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This photograph was taken on May 4, 1995, at the Descanso Observatory, California, USA, and shows, standing, from left to right, Robert Lunsford, Rainer Arlt, and Jürgen Rendtel, and, sitting, from left to right, David Holman and George Zay.

In this issue:

- Updated working list of visual meteor showers
- Practical information for all observers
- First report on the 1995 Perseids
- Lots of information on the Leonid Meteor Stream
- Historical notes on meteor astronomy
- A recently discovered crater complex in Argentina
- Observational results

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Useful Information

The October Issue *(WGN 23:5)*

The *October issue* is anticipated to be another thick issue and will be mailed towards the middle of September. Contributions are due on *September 29* at the latest. They should be sent to *Marc Gyssens.*

Administrative Correspondence

Ordering *IMO* publications is done in the same way as paying subscription/membership fees. Complaints about not receiving *WGN* or changes of address should be sent to *Paul Roggemans.*

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

From the Editor-in-Chief

Marc Gyssens

Professional obligations abroad of the editor on the one hand and the desire to continue a tradition of providing first-hand information on the Perseids in the August issue are responsible for this issue being late. Japanese observations confirm that the Perseids peaked at about the same solar longitude as last year. Elsewhere in this issue, you find a summary of the reports available thus far, compiled by Jürgen Rendtel. All observers are kindly requested to send in their summer observations to the appropriate person as soon as possible to prevent delays in compiling a more final report.

Special thanks are due to Cis Verbeeck, whose assistance in editing this issue is greatly appreciated.

Letters to WGN

compiled by Marc Gyssens

Dark meteors

Anomalous meteor-like phenomena seem to spark a lot of controversy among meteor observers, judging from the large number of letters on this subject in WGN*. David Holman and George Zay comment on Alastair McBeath's article on dark meteors in the June issue (*WGN 23:3*, pp. 91–96) from their own experience. Marco Langbroek, on the other hand, does not go into the nature of the phenomenon, but suggests that it has a long history.*

Regarding Alastair McBeath's "Dark Meteors," I have some comments and observations to share. My experience with dark meteors is similar to McBeath's, that is two, one, or most often, zero per night. I certainly seem to have more than my share of floaters, especially during certain day-time conditions, but it may only seem that way because my vision is very sharp otherwise, so I notice them more. When visually observing, I let my vision wander around my stated field center, sometimes quite far, and often shift my vision suddenly if alerted by something in my peripheral vision like a star twinkle, an aircraft, or sometimes an actual meteor. I have never kept track, but dark meteor occurrances seem to be associated with vision shifts. I also tend to see them against the bright parts of the Milky Way, but not exclusively. On one occasion, while watching a dark meteor that happened to be moving in the same direction, I was moving my vision, I suddenly shifted my vision about 90° from the dark meteor path, and the "dark meteor" changed direction to match! I have disregarded them ever since.

I would not completely rule out flying creatures (bats, birds, and insects) either. More often than not, my visual observing is done from remote sites that are miles from the nearest artificial light source, or any other human. It is quite close to being silent, in that internal noise seems to be the limiting factor as far as hearing sensitivity is concerned. It is not unusual for any of these types of creatures to be nearby without generating any discernible sound whatsoever. Of course, at such a site almost any object viewed against the night sky is pitch black by comparison. Even at limiting magnitude 6.5, the sky is far from completely black. If we could see darker objects than the glowing air *through* the glowing air, then we should be able to see the pure blackness of space unimpeded by the atmosphere, which of course, we cannot.

I have also noticed that if I am startled by a sudden sound and I jump or flinch even slightly, the sky gets noticeably darker instantaneously. Star counts made immediately after being startled are the same as those made before while in a normal state of mind. This may be related to the ganzfeld state.

David Holman, July 5, 1995

I was fascinated by Alastair McBeath's article about Dark Meteors and his reference to my letters [1,2] about the subject. As I mentioned in my April 1995 letter to WGN on Dark Meteors, electrophonic meteors, mysterious noises and a UFLO, I feel that a high percentage of what I saw were visual artifacts within my own eyes. However, when I observed those three objects that I talked about in the letter of June 1993 [1], I felt certain that these were real. In reference to the linear object moving perpendicular to its long axis, I feel confident that this must have been some sort of illusion. As to how it was done, however, I am very baffled. I am well aware about "floaters" and their causes. At the time I saw my linear object, I initially considered floaters as a possibility but quickly discounted them because it just did not move like any floaters I have ever perceived. Simply put, it did not "float"—it moved with a propelled direction. For it to be real, I have reasoned its fragile appearance would be quickly torn apart. It was not. It stayed intact along its entire "path." The most unusual object was that 3rd magnitude meteor that sparkled in places. I have not seen any more objects that resembled the linear object nor the "sparkler."

However coincidental as it may seem, just last week I saw (either on July 2-3 or July 4-5) a meteor that may be related to the "sparkler." It appeared broad-shaped like the "sparkler," but it did not sparkle. It was "solid" and of 3rd or 4th magnitude. The light from it seemed homogeneous and soft. The best way I can describe it was to say that it resembled a section of a bright persistent train that moved like a meteor. Other than saying to Lunsford that the meteor was funny looking, nothing more was said. Unfortunately, Lunsford was recording data from a previous meteor at the time I made my sighting.

As to the broad-shaped "dark meteors," It seems that I have seen far too many for Lunsford to not notice them also. I believe he has mentioned seeing only one possible object. Robert often sees meteors that I do not. His perception is excellent. If dark meteors are real, it seems logical to conclude that he would see more than I, but he does not. I still see dark meteors on occasion, but I tend to ignore them as nuisances rather than objects. Unless they are brighter or exhibit some other interesting characteristics I do not want to get hung up on them. Also, I am confident to say that what I "see" are not bats or night flying birds.

[1] G. Zay, "in Letters to WGN", *WGN* 21:3, June 1993, p. 81.

[2] G. Zay, "in Letters to WGN", *WGN* 23:2, April 1995, pp. 27–28.

George J. Zay, July 9

Last June's issue of *WGN* contained an article by Alastair McBeath about "black meteors." While I do not want to go into the issue of the nature of these "black meteors" (apart from the passing reference that I regularly "observe" them myself, but have always believed them to be phenomena of a physiological character), I would like to point out that the observation of "black meteors" goes back to the ancient times when the very first textual references to meteoric phenomena were made. There exists quite a number of Hittite hieroglyphic and Akkadian cuneiform clay tablets from about 1200 BC onwards which contain references to "falling" or "flashing" stars (*kakkabu maqātu* and *kakkabu sarāru* in Akkadian). They are always astromantic in character (i.e., describing the omen of an event to happen), e.g., statements like this (from a letter by a court astronomer, 8–7th century BC):

> *If a fireball flashes and its flashing is as bright as daylight and it has a tail like a scorpion while it is flashing, it is a favorable omen, not for the master of the house, but for the whole land.*

Interestingly, there exists a text which contains several meteoric omens, amongst which two refer to the subject of "black meteors:"

> *If a meteor comes from above the Wagon Star* [the constellation Ursa Major] *and is dark and passes at the right of the man, that man will see injury.*

I hope George Zay is still all right after this bad omen! Luckily, however, we can also read the following:

> *If a meteor comes from above the Wagon Star and is dark and passes at the left of the man, that man will see the distress of his adversary.*

The particular word used is *salmu*, meaning both "dark" and "black." Other omens in the text speak of "red," "bloodstained," "golden," and "greenish lapis lazuli" colored meteors.

A compilation of Hittite and Akkadian references to meteors, including those mentioned above, is to be found in [1], with references to the particular translations from which they have been compiled.

[1] Bjorkman J.K., "Meteors and meteorites in the ancient Near East", *Meteoritics* 8, pp. 91–130, 1973.

Marco Langbroek, July 8, 1995

Limiting magnitude determination

*David Holman also comments on "An Investigation of Limiting Magnitude Determination: A Pilot Study" by Lanfranco and Baldacchino (*WGN 23:3*, pp. 87–90). Next, Visual Director Rainer Arlt compares the two methods discussed by Lanfranco and Baldacchino.*

Regarding "An Investigation of Limiting Magnitude Determination: A Pilot Study," two sources of error in the star count method were not mentioned, that is, uncertain borderline stars, and experiential knowledge of the count area's interior. The first could be solved by creating an atlas of enlarged maps of all count areas showing precise boundaries down to 8.0 or darker. The second is related, but a bit more problematic.

After observing 240 hours since 1992, I still have to re-familiarize myself with the interior details of the count areas I am using each time I observe. I think that more active and experienced observers generally have a better memory of count area details and can count more stars in an area than a less active or experienced observer simply because the faintest stars are easier to find if you know where to look for them, regardless of the type of vision used. I have found that I can get higher counts after scanning the count area with binoculars to locate potentially visible stars and split close doubles. The aforementioned maps could help here in some extent. I have been advised both pro and contra for using averted vision in counts by more experienced observers, and I find that I habitually use averted vision in my counts.

David Holman, July 5, 1995

In response to the article about limiting magnitude estimation by Sandro Lanfranco and Godfrey Baldacchino, I would like to answer the question about the standard of limiting magnitude determination. The study clearly shows that the direct vision faintest star method is not appropriate for meteor observing. In fact the vast majority of meteors are spotted outside the direct view. The faintest star method using adverted vision frequently caused contradictions to the numbers of meteors seen. Observers who are very experienced in this method often reported a higher limiting magnitude than the observed meteor number would suggest.

Scanning a certain area on the sky for faint stars resembles the watching for meteors closely. The observer moves his center of vision around the star field and counts the number of stars seen within the field, i.e., by adverted vision. The observer should not significantly increase his attention, compared to the average attention paid to meteor observing. Many observers reported that seeing moving meteors appears easier for them than spotting a resting point of the same magnitude. Hence, a slightly increased attention when counting the limiting magnitude fields may be appropriate. The estimate of the limiting magnitude is more reliable when two or three fields are counted, and the resulting limiting magnitudes averaged.

Systematical errors in the limiting magnitude estimates can be compensated by the perception factors derived for every observer during major shower analyses. A correction of the limiting magnitude, Δlm, is applied to the lm determined. However, this method only works if the limiting magnitude stays in a certain range of about 1 magnitude width. Observations under very bad conditions are likely to be compensated incorrectly.

Let me summarize the standard for limiting magnitude determination:

- Pre-defined star fields are counted using averted vision.
- Two or three of these fields should be counted for one estimate of one limiting magnitude.
- The limiting magnitude is estimated in half-hour intervals to one-hour intervals.
- Attention should not be significantly increased during the star field count, compared to the overall observation.
- Observations should be stopped when the limiting magnitude gets out of the normal range of about 1 magnitude width.

Details on problems when counting the star fields can be found in [1].

[1] Arlt R., "Frequently Asked Questions on Observing Methods", *WGN* 22:5, October 1994, pp. 156–157.

Rainer Arlt, July 15, 1995

Some thoughts about meteor clustering

*Meteor clustering is also a topic that apparently appeals to meteor observers. Below is a reaction by Andrey Grishchenyuk to a letter by Elmano Dorio (*WGN 23:2*, pp. 28–29).*

The mechanism of meteor clustering from randomly distributed particles is considered quite clearly in Dorio's letter. Indeed, clusters are revealed statistically only in the cases when we have large enough numbers of shower meteors (for the Perseids, this corresponds with the period between August 11 and 14) and small averaging time intervals. I would like, however, to recall our earlier suggestion about the classification of clusters [1] that can be discussed once more.

All clusters can be divided in 3 classes :

A. "Twins" or "streams" are the meteors that appear in a small part of the sky for very short time intervals (1 to 5 seconds).

B. Clusters of meteors ranging from 30 seconds till 3 minutes. Meteors appear within such cluster evenly or randomly or with small extrema. Such clusters are separated usually by "empty" time intervals.

