution of the radiant points. E.g., in a large number of ensembles of observed radiant points, 68% of the motions in right ascension would fall between $+0^\circ\!.83$ and $+0^\circ\!.97$ and 95% would fall between $+0^\circ\!.76$ and $+1^\circ\!.04$.

Table 4 – Average orbits (J2000.0) of the 1993 and 1995 samples of *DMS* video orbits compared to the orbit as derived from photographic observations.

Source	N	q	a	e	i	ω	Ω	V_g
Video 1993 [1]	17	0.598	18.9	0.970	163°9	79°3	25°8	66.8
Video 1995	32	0.585	13.0	0.956	164°5	81°1	28°3	66.6
Video average	49	0.590	14.6	0.961	164°3	80°5	27°4	66.6
Photo *IAU* [10]	27	0.575	11.5	0.951	164°3	82°7	28°9	66.3

It is not clear why the current value of the motion in right ascension is higher than found from the *IAU* database. However, it can be noticed that the current sample is twice as large as the *IAU* sample and is more homogeneous in accuracy. The accuracy of individual radiant points in the current sample can easily be assessed from Table 2 for the meteors observed from 3 stations. Here, the errors in the coordinates of the radiant are very certain, because they are derived from the differences between the three radiant points found from three possible pairs within a set of 3 meteor trails.

A theoretical way to estimate the radiant motion of a meteoroid stream is to assume that during passage of the stream all orbital elements of the stream remain constant, except for the ascending node. This model is correct when the widening of the stream through the ages occurs much faster in the ascending node than in other orbital elements. For long period streams such as the Perseids ($\Delta\alpha = +1\overset{\circ}{.}39$, $\Delta\delta = +0\overset{\circ}{.}27$) and the η-Aquarids ($\Delta\alpha = +0\overset{\circ}{.}93$, $\Delta\delta = +0\overset{\circ}{.}37$), the sister stream of the Orionids, this model works remarkably well. Therefore, this model is expected to be also applicable to the Orionid stream, for which it results in values of $+1\overset{\circ}{.}03$ in right ascension and $-0\overset{\circ}{.}04$ in declination per degree of solar longitude. Indeed, the values found from the current sample lie closer to these model values than the "old" literature values for the Orionid radiant motion.

Once the radiant motion is known, it is possible to draw the radiant area by moving all individual radiant points to a common solar longitude (see Figure 1). The radiant area does not exhibit much structure; it has a dense circular core with a diameter of about 1° and an "outfield" of mainly weaker meteors, especially along the right ascension axis, but also slightly to the north of the core. These observations are also manifest from Table 5, where the variances of the distributions of radiant points for the three samples are listed. It should be realized that the wider radiant for the smaller particles is a real effect rather than an observational artifact due to the lower accuracy of the video observations. E.g., with the video observations in [8], a variance of $0\overset{\circ}{.}27$ was found in the radiant coordinates of the α-Monocerotids during their 1995 outburst.

The effect of a decreasing radiant width as a function of increasing solar longitude, as found from radar observations in [6], is not confirmed by the present observations. Also, no evidence is present for a secondary Orionid radiant north of the main radiant in the magnitude interval studied by video (+1 to +6). Only meteor 95361 could belong to such a radiant.

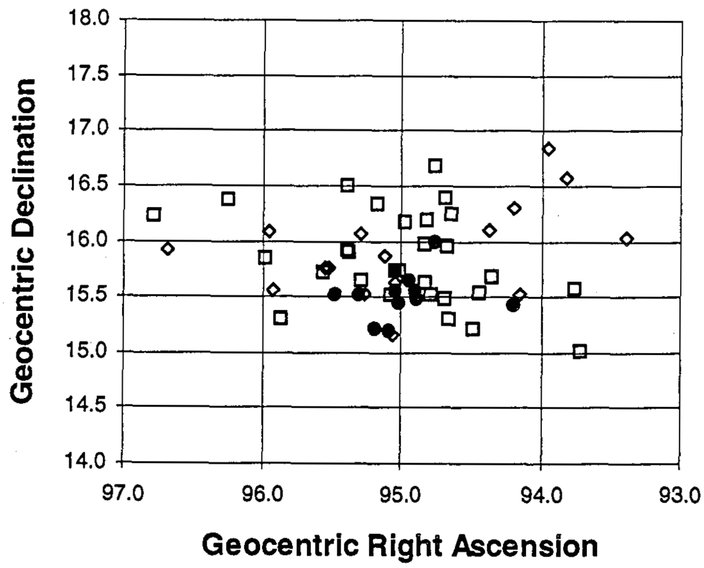


Figure 1 – Sixty-one Orionid radiant points moved to solar longitude $\lambda_\odot = 208\overset{\circ}{.}00$. The squares are the new video data, the diamonds are the old video data from [1], and the circles come from the *DMS* photographic database [7].

Table 5 – Width of the radiant area in terms of variances ($\sqrt{\mathrm{avg}\{[x - \mathrm{avg}(x)]^2\}}$) for the three different samples drawn in Figure 1.

Sample	$\overline{\Omega}$	var_α	var_δ
Video 1995	28°28	1°16	0°95
Video 1993	25°81	1°14	0°41
DMS photo	27°02	0°31	0°21

4. ε-Geminids

Strikingly absent in the list of observed meteor showers is the ε-Geminid shower. According to [3] and [4], the visual ZHR of this shower is supposed to be 1.5 at solar longitude $\lambda_\odot = 208°$. Given the fact that the r-value for ε-Geminids is said to be the same as for the Orionids, that the ZHR of the Orionids is 16 at the observed longitude, and that the radiant of the ε-Geminids has a slightly higher elevation than that of the Orionids, the expected number of observed ε-Geminids is 3 to 4. Similar discrepancies, i.e., a too low number of observed ε-Geminids, were found in the video observations of [1], where 3 ε-Geminids were expected near longitude $\lambda_\odot = 205°8$, and only a single member was observed, and of [9], where 3 ε-Geminids were expected near longitude $\lambda_\odot = 208°7$, and only a single member was observed.

The discrepancy would be somewhat softened if the r-value of the ε-Geminids were to be 2.0 rather than 3.0. This would decrease the visibility of the stream at video magnitudes and also explain why the stream was discovered via photographic rather than visual observations. These considerations suggest that the activity of the ε-Geminid shower at visual magnitudes is at least a factor 2 lower than reported in [3] and [4], and that the r-value might be considerably lower than commonly believed. In fact, the activity of the stream does hardly reach the visual (plotting) detection limit. The higher reported r-value and ZHRs are probably due to sporadic pollution; indeed, Table 2 shows a lot of fast sporadic radiants east of the Orionid radiant.

5. Leo Minorids

Although the Leo Minorids are recognized as a stream in the literature [3,10], observational material is scarce, and, as a result, they have not yet been included in the *IMO Shower Calendar*. It was therefore a surprise that the current sample of 67 meteoroid orbits contained no less than 3 Leo Minorids. From photographic sources, only 4 high-precision Leo Minorid orbits are known [7,10], so the current sample is a significant addition to this number. The average orbits from the photographic and video observations, as well as an overall average orbit, are listed in Table 6. Two additional video Leo Minorids can be found in [9], but these orbits were not included in the averages. Note that the video radiants have a slightly smaller declination than the photographic radiants, resulting in corresponding differences in q, i, and ω. Note also that the orbits are strongly concentrated around solar longitude $\lambda_\odot = 209°$, suggesting that the stream may be narrower than generally believed (e.g., 6 days above $\mathrm{ZHR}_{\mathrm{max}}/e$ in [3]). Finally, the larger sample of Leo Minorid data allows for an estimate of the geocentric radiant motion and the size of the radiant area:

$$\alpha_g = 159°95 + (+0°96 \pm 0°15) \times (\lambda_\odot - 209°00) \text{ and } \mathrm{var}_\alpha = 0°5;$$
$$\delta_g = +36°78 + (+0°08 \pm 0°24) \times (\lambda_\odot - 209°00) \text{ and } \mathrm{var}_\delta = 0°7.$$

Table 6 – Orbital elements and radiants (J2000.0) of the known high-precision Leo Minorids.

Source	N	q	a	e	i	ω	Ω	V_g	α_g	δ_g
Photo *DMS* + *IAU*	4	0.641	33.6	0.985	124°5	106°3	209°9	61.8	160°7	+37°2
Video *DMS*	3	0.607	58.1	0.989	125°9	102°4	208°3	62.0	159°5	+36°2
Average	7	0.627	41.0	0.987	125°1	104°6	209°2	61.9	160°2	+36°8

6. Conclusion

Once more, video observations provide an important complement to existing visual and photographic observations. This holds both for major streams (Orionids) and minor streams (ε-Geminids and Leo Minorids).

References

[1] M. de Lignie, K. Jobse, "Double-station video observations of the 1993 Orionids", *Radiant* 17, 1995, pp. 99–106.

[2] M. de Lignie and K. Jobse, "Double-station video observations of the 1995 Quadrantids", *WGN* 24, 1996, pp. 20–26.

[3] P. Jenniskens, "Meteor stream activity I: The annual streams", *Astron. Astrophys.* 287, 1994, pp. 990–1013.

[4] J. Rendtel, R. Arlt, A. McBeath, eds., "Handbook for Visual Meteor Observers", IMO Monograph No. 2, 1995.

[5] G.W. Kronk, "Meteor Showers: A Descriptive Catalogue", Enslow Publishers Hillside, New Jersey 1988.

[6] J. Jones, "Radar observations of the Orionid meteor shower", *Mon. Not. R. Astr. Soc.* 204, 1983, pp. 765–776.

[7] H. Betlem, "Summer and autumn 1995: a fine harvest of double-station meteors", *Radiant* 18, 1996, pp. 75–77.

[8] P. Jenniskens, H. Betlem, M. de Lignie, M. Langbroek, "The detection of a dust trail in the orbit of an Earth-threatening long-period comet", *Astrophys. J.* 479, 1997, pp. 441–447.

[9] Y. Shigeno, H. Shioi, S. Tanaka, "Double-station TV meteor observations", *WGN* 24, 1996, pp. 37–42 and 161–170, and *WGN* 25, 1997, pp. 161–165.

[10] B. Lindblad, "Physics and orbits of meteoroids", in *The Evolution of Small Bodies of the Solar System*, Soc. Italiana di Fisica, Bologna, Italy, 1987.

Call for Photographs!

Marc Gyssens

A lot of people will observe the Perseids and other showers the upcoming months, and after that the Leonids, of course, photographically. Please send a print of your best photographs to *WGN*! Of course, there are only 6 issues each year, so we cannot guarantee that your photo will effectively be published, but give it a try, and who knows...

To qualify for the front cover, the photograph must be of the right format (i.e, horizontal and approximately 18 cm by 13 cm, or scalable to the format) and of good contrast, as some faint features get lost inevitably.

I am eagerly awaiting your results!

Observational Results

Double-Station TV Meteor Observations of the α-Capricornids and Aquarids in Late July

Yoshihiko Shigeno, Tomoko Shigeno, and Hiroyuki Shioi

We conducted double-station TV meteor observations of the α-Capricornids and Aquarids in Late July in Australia. We identified 185 double-station TV meteors within five observations. Their radiants were widely spread. Therefore, we consider the conventional classification to be inadequate.

1. Introduction

The α-Capricornids, Northern ι-Aquarids, Southern ι-Aquarids, Northern δ-Aquarids, and Southern δ-Aquarids are well-known meteor showers, being active from late July to mid-August [1–4]. The radiants and orbital elements of the meteoroid streams are well analyzed and published, and these meteor showers are very popular.

Figure 1 shows the distribution of the radiants, based on the data of radiants provided by McCrosky and Posen [5] and Koseki [6]. There are areas in which the radiants are concentrated, but many more radiants are scattered around these areas. The problem is how to find the target meteor shower from the area where the radiants appear diffuse. Figure 1 also shows the radiants over a month. It is necessary to look at observations within a short period for easier comprehension.

Table 1 – Radiants and orbits of the α-Capricornids.

Date (UT) (YMD)	$\lambda_\odot$ (2000.0)	α (2000.0)	δ (2000.0)	SD	V_g (km/s)	SD (km/s)	a (AU)	e
19980731.619	128°.229	305°.2	−08°.5	0°.6	20.8	1.0	2.33	0.729
SD ±0.019	0°.019	1°.6	1°.0	0°.3	0.8	0.3	–	0.022
19980801.648	129°.213	303°.9	−08°.1	0°.9	20.0	0.8	2.31	0.714
SD ±0.027	0°.026	2°.2	2°.0	0°.3	0.6	0.3	–	0.021
Cook	128°	308°	−10°		22.8		2.53	0.77
Lindblad	(129°.2	308°.4	−08°.7		22.3)		2.42	0.758
Kronk	129°.3	307°.4	−08°.1					
IMO	127°	307°	−10°		22.4			

Table 2 – Radiants and orbits of the Southern δ-Aquarids.

Date (UT) (YMD)	$\lambda_\odot$ (2000.0)	α (2000.0)	δ (2000.0)	SD	V_g (km/s)	SD (km/s)	a (AU)	e
19980727.626	124°.410	338°.8	−17°.1	0°.3	39.3	1.1	1.84	0.956
SD ±0.006	0°.006	2°.0	0°.6	0°.1	3.0	0.3	–	0.025
19980731.634	128°.243	341°.7	−15°.6	0°.4	39.5	1.1	2.10	0.963
SD ±0.015	0°.014	0°.8	0°.7	0°.2	0.9	0.5	–	0.006
19980801.653	129°.217	342°.5	−16°.1	0°.6	38.5	1.1	1.90	0.951
SD ±0.034	0°.032	1°.5	1°.4	0°.5	1.6	0.4	–	0.016
Cook	126°	334°	−16°		41.4		2.86	0.976
Lindblad	(129°.2	341°.9	−15°.7		40.2)		3.09	0.967
Kronk	125°.7	339°.7	−16°.7					
IMO	125°	339°	−16°		39.4			

If you observe the Aquarids in Japan, you will find that the radiants culminate at an elevation of about 30°. If observed in Australia, the radiants come close to the zenith. This means that you will be able to observe many meteors. Therefore, we conducted the double-station TV meteor observations in Australia.

2. Observations

We conducted double-station TV meteor observations near Atherton ($\lambda = 145°29'$ E, $\varphi = 17°16'$ S), and Hughenden ($\lambda = 144°12'$ E, $\varphi = 20°51'$ S), two sites in Queensland. The base line near Atherton was 43.7 km long, and that near Hughenden was 47.3 km long. We used an image intensifier with a CCD [7] and two lenses with a focal length of $f = 85$ mm, $f/1.4$ and $f = 50$ mm, $f/1.2$, respectively. The fields of view were 7.5° × 9.5° and 13° × 17°, and the limiting stellar magnitudes were +10.7 and +9.8, respectively. The average measurement error was 123″, and the average error of the radiants was 0°62. We identified meteors at an Hourly Rate (HR) of 20 using the 85 mm, $f/1.4$ lens, and identified them at an HR of 30 using the 50 mm, $f/1.2$ lens. Figure 2 shows the distribution of the radiants of this work. There are areas on which the radiants of the α-Capricornids and Southern δ-Aquarids have concentrated while the radiants are widely scattered around these areas.

3. α-Capricornids

Table 1 lists the averages of the observed values and comparison data. The radiants appear as a diffuse area, hence the result of the calculation depends on how the range of the radiants is determined. Therefore, many gaps exist in the comparison data.

Table 1 – Continued.

Date (YMD)	$\lambda_\odot$ (2000.0)	q (AU)	ω	Ω	i	Obs Mag	H_b (km)	H_e (km)	N
19980731.619	128°229	0.631	264°1	128°2	7°2	6.2	99.0	86.9	6
SD ±0.019	0°019	0.025	3°2	0°0	0°9	0.7	3.4	2.7	
19980801.648	129°213	0.662	260°6	129°2	7°5	6.1	98.3	87.3	5
SD ±0.027	0°026	0.029	4°5	0°0	1°2	1.3	1.3	–	
Cook	128°	0.59	269°0	127°7	7°0				
Lindblad	(129°2)	0.586	270°2	127°6	7°3				

Table 2 – Continued.

Date (YMD)	$\lambda_\odot$ (2000.0)	q (AU)	ω	Ω	i	Obs Mag	H_b (km)	H_e (km)	N
19980727.626	124°410	0.081	152°1	304°4	26°2	7.1	101.1	84.5	6
SD ±0.006	0°006	0.012	1°7	0°0	2°4	0.9	2.0	2.1	
19980731.634	128°243	0.078	151°9	308°2	25°7	4.8	98.6	83.2	8
SD ±0.015	0°014	0.008	1°6	0°0	3°0	2.0	3.3	1.2	
19980801.653	129°217	0.093	149°8	309°2	25°5	5.2	100.4	85.5	23
SD ±0.034	0°032	0.017	2°6	0°0	2°9	1.9	2.4	4.1	
Cook	126°	0.069	152°8	305°7	27°2				
Lindblad	(129°2)	0.102	149°5	310°3	26°2				

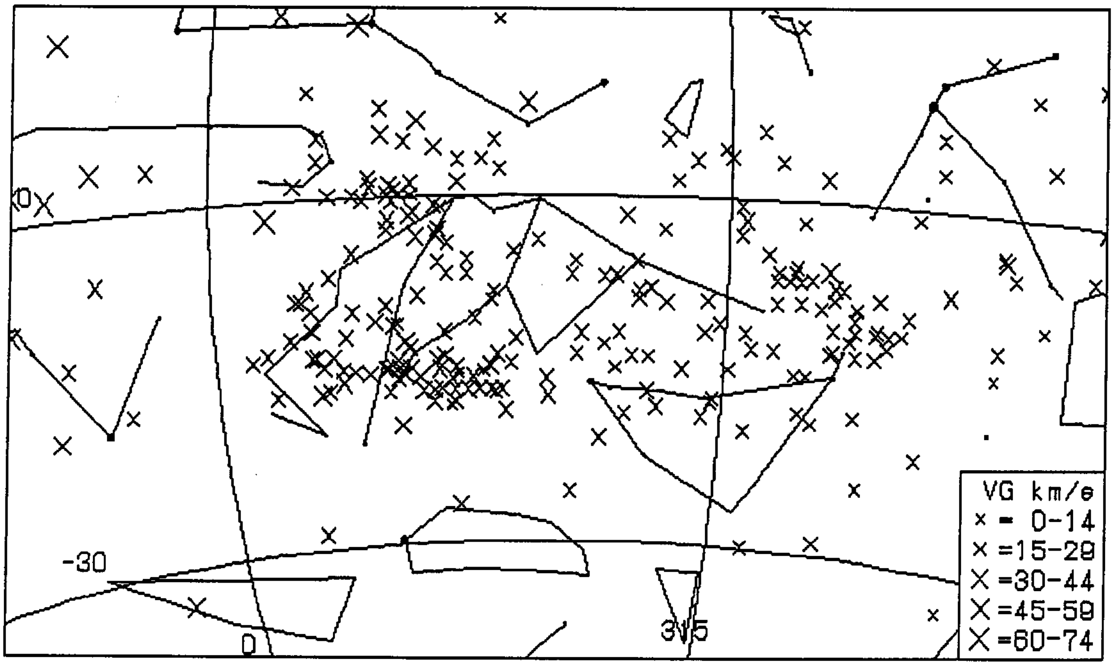


Figure 1 – Corrected radiants chart of the photographic observations from late July to mid-August by McCrosky, Posen, and Koseki.

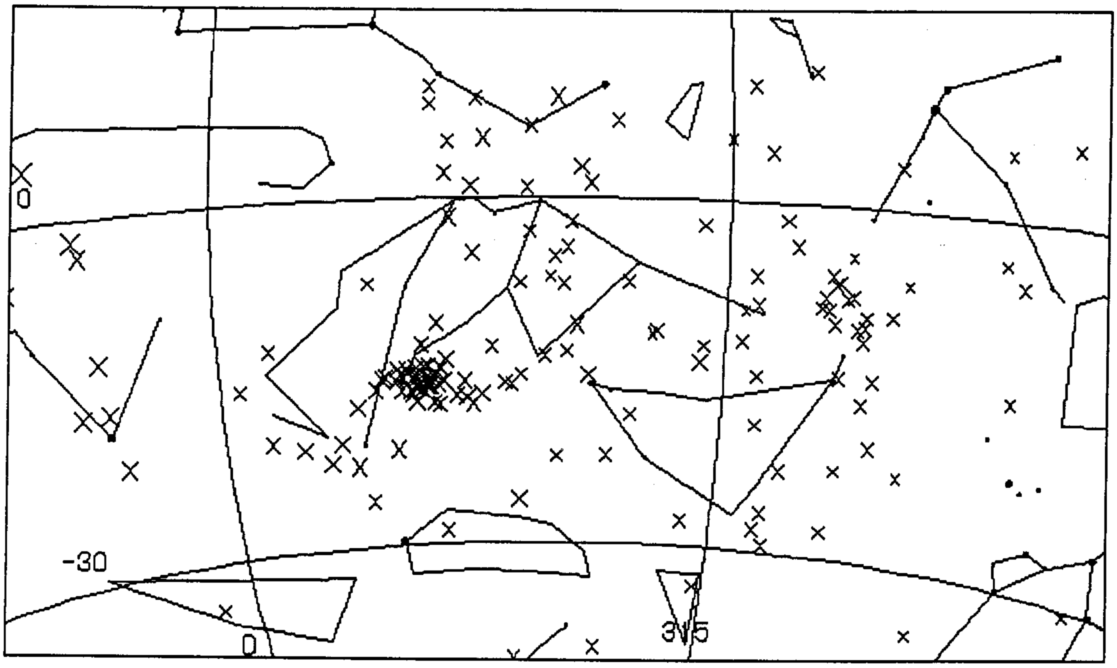


Figure 2 – Corrected radiants chart of this work.

4. Southern δ-Aquarids

Table 2 lists the averages of the observed values and comparison data. Because the areas (on which the radiants are concentrated) are clear, it simplifies the calculation. The conformance with the comparison data is good. The gap in the velocity is thought to be caused by the low accuracy of the TV observation. Table 3 shows the formula to find the motion of the radiants. The conformance with the comparison data is good.

5. Northern ι-Aquarids, Southern ι-Aquarids, and Northern δ-Aquarids

The Northern ι-Aquarids were not active during the observations, while the Southern ι-Aquarids and Northern δ-Aquarids were active, but we did not find an area in which the radiants concentrate. Therefore, it was not possible to perform the calculation. Many radiants were scattered over a rather large region in Capricornus and Aquarius, thus preventing classification.

Table 3 – Radiant motion of the Southern δ-Aquarids (J2000.0).

Source	Right ascension	Declination
This work	$\alpha = 339\overset{\circ}{.}31 + 0.75 \times (\lambda_\odot - 125\overset{\circ}{.}0)$	$\delta = -16\overset{\circ}{.}85 + 0.22 \times (\lambda_\odot - 125\overset{\circ}{.}0)$
Cook	$\alpha = 333\overset{\circ}{.}2 + 0.80 \times (\lambda_\odot - 125\overset{\circ}{.}0)$	$\delta = -16\overset{\circ}{.}4 + 0.18 \times (\lambda_\odot - 125\overset{\circ}{.}0)$
Kronk	$\alpha = 339^\circ + 0.8 \times (\lambda_\odot - 125^\circ)$	$\delta = -17^\circ + 0.4 \times (\lambda_\odot - 125^\circ)$
IMO	$\alpha = 339^\circ + 0.75 \times (\lambda_\odot - 125^\circ)$	$\delta = -16^\circ + 0.21 \times (\lambda_\odot - 125^\circ)$

6. Conclusion

We made a detailed research of the meteor showers with radiants in the region of Capricornus and Aquarius between end-July and mid-August. During our program, we observed many meteors within a short period of time. However, during our investigation, we found that the radiants were distributed over a wide area. Therefore, we consider that the conventional classification is inadequate. Visual observation using the conventional classification may prevent correct calculation.