C. Clouds of meteors that are large scale formations from 3 till 30 minutes seen at different stations simultaneously.

Meteors of class A probably have a genetic connection, and are created as a result of disintegration of larger particles near the Earth (maybe in the magnetosphere) or near the perihelion. A possible mechanism for this process is described in [2].

Meteors of class C also have a genetic relationship. They are remnants that give evidences about the unevenness of ejections from the comet. In his letter, Dorio proposed a mechanism for the formation of clusters of class B. It is not only possibly, but likely.

It is also necessary to say a few words on problems about more investigations of clusters.

1. Counting the distribution of meteors against the time, we cannot say that all 100% of meteors are registered. It is possible that meteors that were not registered by observers can change obtained samples essentially in one way or another.
2. The existence of tele-meteors is very important. Tele-meteors can exist in much higher abundances than visual ones. Therefore, taking in mind tele-meteors can change the total result . Therefore, we can say something about clusters only indicating the threshold of registration.

[1] Grishchenyuk A.I., "Large-Scale Structure of the Perseid Meteor Shower from Long-Basis Observations", *WGN* 19:4, August 1991, pp. 142–147.

[2] Piers P.A., Hawkes R.L., "An Unusual Meteor Cluster Observed by Image-Intensified Video", *WGN* 21:4, 1993, pp. 168-174.

Andrey Grishchenyuk

Automated radio meteor monitoring

*In the June issue (*WGN 23:3*, pp. 75–76) George Zay expressed his concern about the reliability of automated radio meteor systems. Below is a reaction by Jean-Marc Wislez.*

It is true that published results of radio meteor systems rarely seem to correspond with visually obtained activity profiles. This was recently once more pointed out by T.R. Manley and J. Riggs [1]. The real problem is however that, currently, raw counts are continuously published by owners of radio meteor systems. These raw counts hold little information about the real meteor activity when a series of parameters describing the set-up are not given. Some of these parameters are very difficult to determine for most amateur systems.

At the Public Observatory of Antwerp, Urania, I have been involved in the development of an automated radio meteor system (i.e., the RAMSES system [2]) and I have been studying the meteor scatter theory for three years now. Our main goal has been to extract physical data from the observations, and till now we did not succeed due to a lack of information on parameters describing our set-up, and due to the complexity of physical mechanisms ruling the observation process.

Unlike what George Zay expresses in his letter, all the problems threatening automated set-ups also mess up manually obtained observations. Whether or not there is a good correlation between visual and radio meteor observations, is mainly dependent on the distance to the transmitter, the transmitter power and the antennas involved, and not on whether the system is automated or manual.

What probably makes manual observations look more reliable sometimes, is that the technique is less sensitive, so mainly the brighter visual meteors yield discernible echoes, increasing the apparent correlation. More sensitive systems, like most automated set-ups, observe fainter meteors. These do not necessarily follow the same activity profiles as the brighter meteors.

Problems like aircraft interference or interference from other sources can be dealt with much more reliably with automated set-ups than with manual ones. Automated set-ups are able to record the profile of meteors, i.e., the evolution of the received power in time. This profile is a signature of the source producing the signal. Signals from meteors are quite different from signals from planes, sporadic-E or lightning. Manual observers can only note there has been a signal, but have no real clue about its origin (even when the broadcast from the transmitter is heard). The main challenge with automated systems in this respect is the development of intelligent algorithms that can distinguish between real meteor signals and other signals. This is one of the current concerns of the RAMSES team.

In essence, I want to point out that good automated systems are much more reliable and versatile than manual systems, but that in both cases extreme care has to be taken in the interpretation or reduction of the observations. Raw counts tell very little about real meteor activity, and still less about visual activity.

[1] T.R. Manley, J. Riggs, "in Letters to WGN", *WGN* 23:2, April 1995, pp. 29–30.

[2] T. Roelandts, W. Depoorter, "Presentation of the RAMSES Automated Forward Scatter Setup", in *Proceedings of the IMC Puimichel, 1993*, P. Roggemans, ed., IMO, 1994, pp. 44–46.

Jean-Marc Wislez, July 14, 1995

Anomalous meteor activity

Below is a request by Dr. Duncan Steel for more information on a possible meteor outburst.

I have recently received an enquiry about some anomalous meteor activity detected during a couple of days with the Jindalee radar in Central Australia (this is a Megawatt, over-the-horizon, 6 to 30 MHz radar operated by the Australian Department of Defense). The activity has been detected in the mornings, peaking on August 4, with a radiant estimated at $\alpha = 06^{h}30^{m}$, $\delta = +20° - +40°$.

Have there been any other reports?

Duncan Steel, Anglo-Australian Observatory, August 5, 1995

Frequently Asked Questions on Observing Methods

compiled by Rainer Arlt

Should meteor photographs be guided or not?

The accuracy of coordinates of meteors from photographs is very high. The errors are generally equal to or less than one arc minute. If the camera was not guided during the exposure, one has to choose the start or end points of a number of trails of reference stars. The meteor coordinates can be derived from the time of the meteor's appearance. The right ascension is shifted by the sidereal time difference between the start (or end) of exposure and the time of the meteor. If all these times are accurately known (± 1 s), the additional correction does not influence the measured coordinates significantly.

The advantage of guided photographs is that the exact time of appearance of the meteor need not be known. A correction in right ascension is not necessary. However, the accuracy of a non-guided photograph can only be obtained if the mounting guides the camera very precisely. Self-made mountings or mobile mountings which are set up in the field generally produce small trails from the stars rather than real dots. These errors fully add to the measuring accuracy. It is not known which is the end and which is the beginning of the trail. The guidance error could also have been non-linear.

If you are not sure about the quality of your mounting or if you see the stars deformed and not point-like on your prints, do not guide the meteor photos. The advantage of a guided photo is unimportant in case of multiple-station photographs as the time is needed to calculate the orbital elements anyway.

Let me recommend exact timings once more. An accuracy of 1 minute results in an uncertainty of $0\overset{\circ}{.}25 = 15'$ which is the angle the Earth rotates over in one minute. Hence, a good measurement is in vain when the times of exposure and meteor appearance are given with a 1-minute accuracy. Even a 5-second accuracy results in $1\overset{\prime}{.}25$ which is of the same order as the measuring accuracy. Please record the begin and end of the exposure as well as the meteor time with an accuracy of at least 5 s. In case of well-guided photographs, only the meteor time has to be known with at least that accuracy for orbital calculations.

The New Working List of Visual Meteor Showers

Rainer Arlt

A look at the past issues of *IMO*'s working list of visual meteor radiants shows a gradual evolution of both the selection of showers and their parameters. The *Shower Calendar* of 1992 contains a number of components of large radiant complexes like the Sagittarids and the Puppid/Velids. Many of these sub-radiants were removed from the list because no radiant analysis of plotted meteors from the appropriate latitudes resolved the radiants until now, and the observations made by the counting-method did not prove a distinct activity of the specific radiant above the sporadic background.

Additionally, some slight changes were necessary regarding the activity periods and the maximum ZHRs, which will represent the expectations of visual observers better. The following is a list of changes for a number of radiants as well as some items pro or contra the inclusion of a shower in the list. Italicized radiants were not included in the new working list. Do not forget that the omission of a shower does not necessarily mean this radiant does not exist. Rather, visual observations cannot provide us with reliable information about this meteor stream. They may nevertheless be interesting for telescopic, photographic, video, or radio observations.

Quadrantids (QUA): The maximum ZHR was changed to 120 according to last years' results.

δ-Cancrids (DCA): Although the activity of this radiant is low, it represents the ecliptical background activity which is notably more or less striking throughout the year. Observations during the Quadrantid activity period showed quite a number of perfect δ-Cancrids whence the activity period was prolonged to start from January 1.

α-Crucids (ACR): A ZHR profile of 97 *IMO* observations shows a value of 2–3 throughout the activity period. No photographic or radar orbits have been associated with this radiant.

α-Carinids (ACN): The profile of 74 *IMO* observations shows ZHRs of around 2 with very large scatters. Photographic or radar meteors associated with the α-Carinids are not known.

α-Centaurids (ACE): This shower produced varying activity in the last decades. An activity profile from 178 *IMO* observations of 1988–1994 shows a distinct maximum with a ZHR of 5.5 ± 0.8. No α-Centaurids have been reported before February 1, therefore, the beginning of the activity period was set to this date.

δ-Leonids (DLE): Since 1911 it is known that there is a separate radiant north of the ecliptical radiants, and it has been detected by several observers hitherto (Denning, Prentice, Hoffmeister, Whitney, Wood). 24 photographic meteors could be associated with the δ-Leonids by Lindblad [1]. According to 70 *IMO* observations the shower reaches ZHRs around 2 in the period February 15 to March 10. In this period most of the mentioned sources report distinct activity.

γ-Normids (GNO): The shower was observed visually since 1929. Radar technique allowed the determination of the orbital elements. Australian observers determined maximum ZHRs of 10 ± 2 and 3.5 ± 1.5 for 1983 and 1986 respectively. An average profile of 53 *IMO* observations shows a peak rate of 8.

β-Pavonids (BPA): (Also called δ-Pavonids.) Very low ZHRs did not prove the visual significance of this radiant. The shower was observed by the West Australian Meteor Section in the 1980s. The maximum ZHR was reported to be 1.9 ± 0.2. No photographic orbit was associated with the β-Pavonids.

Virginids (VIR): This ecliptical shower has been observed since the last century. The δ-Cancrid activity period ends on January 24 whereas the Virginids started on February 1 in the 1994 shower list. As there is no reason why the ecliptical activity should pause for a few days, the Virginids now start on January 25. The Virginid activity ends on April 15 and is taken over by the Sagittarids on the same day.

θ-Centaurids (TCE): Although the ZHR profile of 190 *IMO* observations shows maximum ZHRs around 4, no distinct maximum could be found. The scatters of these maximum values is larger than 1. About the same picture appears in [2] with maximum ZHR < 4.5. No photographic or radar orbits were found for this shower.

o-Centaurids (OCE): ZHRs are between 2 and 3. No photographic or radar orbits could be associated with this radiant.

Lyrids (LYR): Although high activity with ZHRs over 50 has been observed in the past, the list gives a ZHR of 15 as the usual value which can be expected by the observer.

α-Bootids (ABO): An analysis of 220 *IMO* observations with only plotted meteors shows a distinct activity profile with a maximum ZHR of 1. No clear ZHR profile could be obtained from the remaining 624 observations of this period with counted meteors. Although careful observations and shower association might thus be able to detect this shower, a huge number of reports would be needed to get a reliable physical information about the stream.

π-Puppids (PPU): No changes were applied to this periodically active radiant.

η-Aquarids (ETA): The time of maximum was changed to May 6 ($\lambda_\odot = 45\overset{\circ}{.}5$) with a ZHR of 60. This is the result of 523 *IMO* observations.

Sagittarids (SAG): This ecliptical radiant complex takes the place of the Virginids on April 15. The Virginid radiant is about 20° west of the Sagittarids. However, as the ZHR of the Virginids falls below 2 on April 1 we assume that the Sagittarid radiant is a better representation of the center of ecliptical activity. As they also interfere with the Capricornids in the end of July, the activity period was restricted to July 15. The ZHR of a mean profile of 129 *IMO* observations did not exceed 5. In order to fit the possible sub-radiants described below better, the declination of the radiant positions was set onto the ecliptic.

α-Scorpids (ASC), κ-Scorpids (KSC), ω-Scorpids (OSC), χ-Scorpids (CSC), β-Corona Australids (CAU), Northern Ophiuchids (NOP), Southern Ophiuchids (SOP), θ-Ophiuchids (TOP), λ-Sagittarids (LSA): A lot of radiants have been proposed in the regions of Scorpius, Sagittarius, and Ophiuchus. I found over 100 different radiants in the literature for the period April to June (Figure 1). The main component, the α-Scorpids, is well represented by the gradually moving radiation area of the Sagittarids (see above). This large complex also comprehends the notable activity of the ω-Scorpids and the γ-Sagittarids. It is likely that no distinct radiant can be found even from a large number of meteor plots in this area and period.