References

[1] A.F. Cook, "A Working List of Meteor Streams", in *Evolutionary and Physical Properties of Meteoroids*, 1971, pp. 183–191.

[2] B.A. Lindblad, "Physics and Orbits of Meteoroids", in *The Evolution of the Small Bodies of the Solar System*, Soc. Italiana di Fisica Bologna, 1987, pp. 229–251.

[3] G.W. Kronk, "Meteor Showers—A Descriptive Catalog", Enslow Publ., 1988.

[4] J. Rendtel, R. Arlt, A. McBeath, eds., "Handbook for Visual Meteor Observers", IMO Monograph no. 2, 1995.

[5] R.E. McCrosky, A. Posen, "Orbital Elements of Photographic Meteors", *Smithsonian Contributions to Astrophysics* 4, 1961, pp. 15–84.

[6] M. Koseki, "Analysis of Meteor Data on a Microcomputer System", *J. Brit. Astron. Assoc.* 96:4, 1986, pp. 232–240.

[7] Y. Shigeno, H. Shioi, S. Tanaka, "Double-Station TV Meteor Observations in 1996", *WGN* 25:4, August 1997, pp. 161–165 (`ftp://ftp.imo.net/pub/data/msswg`).

On the 1998 Perseids in Poland

Arkadiusz Olech, Warsaw University Observatory

Visual observations of the 1998 Perseids are reported. Based on almost 900 hours of observing time collected by 35 observers, an activity profile from July 15 to August 25 is given. The maximum of activity with ZHR $= 52 \pm 3$ was noted during the night of August 12-13, 1998 ($\lambda_\odot = 140\overset{\circ}{.}0$). After averaging in shorter periods of time, the highest activity does not differ much from the mean level. The highest ZHR equal to 59 ± 8 was noted at $\lambda_\odot = 139\overset{\circ}{.}96$ (i.e., August 12.87 UT). This result is significantly lower than values obtained for the traditional maximum of the Perseids during previous years. That difference diminishes after adopting a zenith exponent $\gamma \approx 1.4$, which may suggest that, for the Perseid shower, the zenith exponent is larger than 1.0. The minimum value of the population index r equal to 2.08 ± 0.03, was obtained for the night of the maximum.

Theoretical calculations made by Williams and Wu [1] suggested that the new peak in the ZHR profile of the Perseid stream should decline in the years 1997–2000. Fortunately for meteor observers, it was still clearly detectable in 1997.

That year the maximum ZHRs equal to 137 ± 5 were noted at solar longitude $\lambda_\odot = 139\overset{\circ}{.}71$. The older, traditional maximum with ZHR $= 94 \pm 2$ occurred at $\lambda_\odot = 140\overset{\circ}{.}03$ [2]. These two moments were not favorable for Polish observers, but excellent weather conditions lasting from August 5 to August 25, 1997, allowed us to collect as much as 937^h23^m of observing time with 8273 Perseids detected [3]. The predictions for August 1998 were slightly better. The traditional maximum was expected around 22^h UT on August 12, which favors Central European observers, including the Polish watchers. On the other hand, the serious disadvantage was the Full Moon on August 8.

In spite of the poor weather conditions during last August, the Polish observers associated in the *Comets and Meteors Workshop* (*CMW*) again obtained a large sample of observational data. From July 15 to August 25, a group of 35 of our observers obtained 896^h57^m of observing time (908 ZHR estimates) with 3342 Perseids detected. The complete list of our observers with the corresponding effective observing times is as follows:

Konrad Szaruga ($97\overset{h}{.}72$), Jarosław Dygos ($94\overset{h}{.}70$), Paweł Trybus ($62\overset{h}{.}18$), Andrzej Skoczewski ($52\overset{h}{.}44$), Jacek Kluczewski ($50\overset{h}{.}25$), Tomasz Żywczak ($49\overset{h}{.}05$), Marcin Konopka ($48\overset{h}{.}58$), Maciej Kwinta ($45\overset{h}{.}33$), Wojciech Jonderko ($41\overset{h}{.}68$), Krzysztof Socha ($34\overset{h}{.}12$), Gracjan Maciejewski ($32\overset{h}{.}92$), Aleksander Trofimowicz ($30\overset{h}{.}12$), Arkadiusz Olech ($29\overset{h}{.}35$), Mariusz Wiśniewski ($28\overset{h}{.}40$), Krzysztof Kamiński ($25\overset{h}{.}73$), Luiza Wojciechowska ($24\overset{h}{.}65$), Paweł Brewczak ($19\overset{h}{.}35$), Marcin Gajos ($18\overset{h}{.}63$), Tadeusz Sobczak ($15\overset{h}{.}33$), Cezary Gałan ($13\overset{h}{.}15$), Tomasz Fajfer ($13\overset{h}{.}00$), Łukasz Sanocki ($10\overset{h}{.}97$), Michał Jurek ($10\overset{h}{.}33$), Krzysztof Mularczyk ($9\overset{h}{.}92$), Michał Marek ($7\overset{h}{.}00$), Ewa Dygos ($5\overset{h}{.}75$), Sylwia Hołowacz ($5\overset{h}{.}05$), Tomasz Krzyżanowski ($4\overset{h}{.}41$), Marcin Dżuła ($3\overset{h}{.}83$), Katarzyna Skoczewska ($3\overset{h}{.}33$), Waldemar Drozdowski ($2\overset{h}{.}30$), Artur Szaruga ($2\overset{h}{.}12$), Bartosz Dąbrowski ($2\overset{h}{.}00$), Karol Fietkiewicz ($1\overset{h}{.}75$), and Sylwia Chełmoniak ($1\overset{h}{.}50$).

One can see the large difference between the number of observed Perseids in 1997 and 1998. Knowing that, in 1997, we did not observe any maximum and, in 1998, the time of the traditional maximum favored the Polish watchers, it seems very strange. The nature of that difference becomes clear after analyzing Figure 1, where we present the distribution of our observations made in July and August 1998.

The good weather conditions allowed us to collect the large amounts of data in the periods July 15–24, August 8–12, and August 15–20. Only the second of these periods was rich in high hourly rates of the Perseids; unfortunately, it coincided almost exactly with the Full Moon. In 1997, the situation was different. The majority of our data was collected during the moonless nights of the first part of August, when the rates were very high.

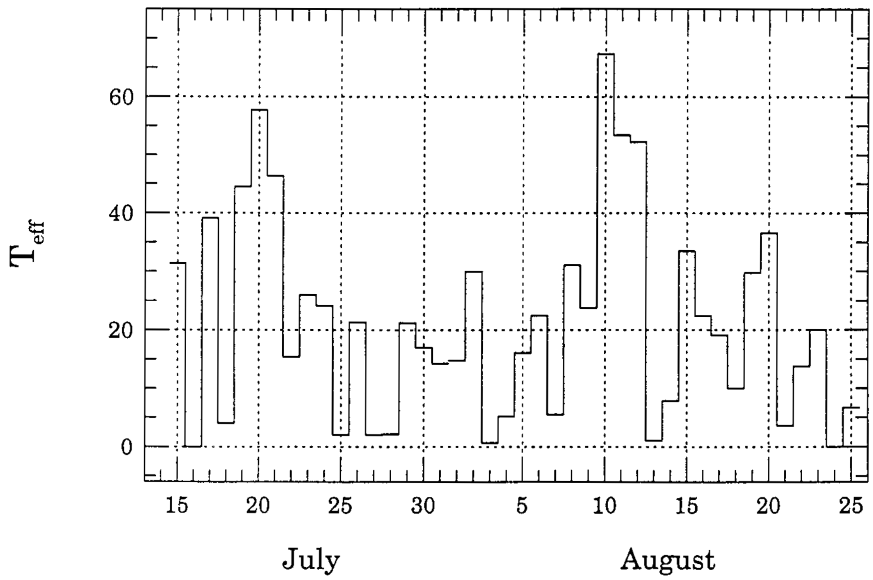


Figure 1 – Distribution of the observations made by Polish observers during July and August 1998.

In 1998, we obtained 3342 magnitude estimates. The distribution of this quantity for the 1998 Perseids is presented in Table 1. Using the probabilities of perception given by Koschack and Rendtel [4], we computed the values of the population index r. The evolution of this quantity around the maximum of activity is presented in Figure 2. Due to the Full Moon occurring on August 8, the error bars are large, but the minimum values of r equal to 2.10 ± 0.03 and 2.08 ± 0.03 were noted on August 11-12 ($\lambda_\odot = 139\overset{\circ}{.}1$) and August 12-13 ($\lambda_\odot = 140\overset{\circ}{.}0$), respectively.

Table 1 – Magnitude distribution of the 1998 Perseids in Poland.

Magnitude	-4^-	-3	-2	-1	0	$+1$	$+2$	$+3$	$+4$	$+5$	$+6$	Tot
Meteors	13	36	87	170.5	327	457	646.5	736	641.5	202	25.5	3342

Knowing the population index profile and adopting a zenith exponent value $\gamma = 1.0$, we can compute ZHRs. The resulting activity profile of the 1998 Perseids is presented in Figure 3. The maximum ZHR value of 52 ± 3 was noted during the night of August 12-13. This is not a high value, and it differs significantly from the result presented by Arlt [5], who obtained ZHR ≈ 80 at $\lambda_\odot = 140\overset{\circ}{.}0$. Our maximum point is the average value of 69 ZHR estimates, and we decided to divide this point into 8 shorter bins each containing from 6 to 12 ZHR estimates. The result is shown in the upper panel of Figure 4. The ZHRs seem to oscillate around the mean value, and no clear trend is detectable. The highest point with ZHR $= 59 \pm 8$ was noted at $\lambda_\odot = 139\overset{\circ}{.}96$ (August 12, $20^{\mathrm{h}}40^{\mathrm{m}}$ UT). This moment is in very good agreement with the result obtained in [5], but the value of the ZHR is still significantly smaller.

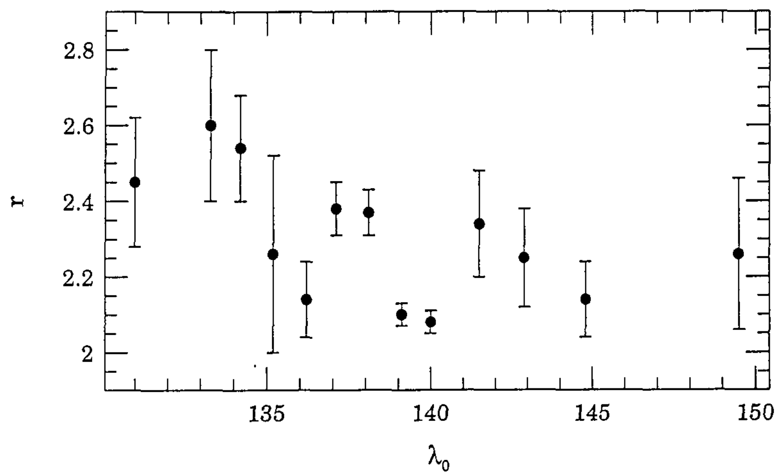


Figure 2 – Profile of the population index r of the 1998 Perseids.

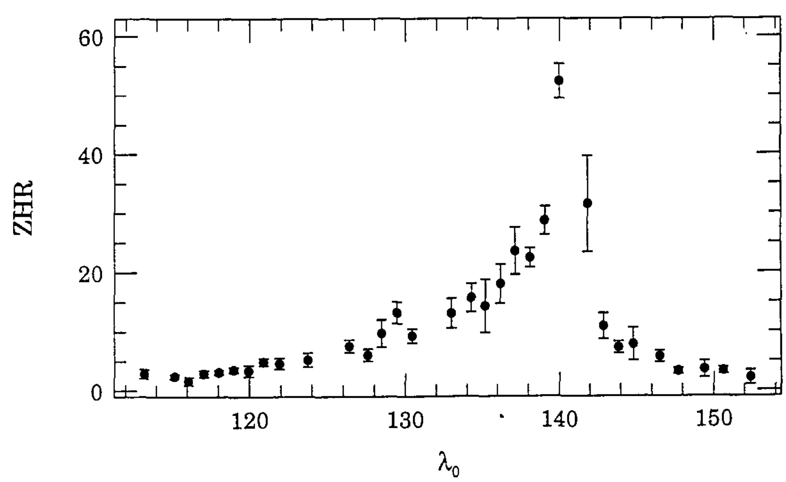


Figure 3 – ZHR-profile of the 1998 Perseids.

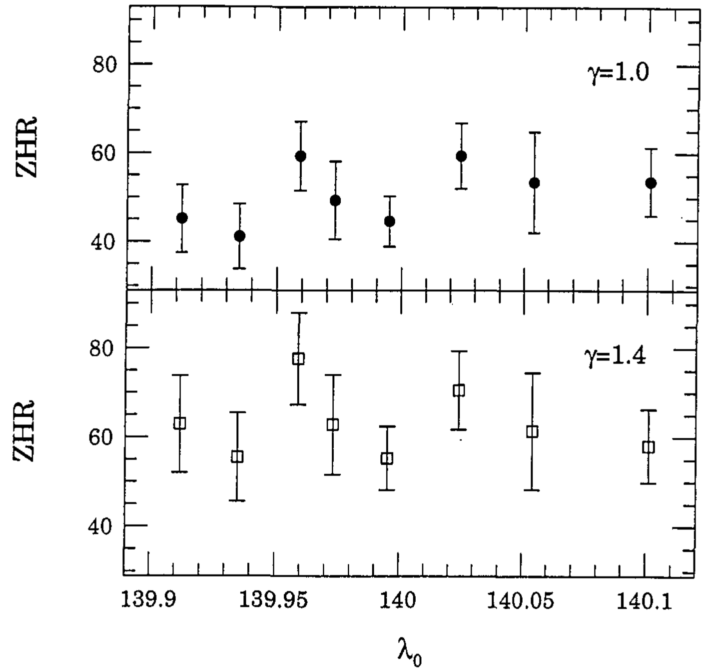


Figure 4 – The activity profile around the traditional maximum of the 1998 Perseids. The upper panel is obtained for $\gamma = 1.0$, and the lower panel for $\gamma = 1.4$.

We recalculated our ZHR profile for the night of August 12-13 using zenith exponent $\gamma = 1.4$. The result is presented in the lower panel of Figure 4. Now, ZHRs are larger with the highest point having ZHR $= 78 \pm 10$. This is almost the same level of activity as noted by Arlt [5], but he adopted $\gamma = 1.0$. The explanation of this fact may lay in the distribution of our observations from August 12-13. The beginning of this night was clear at almost all Polish locations. Unfortunately, the good weather conditions lasted shortly, and, at the end of the night, only few of our observers had clear skies. So, the majority of our ZHR estimates obtained on August 12-13 were made during the evening, when the radiant altitude is low. The computation of the ZHR values is more sensitive for the value of zenith exponent for low altitudes of the radiant than for the high ones. Arlt's [5] result was presumably obtained from a more uniformly distributed sample, and adopting $\gamma = 1.0$ was enough for producing the higher values of ZHR. The arguments above suggest that, especially for the maximum of activity of the Perseid shower, the zenith exponent may be larger than 1.0. A similar result for the 1993 Perseid maximum was obtained by Bellot Rubio [6].

The preliminary results presented by Arlt [5] showed that the activity of the new peak in 1998 was around ZHR ≈ 180. It suggests that the new peak is still clearly visible in the activity profile. The New Moon on August 11, 1999, will give an excellent opportunity to study in detail the ZHRs around the Perseid maximum.

Acknowledgments

This work was supported by KBN grant 2 P03D 002 15 to A. Olech.

References

[1] I. Williams, Z. Wu, *MNRAS* 269, 1994, p. 524.
[2] R. Arlt, *WGN* 26, 1998, p. 61.
[3] A. Olech, *WGN* 26, 1998, p. 71.
[4] R. Koschack, J. Rendtel, *WGN* 18, 1990, p. 54.
[5] R. Arlt, *WGN* 26, 1998, p. 218.
[6] L.R. Bellot Rubio, *Astron. Astrophys.* 310, 1995, p. 602.

SPA Meteor Section Results: September–October 1998

Alastair McBeath

A summary of news and results submitted to the *SPA Meteor Section* for September and October 1998 is given. The α-Aurigid peak in early September was seen primarily in the radio data, as visual coverage of the month was very patchy thanks to poor weather. Many European observers attempted to cover the expected Draconid epoch, but its timing meant the best detection again occurred for radio methods. The Orionids were generally well-seen, with magnitude and train analyses possible for the shower. An enhancement in Orionid rates was seen on October 17-18, ahead of the main peak, with ZHRs perhaps 27 ± 10 at best then. The main Orionid peak was unusually sharp in both visual and radio data around October 21-22 (ZHRs of 32 ± 4), though the radio peak timing was slightly ambiguous in some data sets. Somewhat enhanced Taurid activity (ZHRs of 7–10) occurred during the final week of October in visual and radio data, with several minor shower fireballs (magnitudes -3 to -5) also seen then.

1. Introduction

Weather conditions were far from ideal in September, but improved markedly in October, allowing observers to cover both the Draconid and Orionid epochs quite well. A great many casual observers were alerted to the possibility of some Draconid activity, with large numbers of—chiefly negative—reports submitted from across Britain in particular. Several dedicated, if non-regular, meteor watchers even sat up most of the night on October 8-9 only to be frustrated by cloudy skies. All who reported their efforts, whether successful or not, are listed below.

The observing totals achieved in both months are given in Table 1.

The photographic details came exclusively from two all-sky fireball patrol cameras operated by the *Arbeitskreis Meteore (AKM)* members Jürgen Rendtel and Jörg Strunk, both in Germany. These, with the other *AKM* details here were taken from the journal *Meteoros*, issues 10 and 11 (1998), submitted by Ina Rendtel.

Radio observations were mainly extracted from *Radio Meteor Observation Bulletins (RMOBs)* 62–64 (October–December 1998, inclusive), provided by Christian Steyaert. These observers included the following persons:

> Enric Fraile Algeciras (Spain), Mike Boschat (Canada), Giorgio Bressan (Italy), Eisse Pieter Bus (the Netherlands), Maurice de Meyere (Belgium), Ghent University (Belgium), Will Kelsey (California, USA), Werfried Kuneth (Austria), Sadao Okamoto (Japan), Chikara Shimoda (Japan), Ilkka Yrjölä (Finland), and Wim T. Zanstra (the Netherlands).

Additional radio notes were provided by Bev Ewen-Smith (Portugal), Kimio Maegawa (Japan), and R.B. Minton (New Mexico, USA). Our standard practices for examining raw forward-scatter data were followed as normal, with the graphs presented here representative of those available.

Visual data came from the following observers:

> *AKM* members (all in Germany, except where noted) Rainer Arlt, Udo Hennig, Sylvio Lachmann, Sven Näther, Jürgen Rendtel (Germany and Mongolia), Janko Richter (Italy), Harald Seifert, Ulrich Sperberg, Manuela Trenn, Roland Winkler, Oliver Wusk (Cuba) and Hans-Georg Zaunick (Italy); Godfrey Baldacchino et al. (Malta), Ştefan Berinde (Romania), John Bonsor (Scotland), Jay Brausch (North Dakota, USA), Ade Dimmick (England), Bev Ewen-Smith (Portugal), Penny Feltham (England), Guy Fennimore (England), Steve Foggo (England), Shelagh Godwin (England), Valentin Grigore (Romania), Tom Hosking (England), John Lambert (England), Marco Langbroek (Netherlands), Anne Lascelles (England), Peter Lascelles (England), Trevor Law (England), Richard Livingstone (Wales), Tony Markham (England), Alastair McBeath (England), Tom McEwan (Scotland), Vasile Micu (Romania), R.B. Minton (New Mexico, USA), Gelu-Claudiu Radu (Romania), Joan Robinson (England), Robin Scagell (England), George Spalding (England), David Todd (England), Stanley Toyn (England), Mihaela Triglav (Slovenia), James Vanderpool (England), Cis Verbeeck (Belgium—report via Marc Gyssens).

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

Month	Visual	DAU	SPI	GIA	ORI	TAU	Meteors	Photo	Radio
September	$61^{h}_{.}8$	54	26	–	–	–	595	$127^{h}_{.}8$	3099^{h}
October	$135^{h}_{.}8$	6	–	42	394	187	1675	–	3140^{h}

2. September

Observer coverage during the month was generally rather patchy, with only a few dates between September 15–24 receiving more than scant attention. Low α- and δ-Aurigid rates were seen, but neither shower peak was at all well-noted in early September thanks to the bright Moon. Low Piscid activity was also detected, but without any clear maximum apparent. Radio coverage enjoyed more success, but suffered from some atmospheric difficulties. The most serious of these was Sadao Okamoto's aerial being blown down by Typhoon 7, which hit Japan around September 22–27. Thankfully, none of our Japanese colleagues was injured during this severe storm.

One of the more complete radio data sets is given in Figure 1, showing longer-duration echoes. Overall, the radio peaks coincided with all of those found previously during the month [1], with the exception of the minor peak at $\lambda_{\odot} \approx 165°$ (eq. 2000.0), which recurred in none of the available observations. One weak maximum not found earlier was seen in all the results, around $\lambda_{\odot} = 158°$–$159°$, which might perhaps indicate a slightly stronger α-Aurigid peak at the start of the month. Too few visual data are on-hand from then to confirm this, however.

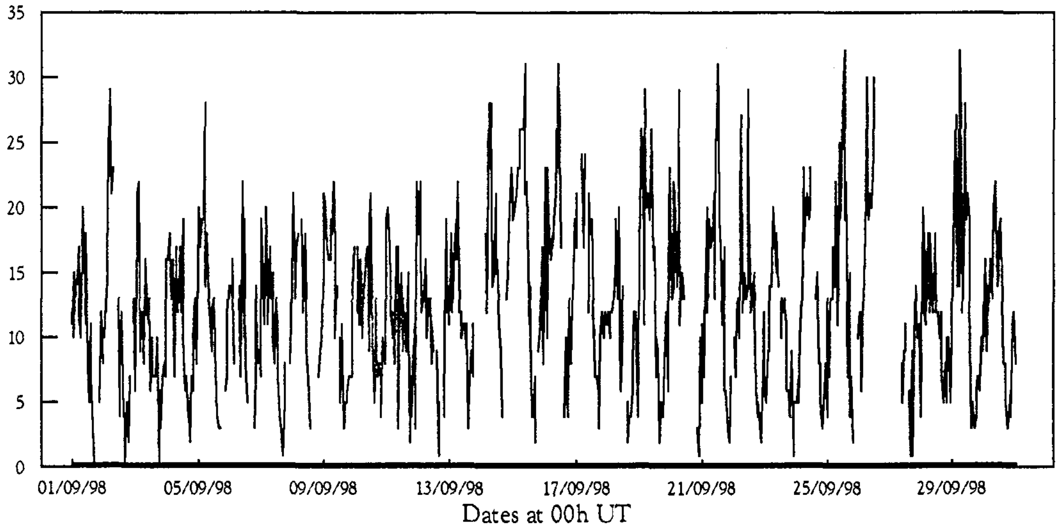


Figure 1 – Raw hourly radio meteor echo counts ($D > 3$ s) from September 1998, in data collected by Werfried Kuneth. Werfried's set-up was operated roughly continuously, with the longest non-operational breaks occurring on September 20 and 26-27. Other gaps were largely due to atmospheric problems, mostly Sporadic-E (Es), which was especially significant during the first half of the month.