June Lyrids (JLY): This shower was discovered by two independent observers in 1966 and observed in detail in 1969. A weaker return is known from 1974. The present annual activity calculated from 64 *IMO* records is at 1.5 ± 0.4 without distinct maximum, i.e., at the detection limit.

June Bootids (JBO): The stream is associated with comet Pons-Winnecke, and a strong meteor shower was observed in 1916 as well as enhanced activity in 1921 and 1927. Since then, no visually significant rates have been observed.

July Phoenicids (PHE): High radio echo rates were observed in the 1950s with several tens of echos per hour. The activity profile of 87 *IMO* observations shows a maximum ZHR of 4.4 ± 0.6. The activity period was changed to July 10–July 16. The maximum occurs on July 14 according to several sources with a radiant at $\alpha = 32°$ and $\delta = -48°$.

July Pegasids (JPE): Very few data are available for this shower. Its activity period was slightly prolonged to July 13. The ZHR turned out to be 3 but might not represent the very short maximum.

Piscis Austrinids (PAU): The activity period was shrunk to July 15 to August 10. Before and after this period ZHRs were below 1, the maximum ZHR being 5.

Southern δ-Aquarids (SDA): The activity period starts later, on July 12, as rates are below visual significance before.

α-Capricornids (CAP): According to the ZHR profile of 1 625 *IMO* observations and the radiant studies in [3], the activity period ends on August 15 with a ZHR of 0.5. The maximum ZHR is 4.

Southern ι-Aquarids (SIA): Since the ZHRs of this shower are very low, the activity period was shortened to the visually detectable period July 25 to August 15. The maximum ZHR did not exceed 2.

Northern δ-Aquarids (NDA): This radiant appeared well in the Aquarid analysis throughout the activity period with a maximum ZHR of 4.

Perseids (PER): The time of maximum is given for the traditional maximum with a ZHR of 100.

κ-Cygnids (KCG): The visual activity period now ends on August 25 when ZHRs fall below 1.0 according to a profile of 5585 *IMO* observations. The maximum ZHR is 3.

Northern ι-Aquarids (NIA): As this radiant is probably the prominent representative of the ecliptical background showers, the activity period was connected to that of the Piscids and ends on August 31. This is about the result of the Aquarid analysis in [3].

π-Eridanids (ERI): No clear activity profile was obtained by Jenniskens [2], where ZHRs were around 2. The same pictures occurs in the activity profile of 42 *IMO* observations of 1988–1994 with ZHRs even lower than 2.

α-Aurigids (AUR): The maximum ZHR was set to 10, although occasionally higher peaks may occur.

δ-Aurigids (DAU): The mean maximum ZHR of 186 *IMO* observations is 6.

(Southern) Piscids (SPI): Connecting to the Northern ι-Aquarids the Piscids start on September 1 and end on September 30 to be continued by the Taurids.

κ-Aquarids (KAQ): The activity profile of 195 *IMO* observations of this shower shows a maximum ZHR of 0.9 ± 0.2. This low rate is likely to be not significant for visual observations by both the counting and plotting method. No photographic records could be associated with the radiant.

October Capricornids (OCC): A maximum ZHR of 1.0 ± 0.1 was derived from 122 *IMO* observations. No clear activity profile can be seen.

σ-Orionids (SOR): This radiant was not mentioned by Kronk [4] in 1988 and Jenniskens [2] in 1994. The activity profile of 174 *IMO* observations shows maximum ZHRs of 2.0 ± 0.6 with large variations from day to day.

Draconids or Giacobinids (GIA): This shower is known for periodic activity. It is noted as a periodic shower; the annual activity is below the visual detection limit.

ε-Geminids (EGE): Several observers had already detected this shower in the first half of this century (Denning, Prentice, Öpik, Hoffmeister). A number of photographic orbits were associated with the ε-Geminids. The activity profile of 239 *IMO* observations shows a maximum ZHR of 3.

Orionids (ORI): No changes were applied.

Northern and Southern Taurids (NTA and STA): The activity period starts on October 1 to take over the ecliptical radiation area of the Piscids.

Leonids (LEO): The Leonids promise increasing maximum ZHRs in the forthcoming years, hence, no ZHR is given.

α-Monocerotids (AMO): No changes were applied. The shower produced rich displays in 1925, 1935, and 1985. Two photographic and two radar orbits could be associated with this radiant.

χ-Orionids (XOR): No changes were applied.

December Phoenicids (PHE): Since the maximum ZHR of this shower is strongly variable, no value is given in the working list.

Puppid-Velids (PUP): This radiant should represent the major part of the numerous radiants in Puppis and Vela suggested in recent years. The activity period of December 1 to December 15 was the only time for which significant ZHRs and photographic orbits could be found. Several sources indicate a maximum ZHR around 10 on December 6.

σ-Puppids I (SPU), τ-Puppids I (TPU), π-Puppids I (PIP), λ-Velids I (LVL): These radiants constituted the major components of the Puppid-Velid complex active from October to January, and they were already a compromise between a jumble of radiants in that region. However, no systematic activity was found for none of the showers, and no photographic or radar orbits could be associated either. Regarding visual observations, only meteor plots can prove one or the other radiant.

December Monocerotids (MON): The declination of this radiant was erroneously given as $\delta = +14°$ in the working lists of 1993 to 1995 in accordance with a different radiant found by Sekanina from radar meteors [5]. The actual value, however, is $\delta = +8°$. Hence, activity calculations will be affected by this error.

σ-Hydrids (HYD): This radiant was not discovered by visual observations but by an association of seven photographic orbits. A total of 393 visual *IMO* observations show a maximum ZHR of 2.

Geminids (GEM): No changes were applied.

Coma Berenicids (COM): No changes were applied. More than 20 photographic and radar orbits count be associated with this stream. The Western Australian Meteor Section reports a maximum ZHR of 6.4 ± 3.2 in 1980, an activity profile of 679 *IMO* observations reaches a maximum of 3.9 ± 0.2.

Ursids (URS): Although the Ursids may produce enhanced activity, the list value for the maximum ZHR was set to 10.

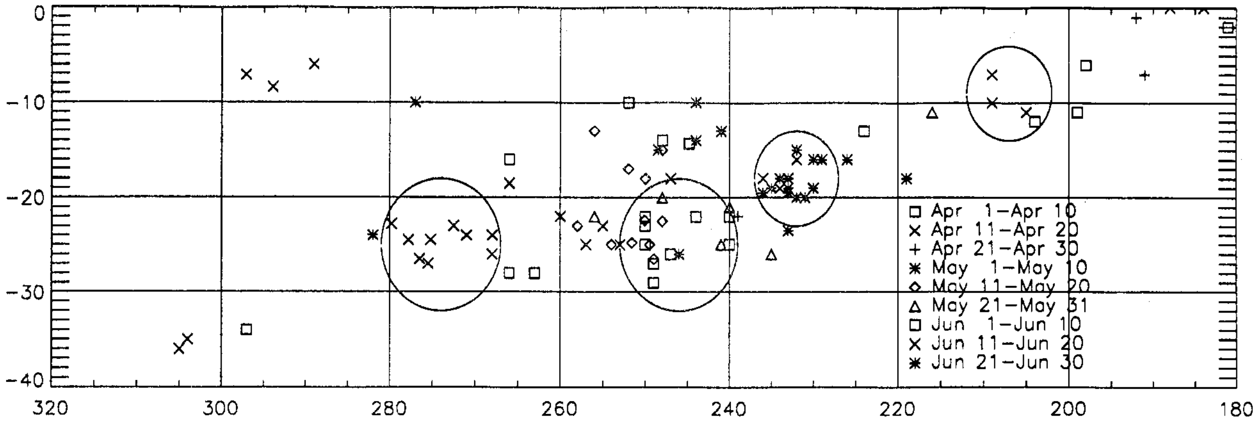

Figure 1 – Radiants found by several authors during the last two centuries. I marked a few clusters which indicate the general motion of the complex.

Table 1 – Working list of meteor showers. Streams marked with an asterisk are periodically or occasionally active, and therefore no ZHR is cited. This list with more information about the showers concerned can be found in the *IMO 1996 Meteor Shower Calendar*.

Shower	Activity	Maximum Date	Maximum $\lambda_\odot$	Radiant α	Radiant δ	Radiant Diam.	V_∞ (km/s)	r	ZHR
Quadrantids (QUA)	Jan 01–Jan 05	Jan 04	282°7	230°	+49°	5°	41	2.1	120
δ-Cancrids (DCA)	Jan 01–Jan 24	Jan 16	297°	130°	+20°	10°/5°	28	3.0	4
α-Centaurids (ACE)	Feb 01–Feb 21	Feb 07	318°	210°	−59°	4°	56	3.0	6
δ-Leonids (DLE)	Feb 15–Mar 10	Feb 25	336°	168°	+16°	5°	23	3.0	2
γ-Normids (GNO)	Feb 25–Mar 22	Mar 14	353°	249°	−51°	5°	56	2.4	8
Virginids (VIR)	Jan 25–Apr 15	Mar 25	4°	195°	−04°	15°/10°	30	3.0	5
Lyrids (LYR)	Apr 16–Apr 25	Apr 22	32°1	271°	+34°	5°	49	2.9	15
π-Puppids* (PPU)	Apr 15–Apr 28	Apr 24	33°5	110°	−45°	5°	18	2.0	
η-Aquarids (ETA)	Apr 19–May 28	May 06	45°5	339°	−01°	4°	66	2.7	60
Sagittarids (SAG)	Apr 15–Jul 15	May 20	59°	247°	−22°	15°/10°	30	2.3	5
Jul Pegasids (JPE)	Jul 07–Jul 13	Jul 11	108°	340°	+15°	5°	70	3.0	3
Jul Phoenicids* (PHE)	Jul 10–Jul 16	Jul 14	111°	32°	−48°	7°	47	3.0	
Piscis Austrinids (PAU)	Jul 15–Aug 10	Jul 28	125°	341°	−30°	5°	35	3.2	5
Southern δ-Aquarids (SDA)	Jul 12–Aug 19	Jul 28	125°	339°	−16°	5°	41	3.2	20
α-Capricornids (CAP)	Jul 03–Aug 15	Jul 30	127°	307°	−10°	8°	25	2.5	4
Southern ι-Aquarids (SIA)	Jul 25–Aug 25	Aug 05	132°	334°	−15°	5°	34	2.9	2
Northern δ-Aquarids (NDA)	Jul 15–Aug 25	Aug 09	136°	335°	−05°	5°	42	3.4	4
Perseids (PER)	Jul 17–Aug 24	Aug 12	140°1	46°	+58°	5°	59	2.6	100
κ-Cygnids (KCG)	Aug 03–Aug 25	Aug 18	145°	286°	+59°	6°	25	3.0	3
Northern ι-Aquarids (NIA)	Aug 11–Aug 31	Aug 20	147°	327°	−06°	5°	31	3.2	3
α-Aurigids (AUR)	Aug 25–Sep 05	Sep 01	158°6	84°	+42°	5°	66	2.5	10
δ-Aurigids (DAU)	Sep 05–Oct 10	Sep 09	166°	60°	+47°	5°	64	3.0	6
Piscids (SPI)	Sep 01–Sep 30	Sep 20	177°	5°	−01°	5°	26	3.0	3
Draconids* (GIA)	Oct 06–Oct 10	Oct 10	196°5	262°	+54°	2°	20	2.6	
ε-Geminids (EGE)	Oct 14–Oct 27	Oct 20	207°	102°	+27°	5°	71	3.0	3
Orionids (ORI)	Oct 02–Nov 07	Oct 21	208°	95°	+16°	10°	66	2.9	25
Southern Taurids (STA)	Oct 01–Nov 25	Nov 03	220°	50°	+13°	10°/5°	27	2.3	5
Northern Taurids (NTA)	Oct 01–Nov 25	Nov 13	230°	58°	+22°	10°/5°	29	2.3	5
Leonids (LEO)	Nov 14–Nov 21	Nov 18	235°2	153°	+22°	5°	71	2.5	var
α-Monocerotids (AMO)	Nov 15–Nov 25	Nov 20	237°	117°	−06°	5°	60	2.7	5
χ-Orionids (XOR)	Nov 26–Dec 15	Dec 02	250°	82°	+23°	8°	28	3.0	3
Dec Phoenicids (PHO)	Nov 28–Dec 09	Dec 05	253°	18°	−53°	5°	22	2.8	var
Puppid/Velids (PUP)	Dec 01–Dec 15	Dec 06	255°	123°	−45°	10°	40	2.9	10
Dec Monocerotids (MON)	Nov 27–Dec 17	Dec 10	259°	102°	+08°	5°	42	3.0	3
σ-Hydrids (HYD)	Dec 03–Dec 15	Dec 11	260°	127°	+02°	5°	58	3.0	2
Geminids (GEM)	Dec 07–Dec 17	Dec 14	262°0	112°	+33°	5°	35	2.6	110
Coma Berenicids (COM)	Dec 12–Jan 23	Dec 19	268°	175°	+25°	5°	65	3.0	5
Ursids (URS)	Dec 17–Dec 26	Dec 22	270°7	217°	+76°	5°	33	3.0	10

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Visual Observers' Notes: September–October 1995

Jeff Wood

1. Introduction

Following the excellent activity of the previous two months, observers tend to feel let down when rates return to normal during September and October. Because of this, nowhere near as much observational work has been carried out during this time even though there is much to see.