3. October

October saw its most intense observer-efforts for the Draconids, despite problems with the bright Moon in early October. As has already been recorded in *WGN* [2], another outburst from the shower did indeed occur, but a few hours ahead of when past returns had led us to expect it. Consequently, the vast majority of our observers, in Europe and North America, were badly-placed to see what took place, though colleagues in Japan, including Kimio Maegawa, painted elegant word-pictures in their correspondence of what the rest of us missed! The contrast is perhaps best illustrated by reference to Figures 2 and 3, where the relative echo counts on October 8-9 are of especial note—highly obvious over Japan, but almost invisible from Europe. Admittedly, Maurice de Meyere's longer-duration echo observations do hint at higher activity on October 8-9, even though he was not operating his set-up at the most critical time (approximately 13^h10^m UT on October 8), but his overall echo trace is quite typical of the European results generally. One European observer, Werfried Kuneth, did record an exceptional spike on October 8-9 in his long-duration echo data ($D > 6.5$ s, not shown here), perhaps because of a better antenna position around 13^h–14^h UT.

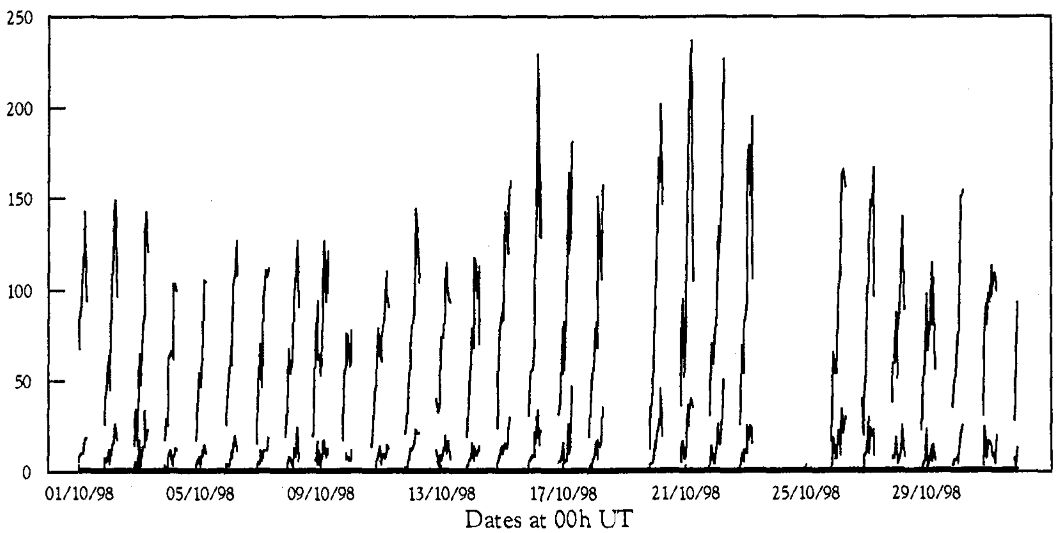


Figure 2 – Raw hourly radio meteor echo counts from October 1998, recorded by Maurice de Meyere. Maurice's set-up was active for around 11 hours daily, between 20^h and 6^h UT until the end of Summer Time on October 25, then from 21^h to 7^h UT. The other breaks mostly resulted from either Es, or storms on October 23–25. The upper line illustrates all echoes detected, while the lower one gives only echoes with $D > 1$ s. The Orionids later in the month are clear enough, and enhanced activity continued beyond their normal obvious radio limits, suggesting enhanced Taurid activity was happening too.

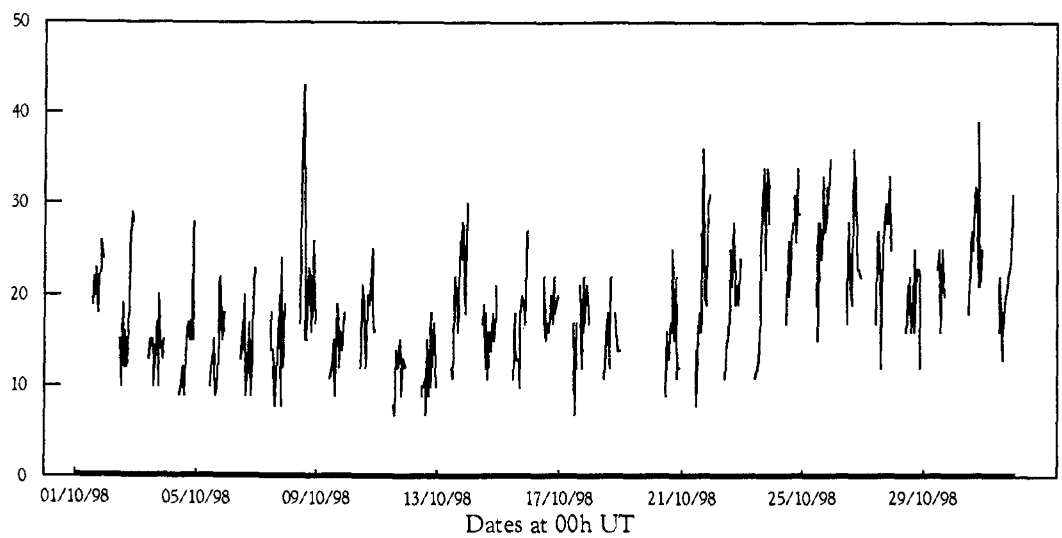


Figure 3 – Raw hourly radio meteor echo counts from 1998 October, as reported by Chikara Shimoda. Chikara observed normally for 12 hours a day, between 11^h and 22^h UT, with a few minor breaks, so luckily was active during the Draconid outburst, which is very obvious in his data. Note too the enhanced activity in late month because of the Orionids and probably the Taurids.

Large numbers of visual reports came in within days of the event—especial thanks are due to all who provided their results so quickly, whether lucky with the Draconids and the weather or not. It was almost possible to draw up a weather map for the UK showing cloudy and clearer sites from the data input! In Britain, observers in the north-east and south-west of England, along with north Wales, were fortunate in getting at least some clearer skies early on October 8-9. They, along with colleagues across Europe who also had better weather, did see a few late Draconids (very obvious because of their low relative speeds) in the 60–90 minutes of reasonably twilight-free skies ahead of moonrise. ZHRs then were at best 8–10, but dropped afterwards, probably with the brighter post-moonrise skies hiding any later generally faint Draconid meteors. No Draconids brighter than magnitude +2 appeared in any European data submitted to us, with only Jay Brausch in the USA spotting one possible very late Draconid fireball (magnitude −5) at 1^h12^m UT on October 9.

The next main event of October was the Orionids, and again, a lot of observers made a special effort to cover the shower, so much so that it has been possible to derive a simple ZHR graph for the shower during the second half of October, Figure 4. From this, it seems that Orionid rates were somewhat enhanced on October 17-18. There is a suggestion of this in the radio results too, especially over Europe, from where at least slightly enhanced counts were found in most datasets in the period from 5^h–7^h UT on October 18 ($\lambda_\odot = 204\overset{\circ}{.}64$–$204\overset{\circ}{.}72$). As Figures 2 and 3 indicate, however, somewhat more active radio rates were seen through much of the $\lambda_\odot = 201°$–$204°$ period, in the lead-up to the Orionid maximum. These were seen rather more clearly in 1998 than has been detected before (cf. [1]). The highest visual ZHRs on October 18 were noted around 05^h–06^h UT in the *SPAMS* data, equivalent to $\lambda_\odot = 204\overset{\circ}{.}64$–$204\overset{\circ}{.}68$, at 27 ± 10. Even the mean rate from Figure 4 is somewhat higher than would normally be expected at this time during the Orionids (ZHRs are usually 8–11 around $\lambda_\odot = 204°$–$205°$, rising to 15 or more only at or after $\lambda_\odot \approx 205\overset{\circ}{.}5$ [4, pp. 221–229]). Such enhanced Orionid activity has been seen before, however, most recently in 1993 [5], when ZHRs of 25–30+ occurred from perhaps $\lambda_\odot = 204\overset{\circ}{.}6$–$205\overset{\circ}{.}0$. Whether the 1998 event was definitely shorter than this period or not cannot be demonstrated from the presently available data. The European radio observers would have problems continuing to detect enhanced Orionid rates much beyond 8^h–10^h UT, due to the low to setting Orionid radiant soon after this time (radiant-set on October 18 being around 11^h–12^h local time), with westering radiants having proven unhelpful previously with most European radio observers currently active.

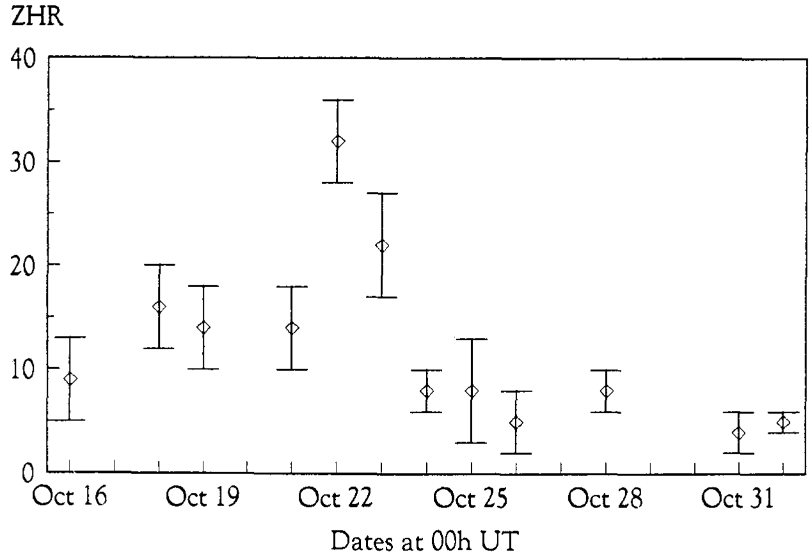


Figure 4 – Mean Orionid ZHRs. All results for a given date were combined into a single datapoint, as the geographical spread was not great enough to allow further details to be determined. An r-value of 2.9 was assumed in making these calculations following data in [3].

The Orionid peak itself was unusually sharply-defined on October 22, both visually and in the radio data. Not all the radio observations show the clearest peak on this date, but the majority do confirm it. Generally, Orionid rates show only slight change for about 2–3 days over their maximum in the radio results, and frequently also in the visual observations, but this was not found in 1998. Mean visual ZHRs reached 32 ± 4 at best, which was also somewhat higher than normal (more typically, 20–25). Sufficient Orionids were seen to allow a global magnitude distribution and some useful train details to be derived, as detailed in Tables 2 and 3.

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

Shower	-3^-	-2	-1	0	$+1$	$+2$	$+3$	$+4$	$+5^+$	Tot	Lm	$\overline{m}_{6.5}$
ORI	3	7	5	24	43	61	77.5	34	9	263.5	5.95	2.63
TAU	5	1	3	7	11	21	16	12	5	81	5.86	2.47
SPO	4	2	6	27	55	103	160.5	131	90	578.5	5.93	3.51

Table 3 – Global train percentages and mean duration in seconds per magnitude class for the Orionids and October sporadics. Train details were available for all the Orionids in the magnitude distribution and 567.5 of the sporadics. The combined Taurid train value during October was a mere 2.5%, too few to further analyze.