Table 1 gives a list of the active showers that occur in these months and Table 2 shows the observing conditions moon-wise. The illuminated part of the Moon is always given for 0^h UT on the date indicated. The dates of the phases of the Moon are also given in UT.

For more details, we refer to the *IMO 1995 Meteor Shower Calendar*. *(For consistency, these notes are based on the working list in the 1995 Calendar, rather than on the updated list presented in the previous article, which is used in the 1996 Calendar, ed.)* Here we highlight some of the showers visible during September and October.

Table 1 – A list of meteor showers to be seen during September and October 1995.

Shower	Activity	Maximum		Radiant			Drift		V_∞	r	ZHR
		Date	$\lambda_\odot$	α	δ	Diam.	$\Delta\alpha$	$\Delta\delta$			
π-Eridanids	Aug 20–Sep 05	Aug 29	155°.7	52°	−15°	6°	+0°.8	+0°.2	59	2.8	
α-Aurigids	Aug 24–Sep 05	Sep 01	158°.6	84°	+42°	5°	+1°.1	0°.0	66	2.5	15
δ-Aurigids	Sep 05–Oct 10	Sep 09	166°.7	60°	+47°	5°	+1°.0	+0°.1	64	3.0	7
Piscids	Aug 15–Oct 14	Sep 20	177°.7	8°	00°	8°	+0°.9	+0°.2	26	3.0	3
κ-Aquarids	Sep 08–Sep 30	Sep 21	178°.7	339°	−02°	5°	+1°.0	+0°.2	16	3.0	3
Puppid/Velids	Sep 28–Dec 30	several		120°	−45°	10°			41	2.9	
Capricornids (Oct)	Sep 20–Oct 14	Oct 03	189°.7	303°	−10°	5°	+0°.8	+0°.2	15	2.8	3
σ-Orionids	Sep 10–Oct 26	Oct 05	191°.7	86°	−03°	5°	+1°.2	0°.0	65	3.0	3
Draconids*	Oct 06–Oct 10	Oct 10	197°.0	262°	+54°	5°			20	2.6	storm
ε-Geminids	Oct 14–Oct 27	Oct 20	206°.7	104°	+27°	5°	+1°.0	0°.0	71	3.0	5
Orionids	Oct 02–Nov 07	Oct 22	208°.4	95°	+16°	10°	+1°.2	+0°.1	66	2.9	25
Taurids S	Sep 15–Nov 25	Nov 03	220°.7	50°	+14°	10°/5°	Table 5		27	2.3	10
Taurids N	Sep 13–Nov 25	Nov 13	230°.7	60°	+23°	10°/5°	Table 5		29	2.3	8

Table 2 – Moonlight and observing conditions in September–October 1995.

Date	k	Date	k
Friday September 1	0.35+	Friday October 6	0.92+
Friday September 8	0.98+	Friday October 13	0.82−
Friday September 15	0.68−	Friday October 20	0.20−
Friday September 22	0.08−	Friday October 27	0.11+
Friday September 29	0.22+	Friday November 3	0.82+

New Moon:	August 26, September 24, October 24
First Quarter:	September 2, October 1, October 30
Full Moon:	September 9, October 8, November 7
Last Quarter:	September 16, October 16, November 15

2. Piscids

This weak ecliptic stream is active from August 15 through to October 14. Rates are generally one or two meteors per hour, but on occasions have passed 5 per hour around the maximum which occurs on September 21. With a Full Moon occurring on September 9, the Piscids can best be observed under dark sky conditions from the southern hemisphere during the periods September 1–4 and September 15–October 3. Observers should face the radiant area and plot all Piscids seen taking care to distinguish them from the sporadic background. In particular, the angular velocity must be taken into account.

Table 3 – Radiant positions of the Piscids.

Date	α	δ	Date	α	δ
Sep 15	0°	−02°	Sep 30	13°	+01°
Sep 20	4°	−01°	Oct 05	17°	+02°
Sep 25	9°	00°	Oct 15	26°	+04°

3. α-Aurigids

The α-Aurigids are active from August 24 to September 5. They reach maximum on September 1. The α-Aurigids produce variable activity from year to year and urgently require attention from meteor workers in the northern hemisphere where they are best seen. The α-Aurigids are fast moving meteors comparable in speed to the Perseids. Intending observers should take into account that the radiant reaches its greatest elevation during the latter part of the night. At maximum, the Moon is at First Quarter phase and so there will be dark skies. Unless the α-Aurigid maximum exceeds a ZHR of 10, all possible shower members should be plotted. Observing fields should be centered no further than 10° from the radiant.

4. Orionids

This major shower has unfavorable Moon conditions in 1995 and is a must on the meteor observer's calendar. We also recall that in 1993 the Orionids gave an unexpected pre-maximum outburst on October 18 with ZHR values reaching 30 meteors per hour—a very unusual figure that early in the Orionids' activity period. Full Moon around that date made it impossible to verify whether this feature reoccurred in 1994. Therefore observers should carefully monitor the pre-maximum period this year.

The Orionids have a complex radiant structure with the center of activity being located just north of the star Betelgeuse at maximum. The Orionids are associated with Comet Halley and, like the η-Aquarids, display a plateau-like maximum. This can vary from year to year but is generally from October 20 to 25. The Orionid maximum occurs on October 21 with a ZHR that is usually in the range of 20 to 30 meteors per hour. Orionids are best observed during the latter part of the night when the radiant altitude rises above 20°. They are observable in both hemispheres and all possible Orionid meteors should be plotted unless the ZHR exceeds 10. Thereafter, classified counts may be taken.

Table 4 – Radiant positions of the Orionids.

Date	α	δ	Date	α	δ
Oct 10	80°	+14°	Oct 25	98°	+15°
Oct 15	86°	+15°	Oct 30	104°	+16°
Oct 20	92°	+15°			

5. Taurids

This shower is broken up into several substreams, the most important of which are called the Northern and the Southern Taurids respectively. The Taurids have one of the longest periods of activity known and last from September 13 through to November 25. They reach a broad maximum in late October and early November. The maxima of November 3 (Southern Taurids) and November 13 (Northern Taurids) given in the radiant list were derived from radio meteor and photographic meteor orbital elements and not visual observations. The last give an uncertain picture. At maximum, Taurid activity is often very erratic with rates ranging from 1–2 meteors per hour to as high as 10 or 15 meteors per hour.

In September and October, the Taurids are best observed during the middle and latter parts of the night. They are noted for their many bright meteors. These are frequently yellow and orange in color, but all of the other colors are also well represented. This together with their relatively low geocentric velocity means that they can be recorded more easily on film than most other showers. Perhaps you could try and photograph some for the *IMO Photographic Meteor Database*.

Since they have a great longevity of activity, the Taurids have parts of their activity period moon-free and others greatly affected by the Moon. They can be easily seen from both hemispheres. When observing the Taurids, all possible shower members should be plotted. In order to distinguish meteors from the branches, the center of field of view should be located between 20° and 40° east or west of the radiant at the same declination.

In September the most favorable center of field of view is around $\alpha = 0°$ and $\delta = +10°$ to $+15°$. This way, Piscid, Northern Taurid and Southern Taurid radiants can all be observed simultaneously. In October the most favorable field of view is located at $\alpha = 80°$ and $\delta = +20°$ which enables both the Taurid radiants together with the Orionid and the ε-Geminid radiants to be monitored at the same time. The *IMO* is particularly looking to obtain Taurid ZHR profiles and to investigate the population index during the 1995 Taurid watch.

Table 5 – Radiant positions for the Taurids South and North.

Date	Taurids South		Taurids North	
	α	δ	α	δ
Sep 15	11°	+01°	08°	+06°
20	15°	+02°	12°	+07°
30	23°	+05°	21°	+11°
Oct 10	31°	+08°	29°	+14°
20	39°	+11°	38°	+17°
30	47°	+13°	47°	+20°
Nov 10	56°	+15°	58°	+22°
20	64°	+16°	67°	+24°
25	69°	+17°	72°	+24°

6. ε-Geminids

This shower is active from October 14 to 27 with a maximum of 5 meteors per hour on October 20. As with the Orionids, Moon conditions are favorable in 1995 and the shower is to be targeted for investigation by the *IMO*. The ε-Geminids can be seen during the last few hours before sunrise in both hemispheres where they often produce fast blue or white trained meteors. The ε-Geminids have angular velocities similar to those of the Orionids and care should be taken when identifying possible shower members. The ε-Geminids should only be observed when the radiant reaches an elevation of 20° or more.

All possible shower members should be plotted. In order to effectively distinguish Orionids, σ-Orionids, Taurids, and ε-Geminids, the center of the observer's field of view must be located around $\alpha = 80°$ and $\delta = +20°$.

Photographic Observers' Notes: September–October 1995

Jürgen Rendtel

This is the period with the highest level of sporadic activity for observers in the northern hemisphere. Furthermore, there are some interesting showers active, promising good prospects for the photographer.

The complex of *ecliptical radiants* now moves through Pisces and Aries, reaching Taurus at the end of October. Visual results show that the rates of the Taurids remain low until mid October. One of the interesting features in meteoroid stream evolution is the formation of several branches or even different streams during long periods of time. These effects depend—among other factors—on the number of revolutions and hence are more obvious in the case of orbits with small semi-major axes like the Taurids associated with 2P/Encke. Here we distinguish a northern and a southern branch. While it is quite difficult to distinguish meteors from the two branches in visual work, photographs may yield interesting information if the camera field is properly chosen. If the radiants of both radiants line up, the only distinguishing parameter is the angular velocity, with very low differences anyway. Therefore, we recommend to center the camera field some 30° to 40° west or east from the radiants. Then we can also make use of the positional information. As usual, the begin and end times of the exposures need to be known precisely. The Taurids are known for a number of bright fireballs particularly towards the end of October—thus a promising target for the photographer anyway.

The *Orionids*, this time with rather little moonlight interference particularly during the second part of their activity period, are an interesting target for photographic observers. As in the case of other cometary showers, bright Orionids may leave long-lasting trains. Here one might get another chance to try train photography as introduced in the hints for photographers in the June issue of *WGN*.

Already in the beginning of September, there are two showers for which any additional information is of great interest: the *α-Aurigids* and the *δ-Aurigids*. The α-Aurigids are already known since their 1935 peak [1], and some photographic orbits are known as well. Nevertheless, any further double station photograph may help to improve our knowledge about this shower. For the δ-Aurigids, the situation is more critical. In the existing archives we also find some orbital data, but we need more information about the duration of activity, as this is not completely clear yet [2]. Camera field centers will be mostly north and west of the radiants, but after local midnight you should try also field centers east of the radiant. This will be easy for the δ-Aurigids. Meteoroids of both showers enter the Earth's atmosphere at high velocities (66 and 64 km/s, respectively). Therefore, the camera field centers are recommended to be about 30° from the radiant, but avoiding elevations higher than 60° (because of the high angular velocity in this case).

I look forward to hearing from your results. Good luck!

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Telescopic Observers' Notes, September–October 1995

Malcolm J. Currie

It is only a short while since I wrote the last of these notes and I have received few observations. Of note are watches on May 28-29 and 30-31 by Chris Hall comprising 6 and 21 meteors. These show the θ-Herculids at $\alpha \approx 276°$, $\delta = +39°$ ($\lambda_\odot = 71°$), but a stronger radiant at $\alpha = 267\overset{\circ}{.}7$, $\delta = +44\overset{\circ}{.}6$. The plot thickens...

Forthcoming events

September is my favorite time for telescopic viewing. The nights are darker and longer than in high summer, but are often clear and not cold; the sporadic meteor rate has such verve that it readily grips my attention, but that is not all; there are showers too including a complicated region in Auriga, Perseus, and Cassiopeia, and there have been some surprises like the α-Triangulids last year. been some surprises like the α-Triangulids last year. Unfortunately, moonlight ruins any prospects of follow-up observations of the α-Triangulids. The visibility of this weak shower of faint meteors being highly susceptible to the sky conditions.

Instead, we kick off with the *α-Aurigids*. For a few days either side of September 1, these swift meteors are best known for their high average brightness and long paths. Even though the visual population index is very low (probably less than the Perseids) the shower does give weak telescopic activity implying that the index increases as the mean magnitude dims. A first look at the 1994 data shows that the radiant lies a few degrees north-west of the visual radiant position in the *IMO* shower list. The α-Aurigids exhibit the expected high fraction of trains; seeing the occasional brighter α-Aurigid and decay of its train is an exhilarating experience. In some years the shower does give visual outbursts tens of times the normal peak rates lasting around a couple of hours as happened in 1935, 1986, and probably in 1994 (suggesting a period of approximately 8 years). Unfortunately because we did not have a team widely dispersed in longitude, we have no telescopic data during the 1994 outburst. As for the Perseids, the average brightness increases during these transient phenomena, and so may not be observable by telescopic means, but we need out look out every favorable year to find out. To see members of this shower it is essential to watch after midnight local time to allow the radiant to attain a reasonable elevation. Also a first-quarter moon will have set by then.

Lasting through the whole period are the *δ-Aurigids*. Like the other showers in the vicinity during these months they comprise fast meteors ($V_\infty \approx 65$ km/s) and their streams have high inclinations, possibly associated with a sun-grazing comet. There is good evidence for four sub-components to this shower. During the first half of September last year, three sub-centers are visible during my preliminary radiant analysis. This year best observable rates are likely during the second half of the September, though a few early ones can be seen at the start of the month. Again post-midnight sessions are needed to see this shower at its best.

More prominent during early September are the lesser-known *September Perseids* radiating from between α and β Persei, though moonlight is going to spoil its best offerings, which were between September 8–13 in 1994 and stronger than the δ-Aurigids. A number of other radiants have been suggested in this region based on visual and telescopic from data in 1971 and 1988 to 1991. The 1994 observations has some evidence for a couple of these, though the study is in its infancy. Around the start of the month the strongest source of meteors was western Cassiopeia and Lacerta ($\alpha = 328°$, $\delta = +44°$), the latter also being recorded in 1989. The former might be the β-Cassiopeids seen best in 1988, but now faded into the strong noise evident in Cassiopeia towards mid-September.

To summarize, there is a complex of radiants during September and October whose activity dates and radiant parameters are at best poorly determined and at worst unknown. Observations by all methods are badly needed over a number of years to describe the properties of these showers, and to investigate if any are interrelated. To cover and indeed to delineate all these real or possible showers, telescopic observers should watch several telescopic fields each clear dark night, and pay special attention to careful plotting.

For early September, I recommend charts 36, 48, and 49 for the β-Cassiopeids and Lacerta radiant, which should be the prime targets until about 23^h. For the remainder of the night, use charts 36, 37, 51, 75, 76, and 39 for the radiants in Perseus and Auriga. The last two are best for the α-Aurigids.

During late September's δ-Aurigids I should select charts 19, 42, 53, 54, and 56.

The *Piscids* are a long-duration shower of medium-velocity meteors. Observations in 1994 clearly show that, as expected, it does indeed give an observable telescopic flux. In 1995, the maximum occurs a few days before New Moon, and so will be better placed than last year. Although not ideal, the south-western charts for the Aurigid program should suffice, as I should prefer observers to concentrate on that. The exception would be those at southerly latitudes where the Auriga-Perseus region is too low, who could plot on charts 114/133, 116, and 92. These should also permit detection of any *κ-Aquarids*, whose visual maximum occurs simultaneously with the Piscids. These are an even weaker shower of which little is known, save that it is expected to have a high proportion of faint meteors, and it has an extremely low velocity, which should help identify any κ-Aquarids from the sporadic background.

Moving to October, it is always worth checking the *Draconids* for enhanced activity, although the next likely chance of an outburst comes in 1998. A Full Moon on October 8 will give strong interference but is about a right angle distant so should not prevent a few early-evening watches to look for any extraordinary Draconid behavior. The smaller particles should disperse more quickly around the stream so we might see some portent for 1998. Suggested charts are 70 and 86.

Now to the highlight of these months.

The *Orionid* shower is arguably the most fascinating of the year because of its complicated radiant structure that can be resolved by telescopic plots, and the high percentage of trained meteors. A graphical look at some of our pre-*IMO*-chart data shows three sub-centers around the main maximum. We should aim to follow the changing radiant structure throughout the shower. There are several maxima due to filaments in the ribbon-like stream. These vary from year to year. For example, in 1993 a strong outburst was seen four days before the normal visual maximum. By combining the resolution of telescopic and video with other techniques we might be able to correlate the different sub-radiants with the maxima. A long-term goal is to determine the magnitude distributions of the main components.

Often, bad weather ruins our Orionid campaigns so I urge all telescopic observers to participate for as long as possible when the clouds are absent. I should like to have a good analysis for a given year (though to fully comprehend the complicated structure will take many years). Despite giving one of the highest shower telescopic fluxes, in previous years too few data have been collected to do this. Also unlike for earlier Orionid campaigns the new charts permit a quick reduction and investigation of the radiant structure.

Prospects for 1995 look excellent with hardly any interference from the moon and the main maximum falling at a weekend. This is an excellent opportunity to follow the fluctuating numbers from the different branches from around October 18 until the end of the month. To separate the various components several field centers should be used each night. Remember that the radiant does not attain a decent elevation until after midnight. My suggested charts are 98, 100, 101, 121, 142–144, and 156. Before October 22, replace 144 with 122. Spend about 30 minutes looking at each field.

There are several known an suspected minor showers during October.

The *ε-Geminids* are synchronic with and resemble the nearby Orionids, though perhaps only at a tenth of the strength. These very fast meteors were first seen by telescopic observations in Czechoslovakia during the mid-1960s. No special measures need be taken to observe them; just concentrate on the Orionid fields and ε-Geminids will be a bonus.

During the end of October, the *Taurids* are steadily increasing their activity towards the broad maximum in early November. These too can be covered reasonably using the Orionid charts, especially 98, 121, 142, and, 156; though before about 23^h local time, I recommend using additional charts 76, 93, 97, and 120 up to October 25, and in the following week or so replace 120 with 140. These will help us to compare the radiant shapes of the shower's two components. Although not rich in telescopic meteors, the Taurids compensate from their low angular speeds and characteristic long paths. Nevertheless a small binocular is preferred for watching this shower.

Theoretical Radiants of Minor Planets and Comets

Dirk Artoos

Below is a list of theoretical radiants of minor planets and comets, some of which may cause meteor activity during September and October.

Table 1 – Theoretical Radiants of Asteroids and Comets in September–October 1995.

Name	$\lambda_\odot$	Date	α	δ	V_∞	Distance
1981 ET3	158.°61	Sep 01	31°	−73°	18 km/s	0.05309 AU
P/1911 II	159.°28	Sep 02	91°	+39°	67 km/s	0.00820 AU
P/1698	159.°89	Sep 02	48°	+24°	70 km/s	0.18926 AU
P/1558	160.°24	Sep 02	32°	−10°	56 km/s	0.05085 AU
P/1864 II	160.°88	Sep 03	58°	+21°	72 km/s	0.02920 AU
1994 RB	162.°77	Sep 05	9°	−56°	22 km/s	0.04538 AU
1986 PA (4034)	163.°97	Sep 06	348°	+18°	18 km/s	0.02154 AU
P/1989 X	164.°60	Sep 07	359°	−19°	33 km/s	0.19442 AU
1989 AZ (5762)	164.°76	Sep 07	351°	−38°	17 km/s	0.16854 AU
P/1919 III	165.°54	Sep 08	359°	−19°	33 km/s	0.19594 AU
P/1932 V	166.°36	Sep 09	60°	−40°	43 km/s	0.15150 AU
P/1264	168.°84	Sep 11	232°	+22°	23 km/s	0.11298 AU
P/1906 V	168.°92	Sep 11	296°	+32°	16 km/s	0.04873 AU
P/1907 IV	169.°37	Sep 12	347°	+ 4°	32 km/s	0.06749 AU
P/1854 III	169.°48	Sep 12	54°	−15°	58 km/s	0.01850 AU
1989 LA	170.°06	Sep 12	215°	+43°	14 km/s	0.19696 AU
1994 PC	171.°53	Sep 14	310°	+35°	13 km/s	0.16457 AU
1979 VA	171.°53	Sep 14	282°	−35°	14 km/s	0.04822 AU
Hephaistos (2212)	171.°80	Sep 15	157°	− 1°	31 km/s	0.12466 AU
1992 NA	172.°72	Sep 15	276°	−69°	16 km/s	0.05640 AU
P/1788 II	174.°28	Sep 16	60°	−50°	45 km/s	0.19228 AU
P/1893 II	175.°13	Sep 18	65°	+11°	70 km/s	0.11462 AU
Midas (1981)	175.°40	Sep 18	140°	−30°	11 km/s	0.03669 AU
Bacchus (2063)	176.°66	Sep 20	7°	−24°	16 km/s	0.10531 AU
Orthos (2329)	177.°17	Sep 20	221°	+40°	20 km/s	0.10222 AU
1990 MF	177.°23	Sep 20	216°	− 6°	14 km/s	0.01803 AU
1994 XG	177.°29	Sep 20	189°	+23°	20 km/s	0.09409 AU
1992 NA	177.°35	Sep 20	265°	−69°	21 km/s	0.05640 AU
P/1683	178.°36	Sep 21	144°	+50°	53 km/s	0.11085 AU
P/1763	179.°50	Sep 22	45°	−23°	48 km/s	0.01956 AU
P/961	179.°60	Sep 22	63°	− 7°	60 km/s	0.10797 AU
1983 RD (3551)	180.°18	Sep 23	281°	+27°	19 km/s	0.07825 AU
1981 ET3 (3122)	182.°03	Sep 24	88°	−78°	18 km/s	0.17841 AU
Toutatis (4179)	183.°00	Sep 26	331°	−10°	16 km/s	0.00673 AU
Anza (2061)	184.°24	Sep 27	274°	− 2°	19 km/s	0.05685 AU
P/1919 II	186.°26	Sep 29	278°	−38°	15 km/s	0.04172 AU
Anza (2061)	188.°53	Oct 01	270°	− 3°	22 km/s	0.05573 AU
P/1499	189.°87	Oct 03	289°	−68°	20 km/s	0.18734 AU
1995 FJ	192.°06	Oct 05	152°	−65°	20 km/s	0.14918 AU
1994 ES1	192.°26	Oct 05	187°	− 5°	23 km/s	0.00651 AU
1979 VA (4015)	193.°15	Oct 06	264°	−11°	14 km/s	0.04793 AU
P/1919 II	196.°75	Oct 10	268°	−37°	15 km/s	0.03687 AU
1994 PC	200.°94	Oct 14	283°	+40°	13 km/s	0.18025 AU
1980 PA (3908)	207.°62	Oct 21	297°	− 7°	13 km/s	0.05171 AU
1995 EK1	208.°26	Oct 22	189°	−15°	21 km/s	0.08437 AU
Hathor (2340)	208.°27	Oct 22	186°	+10°	17 km/s	0.00623 AU
1980 PA (3908)	210.°62	Oct 24	294°	− 7°	12 km/s	0.05134 AU
1991 GO	211.°09	Oct 24	32°	− 4°	16 km/s	0.02050 AU
1982 TA (4197)	212.°38	Oct 26	40°	+ 1°	27 km/s	0.08367 AU
Poseidon (4341)	216.°60	Oct 30	39°	− 3°	24 km/s	0.19636 AU
1995 FO	216.°80	Oct 30	8°	−45°	26 km/s	0.14068 AU