Magnitude	-3^-	-2	-1	0	$+1$	$+2$	$+3$	$+4^+$	Tot	%
Train % ORI	67	86	100	67	58	20	14	12	81	30.7
Duration % ORI		3.6	2.5	2.5	1.5	1.2	0.8	0.5		
Train % SPO	25	100	33	37	13	5	1	0	28	4.9
Duration % SPO	2.0	2.5	2.3	1.6	1.1	1.3	0.5			

Another unusual feature of October 1998 was the failure of the radio echo counts to drop as fast as normal after the Orionid maximum, with all radio datasets showing a minor, but pronounced peak around $\lambda_\odot = 216°–217°$ (October 29-30) not previously reported. A single data set in 1996 did show the Orionid "bulge" continuing until these solar longitudes, however, as noted in [1], even so, not as clearly as occurred in 1998. This radio activity was also coincident with some abnormally enhanced visual Taurid rates, as shown in Figure 5. ZHRs beyond the normally-expected parameters (5–7 [4, pp. 230–235]) were found on October 27-28 and from October 30 to November 1, with combined Taurid ZHRs comparable to the usual maximum rates, 9–10, seen on at least two dates. Bright moonlight in early November prevented any further reliable visual ZHRs to be calculated before November 15, but the radio data show no notable anomalies after $\lambda_\odot \approx 218°$ (November 1) in any case. Looking at the combined Taurid magnitude distribution (Table 2), an unexpectedly high proportion of Taurid fireballs can be seen, all detected from October 23 onwards. Indeed, including preliminary results from November (to be detailed in a later paper) almost 7% of the Taurids reported to the *SPAMS* in 1998 were fireballs. Though the overall small meteor number (total number of Taurids in October and November combined equals 102) makes this value less reliable than it might be, looking at past *SPAMS* Taurid data shows a typical mean fireball proportion no greater than about 3%, which the 1998 value significantly overstepped. The October sporadics by contrast showed their usual more modest 0.7% fireballs. The majority of Taurid fireballs were minor (magnitudes −3 to −5), but one magnitude −8 event was noted by the author at $2^h54^m50^s$ UT on October 31. As far as the remaining radio echo count peaks from [1] were concerned, all were detected again (but note the various comments already made above), with only the $\lambda_\odot = 216°–217°$ peak being new. One minor point should be made about the weak $\lambda_\odot \approx 199°$ enhancement, as this was again better detected around $\lambda_\odot \approx 198°$ instead, as in 1997.

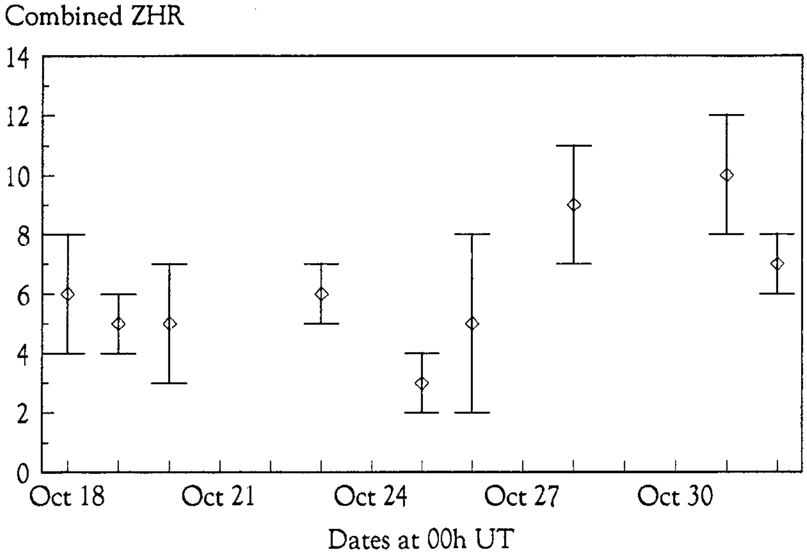


Figure 5 – Mean Taurid ZHRs for each given date, combined as those in Figure 4, and for similar reasons. Too few Taurids were segregated into their respective branches for a more detailed survey at this time. An r-value of 2.3 was assumed for these computations, after [3].

Acknowledgments

Once again, my grateful thanks go to every contributor during this period. With October proving so exciting, and not just for producing something interesting during the Draconid epoch, this is yet another reminder to all to remain alert even when nothing unusual is expected. Good luck with your next observations and clear skies!

References

[1] A. McBeath, "The Forward Scatter Meteor Year", in *IMC Proceedings 1997*, Petnica, Yugoslavia, A. Knöfel, A. McBeath, eds., IMO, 1998, pp. 39–54.

[2] R. Arlt, "Summary of 1998 Draconid Outburst Observations", *WGN* 26, 1998, pp. 256–259.

[3] A. McBeath (comp.), "Meteor Shower Calendar: October 1998–March 1999", *WGN* 26, 1998, pp. 147–153.

[4] J. Rendtel et al., "Meteor Shower Descriptions", in *Handbook for Visual Meteor Observers*, J. Rendtel, R. Arlt, A. McBeath, eds., IMO, 1995.

[5] J. Rendtel, H. Betlem, "Orionid Meteor Activity on October 18, 1993", *WGN* 21, 1993, pp. 264–268.

TV Observations of the 1998 Giacobinid Outburst

Satoru Suzuki, Toshimichi Akebo, Takatsugu Yoshida, and Kazuhiro Suzuki

Simultaneous multi-station TV observations by the *Damine Meteor Observatory* (*DMO*) group have been performed since 1988. On October 8, 1998, the Giacobinids showed an outburst at $13^{\mathrm{h}}.2$ UT. Precise trajectories and orbits could be calculated for 20 Giacobinid meteoroids. It is found that the distribution of the radiant positions constitutes a small cluster. The cluster is located around $\alpha = 263^\circ.2 \pm 1^\circ.4$ and $\delta = +55^\circ.42 \pm 0^\circ.70$ (J2000.0).

1. Introduction

The Giacobinid meteor shower has shown significant activity in 1933, 1946, and 1985. The activity seemed to be related to the return of the parent comet 21P/Giacobini-Zinner, which was due to reach perihelion in November 1998.

On October 8, 1998 (UT), many Japanese observers observed the burst of Giacobinid meteors near a solar longitude $\lambda_{\odot} = 195\overset{\circ}{.}07$ (J2000.0). The multi-station TV observations by the *Damine Meteor Observatory* (*DMO*) group recorded faint meteors and calculated their orbits and trajectory parameters since 1988 [1,2].

The (*DMO*) group observed more than 50 simultaneous meteors. We present the first results of 20 Giacobinid meteors obtained by S. Suzuki and T. Akebo.

2. Observations

On October 8 (UT), 1998, the multi-station TV observations of the (*DMO*) group set up at four observing sites. The locations and the TV systems are given in Table 1.

Table 1 – Locations and observational equipments.

Observer	T. Yoshida	S. Suzuki	K. Suzuki	T. Akebo
Longitude	137°31′48″ E	137°30′15″ E	137°19′26″ E	137°13′28″ E
Latitude	35°03′54″ N	34°54′29″ N	34°48′47″ N	34°54′38″ N
Lens	135 mm, $f/2$	85 mm, $f/1.2$	135 mm, $f/2$	85 mm, $f/1.4$
Field	8° × 6°	13° × 11°	10° × 10°	16° × 16°
Video camera	WV-VD400	WV-BD800	GR-S95	AG-400
PC digitizer (pixels)	512 × 512	512 × 480	512 × 480	–

Our systems were equipped with MCP image intensifiers (Hamamatsu VP1366P, type S25), medium focal-length telelenses (with low f ratio), CCD cameras, and video cassette-recorders, set up on an equatorial mounting. The cameras were aimed at a position about 20°–25° from the radiant point of the Giacobinids. The cameras were guided by motor drive systems. So, we could record a fixed field and very faint Giacobinids because of the slow angular velocity. The measurements of the positions of the comparison stars are very easy.

3. Data reduction

In the first step, we watched the video tapes to find out the occurrences of meteors. After this hard work, we compared the meteor direction, velocity, and brightness to identify the simultaneous meteors. In the second step, for example, S. Suzuki uses a video-digitizing card with a resolution of 512 × 480 pixels and a personal computer (Pentium 90 MHz, 32 MB RAM, 1.8 MB hard disk, 230 MB MO-drive). We measured about 15 reference stars around each meteor path to determine the position of a meteor. The mean positional error was $1\overset{'}{.}16$ in this study. In the final step, the atmospheric trajectory parameters and heliocentric orbits were calculated with the MEXY4, ORBIT3 software developed by M. Ueda. The D-criterion [3] and the D'-criterion [4] were calculated with the DHANT software written by Y. Shigeno.

4. Obtained data

The results of the meteor data are listed in Table 2. The standard deviations in the orbital elements was determined by the errors of the positional measurements of the meteors estimated by 10 different ways giving deviations of the parameters. The apparent magnitude was estimated by comparing with nearby stars along the path of the meteor across the screen.

5. Discussion

Figure 1 shows the distribution of the radiant points of the Giacobinid meteors. The mean radiant point of the Giacobinids is $\alpha = 263\overset{\circ}{.}2 \pm 1\overset{\circ}{.}39$, $\delta = +55\overset{\circ}{.}42 \pm 0\overset{\circ}{.}695$ (J2000.0) which is similar to other data (e.g., [5]). The radiant area has an elliptic core, but mass-dependent effects are not visible in our TV results.

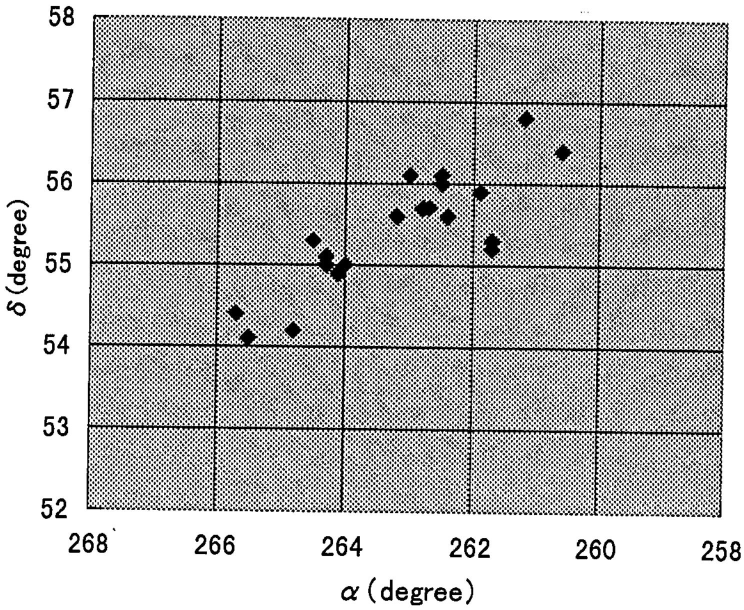


Figure 1 – Geocentric radiant point of the Giacobinid meteors observed by the *DMO* group on October 8, 1998.

Table 2 – The trajectories and orbits of Giacobinid meteors. This table lists the appearance time (UT), the apparent magnitude, geocentric radiant point, geocentric velocity, beginning and end heights, orbital elements, absolute magnitude, Q (the angle between the meteor trails from both stations; absolute values), D, and D'.