The Perseids

Perseids 1995—A First Summary of Reports

Jürgen Rendtel

This is a summary of data for the 1995 Perseid maximum period sent in by numerous observers. The results clearly show that the dense and high Perseid peak re-occurred in 1995 $\lambda_\odot = 139.^\circ64 \pm 0.^\circ06$ corresponding to 18^h UT on August 12, i.e., almost at the same position as in 1994. The maximum ZHR of the peak can be roughly estimated to ZHR $= 160 \pm 80$. Due to intense moonlight, all optical (particularly visual) data must be considered with great care.

1. Introduction

The Full Moon on August 10 kept the attention of the visual meteor observers quite low. It is known that intense light pollution dramatically reduces the reliability of visual counts due to the uncertainties of the corrections and the sample which can be observed. Consequently, the main aim of the Perseid maximum observations in 1995 was to find out whether the peak re-occurs and at which time.

Forward scatter observers at suitable longitudes were in a better position to detect the peak. As discussed several times, these data need careful reduction for the geometry of the transmitter-receiver-meteor path.

2. The 1995 return

In 1995, reports of observations came in at a surprisingly low rate.

The first report of the peak came from K. Suzuki of Japan [1]. He reported that the maximum hourly rate of echoes reached 300 during August $12.^h71$–$12.^h79$ UT (i.e., $17.^h0$ to $19.^h0$ UT, corresponding to a solar longitude of $\lambda_\odot = 139.^\circ6$ (2000.0)). The hourly rate of echoes of more than 5 s increased to 5–8 times the usual rate.

E.P. Bus reported similar results from his forward scatter observations [2]. He subtracted the average sporadic background and corrected the rates with an observability function after Hines [3]. The highest rate in his series occurs in the 18^h–19^h UT interval, flanked by similar rates in the 2 hours before this and the hour 19^h–20^h UT.

The only visual reports close to the peak were of Ucrainean observers [4], starting at 17^h45^m UT. Other (central) European observers were able to start at 19^h45^m UT only. At this time the activity had already dropped to much lower rates. However, the ZHR returned to the "reference level" (i.e., the ZHR without the peak) by 21^h UT on August 12. It increased slightly after 23^h UT, but we will not discuss the "traditional maximum" here. Figure 1 gives an overview of the averaged and smoothed ZHR of for the period August 12, 17^h UT to August 13, 9^h UT. It is based on reports sent by the following observers:

> Rainer Arlt, Andrey Grishchenyuk, Ralf Koschack, Robert Lunsford, Ina Rendtel, Jürgen Rendtel, Anna Sikchina, Alexandr Smetanko, Manuel Solano, David Swann, Nikolai Wünsche, and Vasiliy Yaremchuk.

Furthermore, we acknowledge the receipt of large number of observations of the pre-maximum period. This will be included in a later analysis.

As already pointed out, the moon caused severe problems with the reduction of the data. Obviously, the influence is different for each individual observer. In order to calibrate the ZHRs, we used the period August 12, 21^h–23^h UT already called the reference level above. Here the ZHR was assumed to be 50. The ZHRs plotted in Figure 1 are corrected with a factor derived from this period, except the North-American observers (i.e., the ZHRs after August 13, 6^h UT).

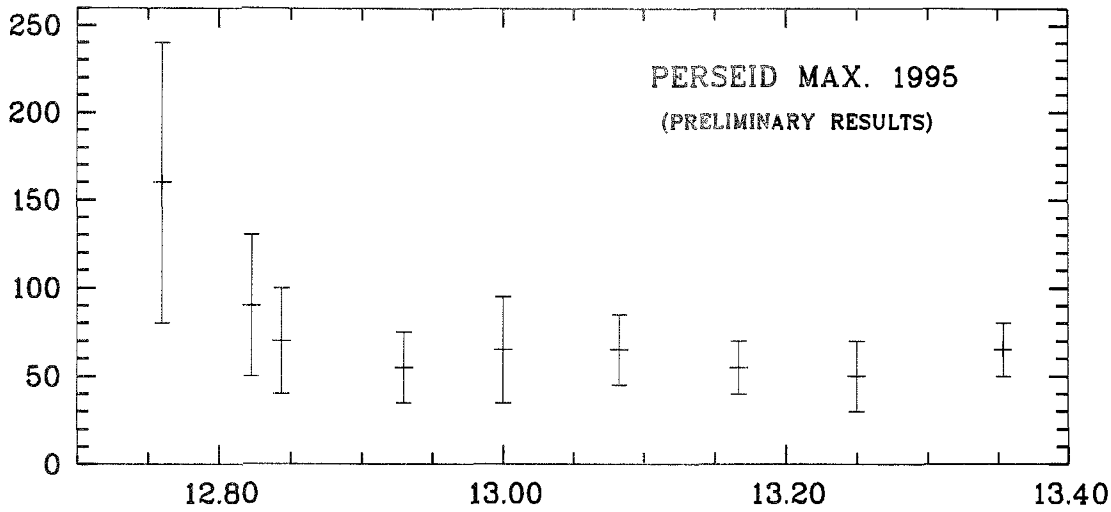

Figure 1 – ZHR graph of the 1995 Perseid maximum period as derived from visual observations. The peak of fresh material re-occurred on August 12, 17^h–19^h UT (corresponding to $\lambda_\odot = 139^\circ\!.64 \pm 0^\circ\!.06$). The data reproduce the regular maximum after August 13, 0^h UT rather poor. Observations were badly effected by strong moonlight.

All ZHRs were corrected *assuming* a population index of $r = 2.5$. The result confirms the forward scatter observations reported in this section.

It is pure speculation, however, to qualify the 1995 peak ZHR as lower than during the previous returns (cf. Table 1 in [5]). The peak ZHR of 160 ± 80 suffers from a large scatter of the individual ZHRs of the four observers involved.

3. Conclusions

The uncertainties of results obtained from light-disturbed observations (also in 1992) emphasize that such data can only be used for deriving upper/lower limits for some parameters. On the other hand, such information is needed to obtain "continuous" data for the "new" peak.

The peak occurred at almost the same position as in 1994. This is a smaller "shift" than between previous returns. The analysis indicates that we may expect the peak on 1996 August 11-12, at $0^h \pm 3^h$ UT.

Acknowledgements

I wish to thank all observers who sent in their data very soon after the Perseids, particularly those who are not explicitly mentioned in the text. The entire material allowed to us present a very first overview already in this issue of *WGN*.

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The Leonids

On When Leonids Woke Up

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Engelhardt Astronomical Observatory

Available data of Leonid 1988–1994 visual observations have been processed by the method worked out in Kazan and taking into account corrections for the moon light interferences. ZHRs of meteors brighter than magnitude +3 are analyzed. It was shown that the shower activity in 1992–1993 was already 2.5 times, and, in 1994, 10 times greater than in 1988–1991.

The first information about the increase of the Leonid activity in 1994 was distributed by Peter Jenniskens by e-mail and published in *WGN* [1]. Even though the highest Leonid activity is expected in 1998 with the P/Tempel-Tuttle Comet apparition, the shower activity increase was already apparent 4 years earlier. So one may wonder that maybe there are indications of an increase of the Leonid shower activity in previous years? We have decided to check it.

The primary observed data for the 1994 Leonids were published in *WGN* [1,2] and some of them were kindly communicated to us by Rainer Arlt from the *VMDB*.

Leonid visual observations from 1988 to 1994 [1–10] have been processed by the method worked out in Kazan [11]. Additional corrections for moon light interferences and radiant zenith distance Z [12] have been taken into account. The last corrections have been modified for the Leonids. The complete formula of the ZHR reduction is:

$$\mathrm{ZHR} = \begin{cases} \frac{Nk\left(1+1.3(1-\cos(PM))(1-\sin(ZM))^{0.3}\right)}{T(\cos Z)^{s-0.9}} & \text{for } ZM < \pi/2; \\ \frac{Nk}{T(\cos Z)^{s-0.9}} & \text{for } ZM > \pi/2, \end{cases}$$

where N is the observed number of meteors for the time interval T, k is the reduction of N to magnitude +3, PM and ZM are the Moon's phase and zenith distance, Z is the shower radiant zenith distance, and s is the mass distribution exponent.

The mass exponent s variation as a function of the solar longitude (2000.0) is shown in Figure 1. There is no indication of differences between values for 1994 and the other years.

Therefore, the data for 1988–1994 were averaged in intervals of solar longitude and mean values and their r.m.s. are shown in Figure 1 and Figure 2. The minimum value of $s = 1.32$ corresponds to solar longitude $\lambda_\odot = 235\overset{\circ}{.}01$.

Leonid ZHR values have been calculated using the formula and averaged values of s. The results are shown in Figure 3.

All data were divided into 3 groups:

(1) 1988–1991;

(2) 1992–1993; and

(3) 1994.

Activity profiles for each group are presented by 4 straight lines found by the least square method.

The first group corresponds to the quiet period of Leonid activity. The maximum activity ZHR of 7.2 corresponds to solar longitude $\lambda_\odot = 235\overset{\circ}{.}84$.

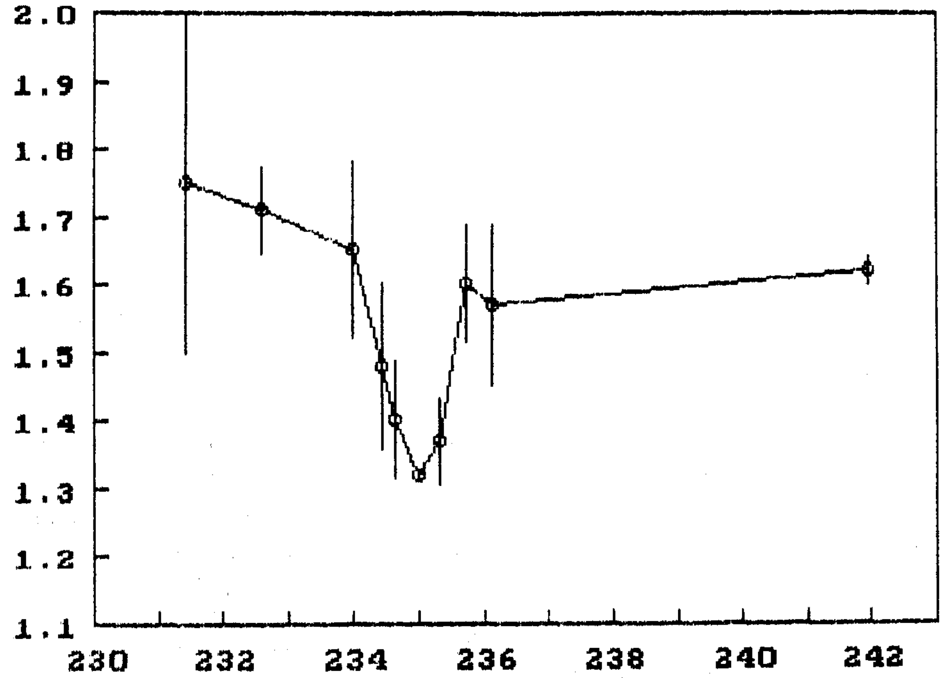

Figure 1 – The mass exponent s as a function of solar longitude (2000.0).