No	Time (UT)	Mag	α	δ	V_g (km/s)	H_b (km)	H_e (km)	Q
1	$12^h36^m27^s$	+6	265°7 ± 1°4	+54°4 ± 0°5	19.4 ± 0.7	102.9	93.9	32°7
2	$12^h40^m19^s$	+5	261°2 ± 1°0	+56°8 ± 0°3	20.7 ± 0.3	102.6	93.1	27°7
3	$12^h44^m57^s$	+7	261°7 ± 1°6	+55°3 ± 0°2	20.7 ± 0.9	96.7	89.7	34°2
4	$12^h45^m52^s$	+4	264°5 ± 0°8	+55°3 ± 0°1	20.9 ± 0.3	101.4	89.0	37°9
5	$12^h58^m20^s$	+2	262°8 ± 0°6	+55°7 ± 0°1	20.6 ± 0.2	105.2	86.0	40°2
6	$13^h07^m24^s$	+5	262°5 ± 1°9	+56°1 ± 0°2	20.9 ± 0.9	102.8	92.2	41°5
7	$13^h10^m41^s$	+6	263°0 ± 2°3	+56°1 ± 0°3	20.0 ± 0.7	102.6	94.5	30°2
8	$13^h11^m03^s$	+5	264°8 ± 1°4	+54°2 ± 0°2	20.0 ± 0.4	105.1	93.9	26°0
9	$13^h11^m09^s$	+6	261°9 ± 1°7	+55°9 ± 0°2	19.7 ± 0.8	101.0	92.3	42°9
10	$13^h11^m41^s$	+3	262°4 ± 0°8	+55°6 ± 0°1	20.3 ± 0.5	103.7	87.4	57°7
11	$13^h12^m42^s$	+7	265°5 ± 1°4	+54°1 ± 0°4	20.7 ± 0.9	100.3	95.7	68°3
12	$13^h12^m52^s$	+5	262°5 ± 1°9	+56°0 ± 0°3	20.5 ± 0.7	101.5	93.4	29°2
13	$13^h17^m37^s$	+6	264°1 ± 2°4	+54°9 ± 0°4	20.0 ± 0.9	100.2	90.9	56°9
14	$13^h18^m59^s$	+5	264°0 ± 2°2	+55°0 ± 0°4	21.1 ± 0.8	102.3	90.8	31°8
15	$13^h22^m52^s$	+5	260°6 ± 2°9	+56°4 ± 0°4	21.4 ± 0.7	102.4	93.2	29°3
16	$13^h26^m40^s$	+7	264°3 ± 2°4	+55°0 ± 0°3	20.4 ± 0.7	102.6	94.9	29°2
17	$13^h29^m39^s$	+6	261°7 ± 1°9	+55°2 ± 0°2	19.8 ± 0.6	101.4	93.6	26°2
18	$13^h32^m31^s$	+3	262°7 ± 0°5	+55°7 ± 0°1	20.8 ± 0.2	105.0	87.1	32°7
19	$13^h37^m51^s$	+4	264°3 ± 1°0	+55°1 ± 0°1	20.3 ± 0.4	103.6	93.5	31°5
20	$13^h41^m33^s$	+6	263°2 ± 2°0	+55°6 ± 0°3	20.7 ± 0.8	101.4	92.4	24°3
Average		+5.2	263°2 ± 1°6	+55°4 ± 0°3	20.5 ± 0.6	102.2	91.9	36°5
Standard dev.		1.4	1°4 0°7	0°7 0°1	0.5	1.9	2.7	11°6

These 20 meteors are clearly Giacobinid meteors judging from the radiant points, the atmospheric trajectory parameters, and their heliocentric orbits, which are similar to that of the parent Comet 21P/Giacobini-Zinner. The orbital elements of this study, those of the parent comet, and the results of 1985 [5] are given in Table 3.

We plotted the beginning (H_b) and end heights (H_e) of the 20 Giacobinids against the absolute magnitude in Figure 2. The two lines are the least-square fits through the data. We would like to suggest that the beginning heights and end heights are correlated to the absolute magnitude. The slopes of the lines of H_b versus the absolute magnitude were compared with the results from slow speed meteors observed and analyzed by the *DMO* group, yielding, for the Giacobinids of 1998 and the sporadics of 1988–1993, respectively,

$$H_b = -0.99\ M + 107.3\ (r = 0.7\ );\ H_e = -1.45M + 84.4\ (r = 0.73);\ \text{and}\ \overline{V}_g = 20.5\ \text{km/s};$$
$$H_b = -0.052M + 103.3\ (r = 0.014);\ H_e = -1.96M + 83.5\ (r = 0.38);\ \text{and}\ \overline{V}_g < 50\ \text{km/s},$$

where M is the absolute magnitude, $\overline{V}_g$ is the average geocentric velocity, and r the correlation coefficient.

6. Magnitude distribution

Figure 3 shows a histogram of the apparent TV magnitudes as observed by S. Suzuki only. In his sample, 84 meteors were Giacobinids and 28 meteors were sporadic meteors. The mean magnitude of the Giacobinids is +5.4.

Acknowledgments

We wish to thank Mr. Masayoshi Ueda and Mr. Yoshihiko Shigeno for their computer programs.

Table 2 – Continued.

No	Time (UT)	a (AU)	e	q (AU)	Ω	i	ω	P (yr)	Abs Mag	D	D'
1	$12^h36^m27^s$	3.07	0.675	0.997	195°05	29°50	174°86	5.39	+6.4	0.07	0.03
2	$12^h40^m19^s$	3.04	0.672	0.996	195°06	31°90	172°36	5.30	+5.5	0.05	0.03
3	$12^h44^m57^s$	3.35	0.703	0.995	195°06	31°46	172°36	6.13	+7.4	0.03	0.02
4	$12^h45^m52^s$	3.72	0.732	0.997	195°06	31°43	174°30	7.16	+4.4	0.04	0.02
5	$12^h58^m20^s$	3.33	0.701	0.996	195°07	31°41	173°15	6.07	+2.3	0.03	0.02
6	$13^h07^m24^s$	3.41	0.708	0.996	195°07	31°87	173°08	6.30	+5.1	0.03	0.01
7	$13^h10^m41^s$	2.90	0.665	0.996	195°08	30°84	173°42	4.94	+6.3	0.05	0.03
8	$13^h11^m03^s$	3.37	0.704	0.997	195°08	30°04	174°20	6.18	+5.1	0.05	0.02
9	$13^h11^m09^s$	2.78	0.641	0.996	195°08	30°47	172°53	4.63	+6.3	0.08	0.05
10	$13^h11^m41^s$	3.14	0.683	0.996	195°08	31°02	172°83	5.57	+3.2	0.05	0.03
11	$13^h12^m42^s$	4.04	0.753	0.997	195°08	30°82	174°66	8.11	+7.3	0.06	0.03
12	$13^h12^m52^s$	3.15	0.683	0.996	195°08	31°35	173°04	5.58	+5.1	0.04	0.03
13	$13^h17^m37^s$	3.21	0.689	0.997	195°08	30°39	173°83	5.75	+6.2	0.05	0.02
14	$13^h18^m59^s$	3.94	0.747	0.997	195°08	31°60	173°86	7.81	+5.2	0.05	0.03
15	$13^h22^m52^s$	3.50	0.716	0.995	195°09	32°56	171°82	6.55	+5.2	0.07	0.03
16	$13^h26^m40^s$	3.44	0.710	0.997	195°09	30°88	174°03	6.38	+7.2	0.04	0.02
17	$13^h29^m39^s$	2.92	0.659	0.995	195°09	30°35	172°21	4.98	+6.2	0.06	0.04
18	$13^h32^m31^s$	3.42	0.709	0.996	195°09	31°61	173°10	6.33	+3.0	0.03	0.01
19	$13^h37^m51^s$	3.36	0.703	0.997	195°10	30°81	174°08	6.15	+4.2	0.04	0.02
20	$13^h41^m33^s$	3.45	0.711	0.996	195°10	31°47	173°45	6.41	+6.0	0.03	0.02
Average		3.33	0.698	0.9963	195°08	31°09	173°36	6.09	+5.4	0.05	0.03
Standard dev.		0.32	0.028	0.0007		0°70	0°83	0.87	1.4		

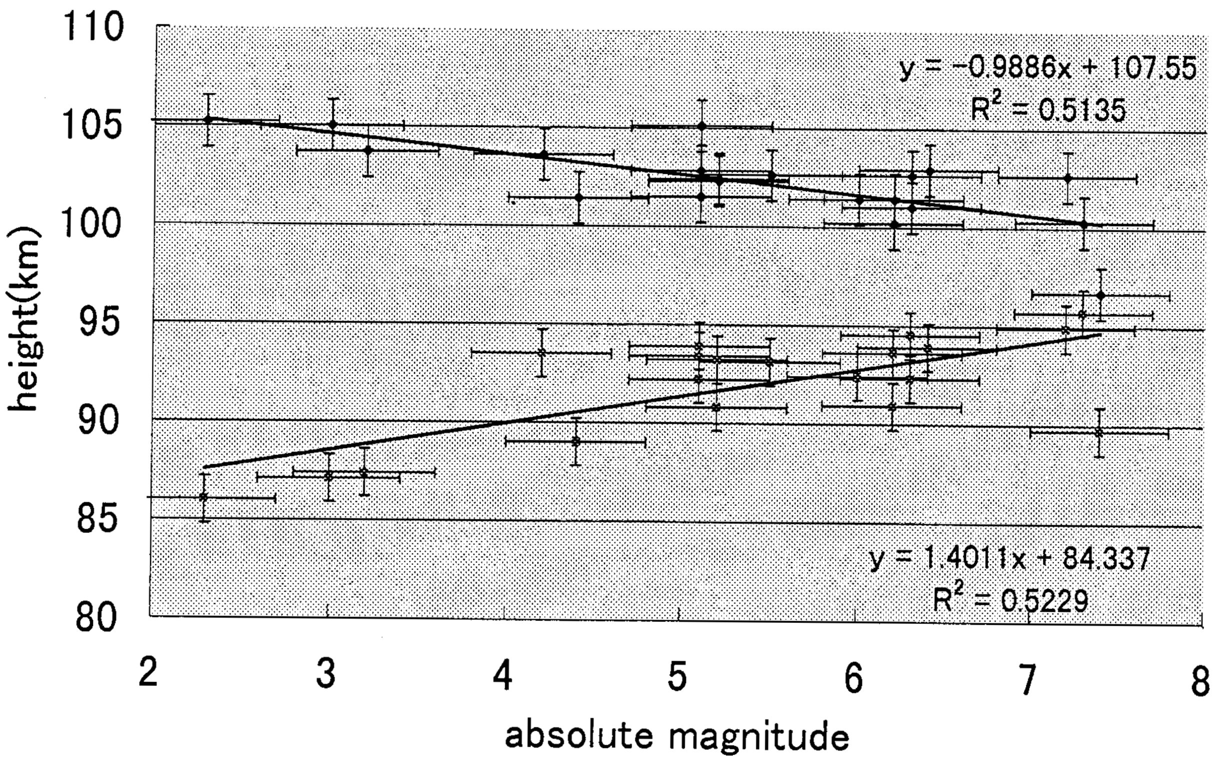


Figure 2 – Giacobinid beginning and end heights as functions of absolute magnitude.

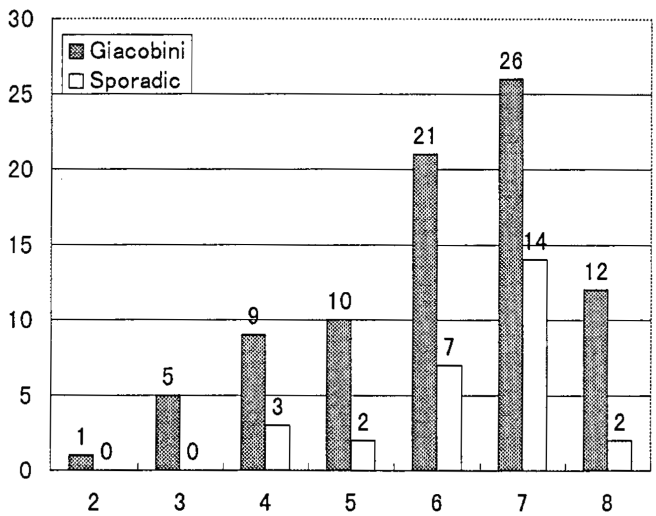


Figure 3 – Histogram of apparent TV magnitudes.

Table 3 – Orbital elements and their standard deviations.

Source	a	e	q	Ω	i	ω	α	δ
DMO Giacobinids	3.33	0.698	0.996	195°.08	31°.09	173°.36	263°.20	+55°.42
Standard deviation	0.32	0.028	0.001		0°.70	0°.83	1°.39	0°.70
21P/Giacobini-Zinner [6]	3.52	0.706	1.0337	195°.397	31°.86	172°.55		
Giacobinids 1985 [5]	3.35	0.703	0.996	195°.3	31°.5	173°.06	262°.7	+56°.1

References

[1] K. Suzuki, T. Akebo, S. Suzuki, T. Yoshida, *WGN* 22, 1994, pp. 50–51.

[2] S. Suzuki, T. Yoshida, K. Suzuki, T. Akebo, *WGN* 22, 1994, pp. 137–139.

[3] R.B. Southworth, G.S. Hawkins, *Smithson. Contrib. Astrophys.* 7, 1963, pp. 261–285.

[4] J.D. Drummond, in *Proc. Southwest Reg. Conf. Astron. Astrophys.* 5, 1979, p. 83.

[5] K. Ohtsuka, *Astron. Circ.* 674, 1998.

[6] S. Nakano, *Minor Planet Circ.* 25184, 1998.

Results of Radio Meteor Scatter Observations for the Outburst of the 1998 Draconid Meteor Shower

Eisse Pieter Bus

Radio observation results by forward scattering are given for the outburst of the 1998 Draconid (Giacobinid) meteor shower. The radio observations showed clearly that the shower was active for at least 6 hours. Activity was rising steeply after about 12^h30^m UT to a sharp maximum at 13^h10^m UT on October 8, 1998, at $\lambda_\odot = 195^\circ\!.075$ (J2000.0).

1. Observing period

Because of the results of B.A. Lindblad [1] and other observers in 1985 [2] and the expectations by E.D. Reznikov [3], the observing period on October 8, 1998, was chosen between 7^h05^m and 20^h55^m UT.

2. The equipment

Meteors were detected by receiving forward scattered VHF radio waves at a frequency of 72.11 MHz. The receiver used was a Bearcat UBC 860XLT scanning radio with an RF sensitivity of 0.5 μV for a signal-to-noise ratio of 12 dB and an IF selectivity of 50 dB at approximately 25 kHz. The transmitter, a Polish broadcast station, is located in Wrocław, the receiver is located in Groningen, the Netherlands. The path length between Groningen and Wrocław is about 740 km. A three-element Yagi antenna with a folded dipole was used at the receiving station. The antenna was directed to azimuth 106° (ESE) with an elevation of 13° towards Wrocław. The main lobe of the antenna was directed towards the 100-km level, vertically above the mid-point of the transmitter-receiver path.

3. The observational data

"Sporadic" activity was observed by listening and counting in 5-minute intervals on October 3, 10, and 11. On October 8, the total meteor activity was observed by listening and counting in 5-minute intervals. The numbers are corrected for "dead-time." Dead-time marks the period in which a certain signal of amplitude may mask other signals of lesser amplitude. The dead-time corrections were applied according to the "Geiger-counter method."

4. The shower rates

The net values of the shower meteors were calculated by subtracting the mean "sporadic" meteor counts as observed during the same observation periods. For each period, this net shower value was divided by the value of the normalized observability function after Hines [4] to obtain the estimated true shower activity.

5. The Draconids

The long-lasting reflections of more than 1 second (open squares) and the total number of all reflections (dots) in Figure 1 show evidently that Draconid activity rose significantly (more than 3σ) above background level after 9^h UT. After about 11^h UT, the number of reflections was rising strongly and after about 12^h30^m UT the number was rising steeply to a sharp maximum around 13^h UT. Between about 12^h55^m and 13^h05^m UT, saturation of the signal occurred. Therefore, no individual reflections were counted during this period. Between 13^h05^m and 13^h25^m UT, a reflection was counted almost every 12 seconds. After 13^h25^m UT, a sharp drop in the activity is monitored, and, after 14^h40^m UT, interference obscured the observations until about 17^h UT, probably caused by nearby computers. Between 17^h UT until 21^h UT, if the Draconids were still active, activity was below the detection level. The increase of activity in Figure 1 after 20^h UT is almost certainly artificial and probably also caused the higher activity before 8^h30^m UT. During the whole observing period, the duration of the long-lasting reflections was in the order of 2–4 seconds and reflections lasting longer than 10 seconds were very rare.

6. The peak

Corrected for "dead-time," "sporadics" (about one per minute between 12^h and 14^h UT) and "observability function" after Hines [4], a maximal value of about 1020 ± 84 is calculated for all reflections and about 315 ± 17 for the long-lasting reflections of more than 1 second. Because of saturation of the signal, the results around 13^h UT are probably too low. A half-width maximum is calculated around 13^h10^m UT at a solar longitude of 195°075 for all the Draconids. Also the maximum of the long-duration reflections of more than 1 second (comparable to the visual brighter Draconids) is found for this time.

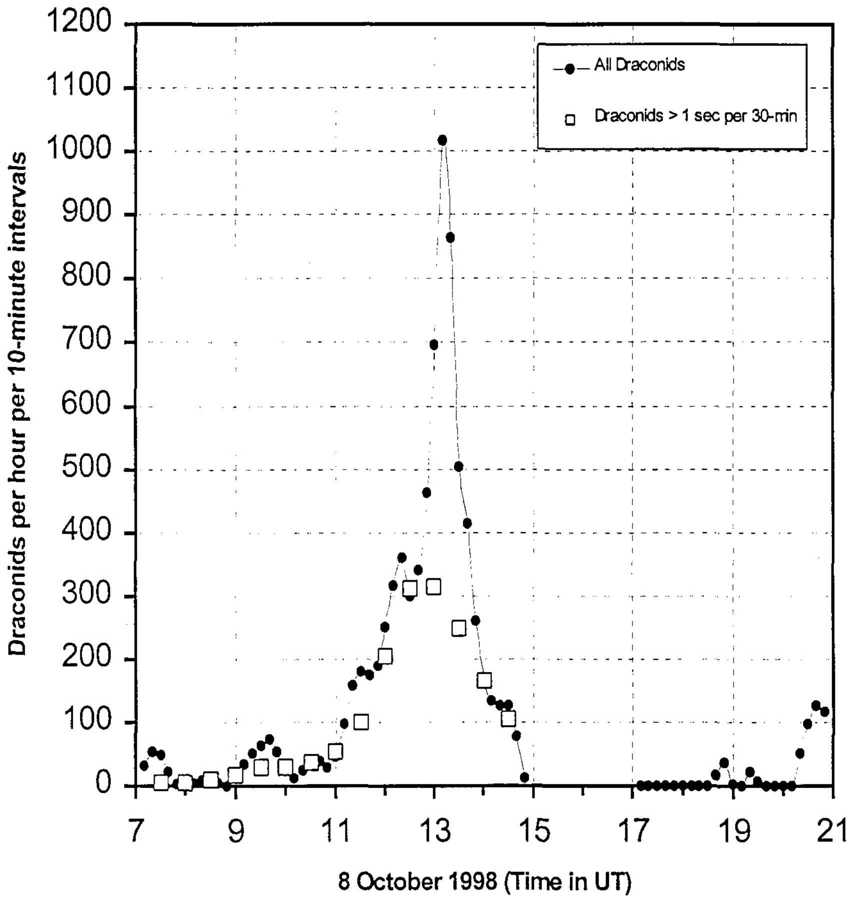


Figure 1 – Hourly radio rates of Draconids (Giacobinids) as recorded on October 8, 1998, corrected for dead-time, sporadics and observability function after Hines [4]. The dots represent all Draconids per 10-minute intervals, and the open squares, Draconids with reflection times of more than 1 second per 30-minute intervals. The "dip" around 12^h30^m UT is probably artificial.

7. Comparison with other observations

The activity profile (between about 11^h and 15^h UT) and the time of maximum is almost exactly the same as found by R. Arlt derived from visual observations [5].

References

[1] B.A. Lindblad, *Astron. Astrophys.* 187, 1987, pp. 928–930.

[2] *IAU Circular* 4120 and 4124, 1985.

[3] E.D. Reznikov, *personal communications*, September 1998.

[4] C.O. Hines, *Canadian J. Phys.* 22, 1955, pp. 493–503.

[5] R. Arlt, *WGN* 26:6, December 1998, pp. 256–259.

The International Meteor Organization

Council

President: Jürgen Rendtel, Seestraße 6, D-14476 Marquardt, *Germany*,
tel. +49 (332) 08 50753, e-mail: `president@imo.net`

Vice-Pres.: Alastair McBeath, 12A Prior's Walk, Morpeth, Northumberld. NE61 2RF, *Engl.*,
tel. +44 (1670) 518 487

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

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

Other council members:
Rainer Arlt, Friedenstraße 5, D-14109 Berlin, *Germany*
Godfrey Baldacchino, "Sirius," Triq-Il-Migbha, ZBR 10 Marsascala, *Malta*
Marc Gyssens, Heerbaan 74, B-2530 Boechout, *Belgium*
André Knöfel, Saarbrücker Straße 8, D-40476 Düsseldorf, *Germany*
Sirko Molau, Weidenweg 1, D-52074 Aachen, *Germany*

Commission Directors

Visual Commission: Rainer Arlt, e-mail: `visual@imo.net`

Telescopic Commission: M. Currie, 660, N'Aohoku Place, Hilo, *HI 96720, USA*,
e-mail: `tele@imo.net`

FIreball DAta Center: André Knöfel, e-mail: `fidac@imo.net`

Photographic Commission: Marc de Lignie, Prins Hendrikplein 42, NL-2264 SN Leidschendam,
the Netherlands, e-mail: `photo@imo.net`

Video Commission: Sirko Molau, e-mail: `video@imo.net`

WGN — The Journal of the IMO and Report Series

Web Site: `http://www.imo.net`

Addresses of contact authors not mentioned above

R. Gorelli, Via di Val Favara n. 72, Pal. B, I-00168 Roma, *Italy*
P. Ziminkoval, Tatranska 6, SK-974 00 Banska Bystrica, *Slovakia*
R.H. McNaught, Siding Spring Observatory, Coonabarabran, *New South Wales 2357, Australia*
E. Ofek, School of Physics and Astr., Tel-Aviv Univ,, Tel-Aviv 69978, *Israel*
J. Rao, 57 Dogwood Lane, Levittown, *NY 11756-1527, USA*
Y. Shigeno, 2024 Kizukisumiyoshi-cho, Nakahara-ku, Kawasaki-shi,
Kanagawa-ken, 211-0021, *Japan*
A. Olech, Warsaw Univ. Astr. Obs., Al. Ujazdowskie 4, PL-00-478 Warszawa, *Poland*
S. Suzuki, 20-11 Ishika, Higashi-ohtomo-chou, Okazaki City, Aichi-ken 444, *Japan*
E.P. Bus, Eerste Spoorstraat 16, NL-9718 PB Groningen, *the Netherlands*

Do not miss it! Register now!

International Meteor Conference 1999

Frasso Sabino, Italy, September 23–26, 1999

Do not miss this unique opportunity to meet like-minded people! We anticipate that due to the location a lot of meteor enthusiasts from all over Europe, in particular Southern Europe, will participate. Results on the 1998 Leonids and discussions on the 1999 Leonids may be expected. Registration information and information on how to obtain financial support from the *IMO* can be found in this issue.

The stock of the IMO

	DEM	EUR	USD
Publications in English:			
Photographic Meteor Data Base (1986)	8	4.09	6
Proceedings International Meteor Conference 1990	10	5.11	8
Proceedings International Meteor Conference 1991	10	5.11	8
Proceedings International Meteor Conference 1992	10	5.11	8
Proceedings International Meteor Conference 1993	12	6.14	9
Proceedings International Meteor Conference 1994	10	5.11	8
Proceedings International Meteor Conference 1995	12	6.14	9
Proceedings International Meteor Conference 1996	12	6.14	9
Proceedings International Meteor Conference 1997	12	6.14	9
Proceedings International Meteor Conference 1998	12	6.14	9
Gnomonic Atlas Brno 2000.0	5	2.56	4
Photographic Astrometry + diskette	13	6.65	10
Visual Handbook	25	12.78	20
WGN Observational Report Series:			
Vols. 1–4 (1988–91): Visual and Fireball Obs., per vol.	15	7.67	12
Vol. 5 (1992): Visual Observations	15	7.67	12
Vol. 6 (1993): Vis. Obs. and Electrophonic Fireball Cat.	20	10.23	16
Vols. 7–10 (1994–97): Visual Observations, per vol.	20	10.23	16
Backissues of the WGN Journal:			
Volumes 19–20 (1991–92): complete, per volume:	20	10.23	16
Volumes 21–22 (1993–94): complete, per volume:	25	12.78	20
Volumes 23–26 (1995–98): complete, per volume:	35	17.90	25
Backissues of Fidac News:			
Volumes 1–6 (1993–98) : complete, per volume:	15	7.67	12