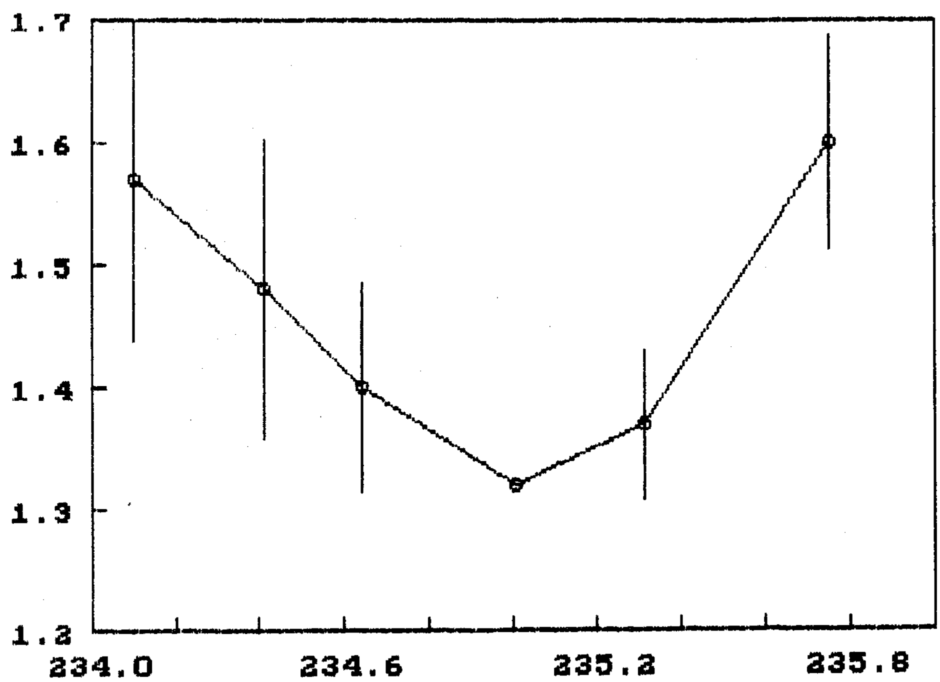

Figure 2 – Details of Figure 1 for the minimum of s.

The activity began to increase in 1992 and remains at the same level in 1993 with a maximum ZHR of 18.4 at $\lambda_\odot = 235\overset{\circ}{.}80$. In 1994, the shower activity jumped to a ZHR of 73 (comparable with the Perseids!) at $\lambda_\odot = 235\overset{\circ}{.}53$. The differences between maximum positions are probably due to statistical errors.

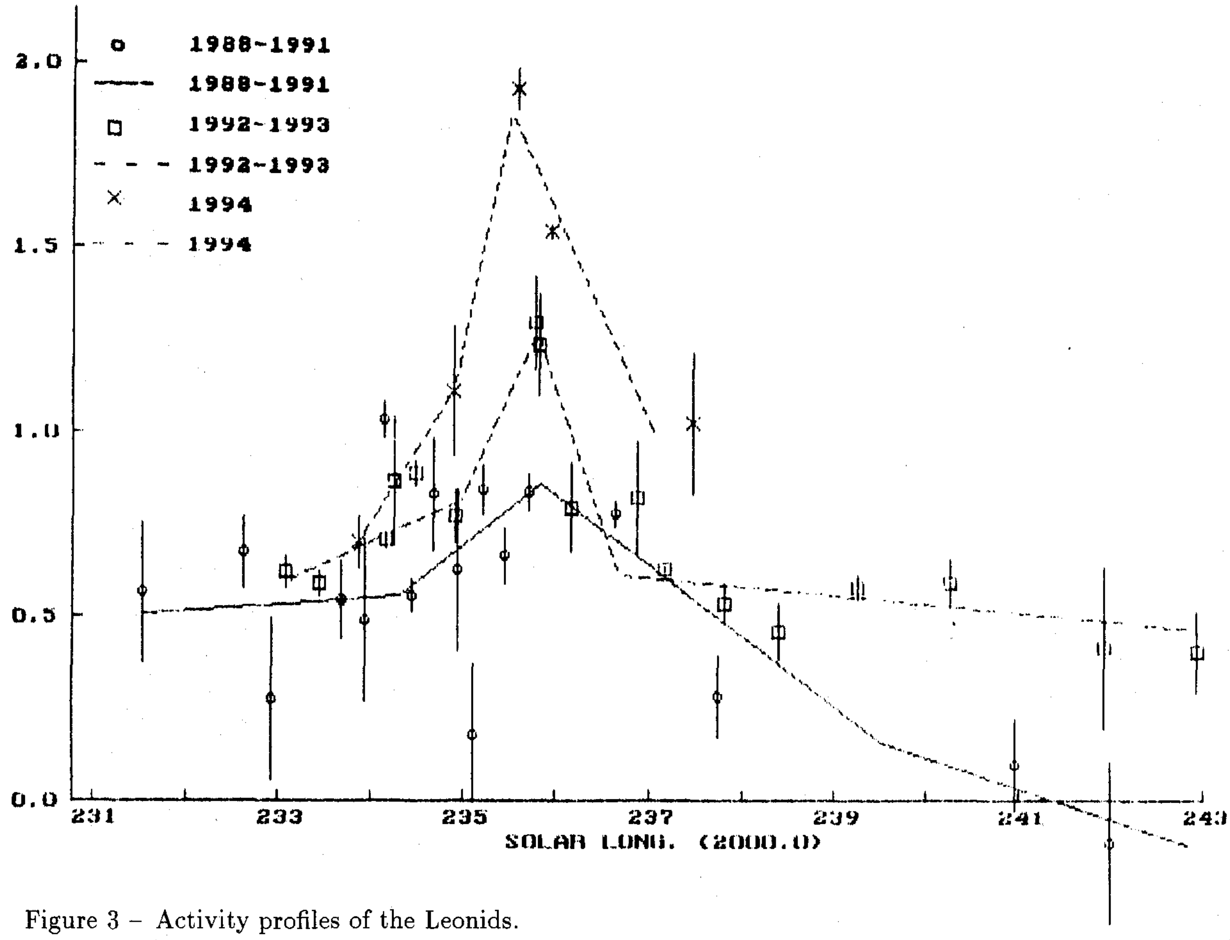

Figure 3 – Activity profiles of the Leonids.

The above data indicate that the Leonid shower already woke up in 1992.

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The Leonids: The Lion King of Meteor Showers

Joe Rao

The night of November 12-13, 1833, sparked awareness of the Leonid meteor shower as well as the birth of meteor astronomy: from much of North America that night, a rain of shooting stars, a shower of flashing light, spread over the entire sky. More than one superstitious person on that spectacular night was certain that the end of the world had come. People kept repeating that the meteors were falling "like snowflakes." In the aftermath of the display, it was realized that meteors could be produced by an extraterrestrial source: streams or swarms of particles that travel around the Sun in more or less well-defined orbits, grazing, at least at one point, the orbit of our Earth.

In 1866, G. Schiaparelli established the orbit of the stream of particles that produce the Leonids, and soon others independently noted a striking resemblance of the Leonids with the orbit of periodic comet Tempel-Tuttle. The comet and meteor stream were subsequently found to be following nearly identical orbits with periods of roughly 33 years. A few years earlier (in 1863) it was discovered that similarly spectacular Leonid meteor displays had occurred prior to 1833, with accounts of the Leonids traceable as far back as A.D. 902. Based solely on the 33-year cycle, a prediction for a meteor storm in the year 1866 verified. In 1899 a re-enactment of the 1833 storm was confidently expected, despite calculations that demonstrated that the orbit of P/Tempel-Tuttle (and probably the associated Leonid particles) were likely perturbed by the planets Jupiter and Saturn. The failure of a storm to materialize seriously damaged the credibility of astronomers in the eyes of the general public.

Since 1899, the Leonids have been following a rather erratic and unpredictable schedule: meteor storms unexpectedly occurred in 1900 and 1901; no storm was noted in 1931 or 1932, leading many to believe that Leonid activity had significantly declined. But during the 1960s, they again revived, capped by a short-lived display in 1966 that possibly rivaled even the 1833 display. Radar observations of this 1966 display showed the densest part of the Leonid stream to be just 35 000 km wide; the Earth swept through this filament of debris in just one hour.

With the impending return of P/Tempel-Tuttle due in February 1998, prospects for another Leonid storm have begun to increase again. D.K. Yeomans definitive study (1981) concerning the orbit of P/Tempel-Tuttle and its implications on future Leonid activity is examined. Yeomans takes into account the distribution of dust surrounding P/Tempel-Tuttle, determining that the majority of dust ejected from the comet evolves to a position lagging behind the comet and outside of its orbit. This is likely an artifact of solar radiation pressure and planetary perturbations on the Leonid particles. In 1994, Yeomans re-calculated the orbit of P/Tempel-Tuttle and re-computed future Leonid shower maxima. Yeomans notes that the conditions in 1998–1999 are optimum for a significant Leonid shower, but cautions that such an event is not certain because the dust particle distribution near the comet is far from uniform.

The author concurs with Yeomans on this final point and concludes, based on the previous six Leonid epochs, that there is a possibility of a "storm" in any year from 1997 through 2000. He also believes that no reliable prediction as to the time of Leonid maximum for any given year can be made because we would be trying to anticipate intercepting not just a single stream along the orbit of P/Tempel-Tuttle, but possibly one of several: each stream having evolved from the solid debris spewed by the comet at previous perihelion passages. To get a storm, Earth must somehow interact with another dense, yet narrow filament of meteoric material which, unfortunately, cannot be anticipated or seen until it impacts with Earth's atmosphere. Still, the upcoming years hold the potential of some truly exciting observing with the prospects of much-better than normal Leonid activity. All night observing sessions worldwide, which would offer the best hope of catching sight of any unexpectedly strong meteor activity, is strongly urged in the coming years on the night of November 17-18.

1. Introduction

On the night of November 12, 1833, the Earth unexpectedly came under attack. The Western Hemisphere was pummeled by a barrage of cosmic shrapnel: a veritable storm of meteors or shooting stars. It was a celestial bombardment that, fortunately, was noiseless and innocuous.

Figure 1 gives an idea of this magnificent scene.

Here is a part of Agnes Clerke's[1] classic description of that incredible scene (Figure 1):

[1] Agnes Mary Clerke (1842–1907) was a prolific British author. She was obviously not an eyewitness to the great Leonid storm of 1833, but her description—published in her first work, *A Popular History of Astronomy During the Nineteenth Century*—was likely based on the accounts of others, most notably Denison Olmstead of Yale University.

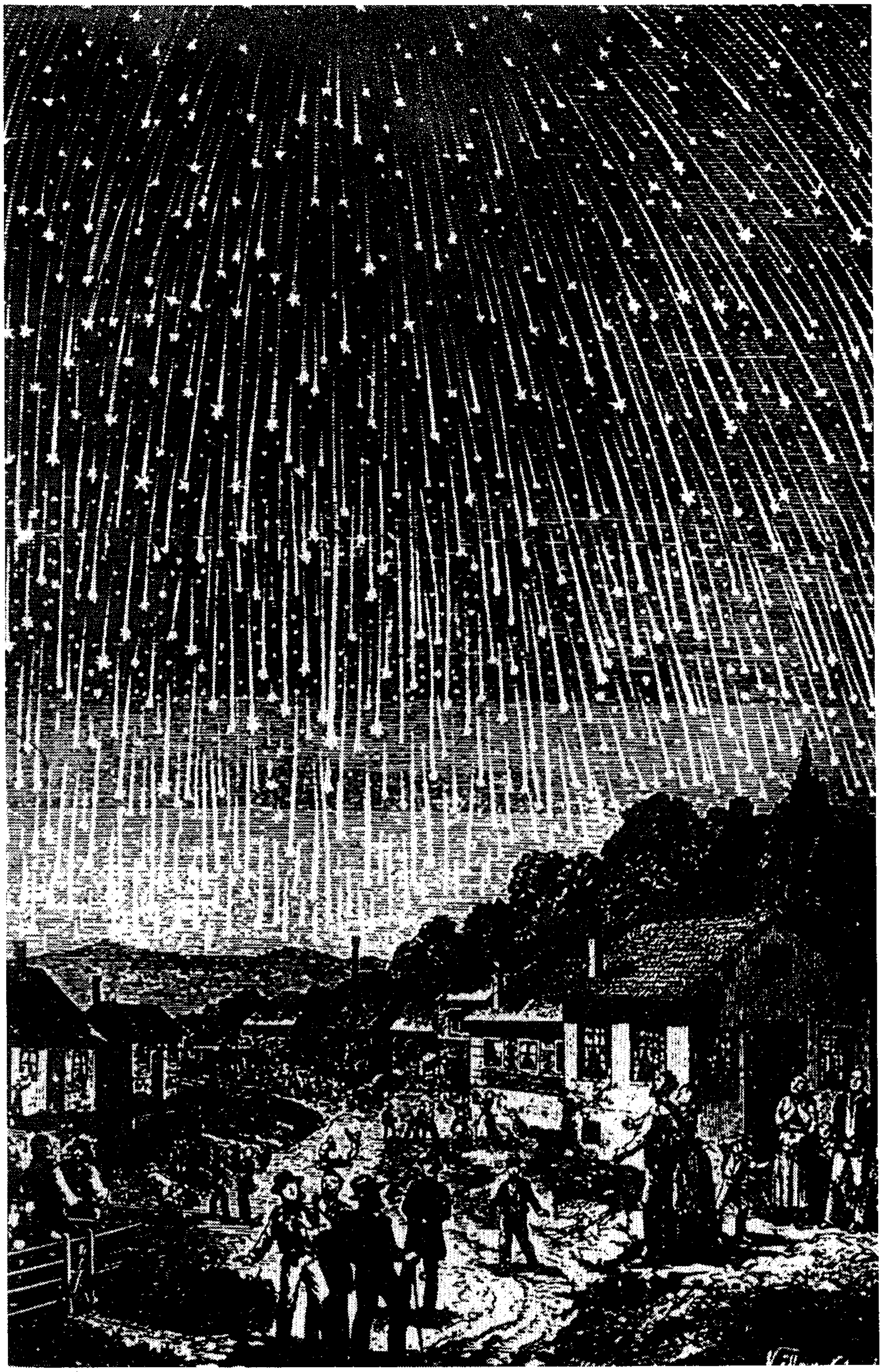

Figure 1 – Probably the most famous old print of the 1833 Leonid storm, done by an artist named Vollmy. The scene apparently depicts the circumstances with the approach of local sunrise: a brightening sky beyond the horizon, with meteors pouring out of a radiant, now high in the sky. Wrote Professor Denison Olmstead of Yale College: *...imagine a constant succession of fireballs, resembling rockets, radiating in all directions from a point in the heavens.*

On the night of November 12-13, 1833, a tempest of falling stars broke over the Earth... the sky was scored in every direction with shining tracks and illuminated with majestic fireballs. At Boston, the frequency of meteors was estimated to be about half that of flakes of snow in an average snowstorm. Their numbers... were quite beyond counting; but as it waned, a reckoning was attempted, from which it was computed, on the basis of that much-diminished rate, that 240 000 *must have been visible during the nine hours they continued to fall.*

Apparently it was a clear, starry late autumn night across eastern North America from Halifax, Nova Scotia, to the Gulf of Mexico.[2] During the hours following sundown on November 12, some may have noted an unusual number of meteors streaking out of the eastern part of the sky, but it was in the early hours of November 13 that left the greatest impression. Just before dawn broke, there burst from the skies literally a rain of meteors. A reliable observer, H.C. Twyning at West Point, New York, estimated that there were at least 10 000 bright meteors per hour at the height of the storm. Another observer, believing that the meteors were stars, thought that there would be no stars left in the sky the next night. One man in New England roused his whole family out of bed and solemnly announced that Judgment Day was at hand.

The great meteor storm burst upon a world unsuspecting, and largely ignorant of such a possibility, yet the records, after later study, demonstrated that it could have been anticipated, if not actually predicted. The fault probably lay as much with the astronomers of that era as with anyone, for until only some years earlier, they had refused to believe that meteors—those streaks of bright light so commonly seen in the night sky—could be produced by an extraterrestrial source. But the great shower of November 1833 dispelled all doubts. Many observers clearly reported that the meteors seemed to radiate from a region within the constellation of Leo and that, as Leo moved slowly westward during the course of the display, the radiant point moved with the constellation. The radiant point was, in fact, an illusion of perspective, as a Yale University mathematician, Denison Olmstead, properly demonstrated (Figure 2).

In reality, the estimated 240 000 meteors that fell that night had followed parallel paths. Named for the direction among the stars in which the radiant point appeared, the Leonids sparked the beginning of an intense study into a new field of astronomy.

Today, we are aware of many annual meteor showers. Although perhaps only perhaps ten or so are well known and produce enough meteors to be worth looking for, literally hundreds of different showers have been identified. They are caused by streams or swarms of particles that travel around the Sun in more or less well-defined orbits, grazing, at least at one point, the orbit of our Earth. As the Earth revolves around the Sun, each year, it reaches its encounter with each stream at, or near the same point in its orbit and, as it runs through the orbit of the stream, scoops into its atmosphere some of the particles that make up the swarm.

The source of the particles that make up a meteor stream was identified by the famous Italian astronomer Giovanni Schiaparelli (of Martian canali fame) in 1866. In that year, he established the identity of the orbit another famous shower, the August Perseids, with the orbit of periodic comet Swift-Tuttle. In the same work, Schiaparelli published his calculations for the orbit of the stream that produces the Leonids, and soon other experts in celestial mechanics, most notably Urbain Le Verrier and Theodor von Oppolzer, all independently noted a striking resemblance of the Leonids with the orbit of the newly-discovered periodic comet Tempel-Tuttle (comet 1866 I). In both cases, the parent comets and the associated meteor streams were found to be following nearly identical orbits, and subsequently other matched comet and meteor stream orbits were found.

[2] There is also evidence that the 1833 Leonids were observed farther to the west over the North American Plains. In 1984, Von Del Chamberlain (Smithsonian Institution) listed the astronomical references for 50 Sioux Indian winter counts, of which 45 plainly referred to an intense meteor shower during the winter of 1833-34. In addition, he listed 19 winter counts kept by other plains Indian tribes, of which 14 obviously referred to the Leonid storm.

Figure 2 – Woodcuts like this one appeared in newspapers and magazines after the great Leonid shower of November 1833. This contemporary print depicts the shower as seen at Niagara Falls, New York. Notice the way the vast majority of the meteors appear to radiate from a single spot on the sky. *Mechanics' Magazine* said this sketch was by an editor named Pickering *who witnessed the scene.*

Although all prominent meteor showers have not been associated with known comets,[3] the relationship seems clear: meteor streams probably represent debris left behind in their orbits by comets that approach the Sun or larger planets.

2. History

While the famous shower of November 12, 1833, may have been the beginning of serious investigation into meteor astronomy, it was neither the beginning nor the end of the history of the Leonid meteors. After the event occurred, reports were unearthed in which observers from the Urals, Arabia, Mauritius, and Europe, as well as ship captains in the middle of the north Atlantic, described large numbers of meteors appearing on November 12, 1832.

Other accounts were later brought to light of a shower of thousands of bright meteors described by the Prussian scientist and explorer Alexander von Humboldt (Figure 3) from his camp in Cumana, Venezuela on November 12, 1799. As he described it, there was *no part of the sky so large as twice the Moon's diameter not filled each instant by meteors.*[4] Another observer in Florida reported that the meteors were *at any one instant as numerous as the stars*, while at Iserstadt, Germany, *bright streaks and flashes* were seen even after the sky was already light.

[3] The rich Geminid shower of December, for example, is unique in that they are the only major shower associated with an asteroid—3200 Phaethon.

[4] Interestingly, Humboldt's inquiry among the natives elicited the information that in 1766 a similar "rain of stars" had been seen.

Figure 3 – Baron Alexander Von Humboldt (1769–1859) described in vivid details the great Leonid display of 1799 as seen from South America.

Figure 4 – The great Leonid shower of 1867 seen from Sandy Hook, New Yersey. The Moon was a bright waning gibbous phase and just past full in Taurus and hence severely hindered observation of this display. Highest hourly rates were in the range of 1000 to 2000 per hour. One wonders what the rate would have been without the presence of the Moon... leading one to suspect that "perhaps" the 167 shower was equal to or greater than the one observed from Europe the previous year.

In the years following 1833, many astronomers investigated the history of November meteors in ancient European, Arab and Chinese documents.

In 1837, the German physician and astronomer Heinrich Olbers suggested that better-than-average displays occurred in periods of 33 or 34 years. The great storms of meteors had occurred in November at these intervals, and they could be expected to continue occurring as long as the meteor swarm remained intact.[5]

In 1863, Yale professor Hubert Anson Newton succeeded in tracing accounts of the Leonids for almost a thousand years. Particularly impressive displays were found to have taken place in 1533, 1366, 1202, 1037, 967, 934, and 902.[6] Even these few dates suffice to indicate a periodicity of about 33 years. Indeed, it was later surmised that there was a dense cloud of matter revolving around the Sun in a period that, in 1866, was established as 33.25 years.

Based on the history of the Leonids, their association with P/Tempel-Tuttle and calculations of its orbit, astronomers predicted that another major shower would occur in 1866 or 1867, and indeed it did, although it was not as spectacular—according to the accounts—as the shower of 1833. The hourly rates for a single observer were reported to be 5000 from Europe on November 13-14, 1866; and about 1000 (despite bright moonlight) from North America on November 13, 1867 (Figure 4).

This behavior is typical of the Leonid shower, that is, one part of the world may have a tremendous downpouring while elsewhere the event is relatively minor.

The return of the shower was anticipated again in 1899. In the intervening years, the Leonids had produced only modest numbers of meteors, about 30 to 50 per hour at maximum. The year 1899, however, was another year in the cycle, and rather wide publicity was given to the possibility that it might bring a re-enactment of the events of 1867 and especially 1833 (Figure 5).

Unfortunately, it did not materialize, and the faith of the public in the infallibility of astronomical calculations was rather badly shaken. American meteor expert Charles P. Olivier later wrote: *This was the worst blow ever suffered by astronomy in the eyes of the public.*[7]

In fairness to astronomers, however, there were some cautions issued before the anticipated event.

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[5] Actually, the calendar date of the Leonids shifted from mid-October in the 10th century to mid-November in the 20th. Part of the drift arises from the difference between the old Julian calendar and the present Gregorian, which was five days in A.D. 933 and 10 days in A.D. 1533. Another part is due to the sidereal year being 20.5 minutes longer than the tropical year, this excess accumulating to 14.5 days in 1000 years. And lastly, the orbit of the Leonid swarm around the Sun is slowly changing as a consequence of the planets' gravitational attractions.

[6] According to A.T. Gerard of St. David's College, Beckenham, Kent, England, an observation of the Leonids may have been made prior to A.D. 902. It reads as follows: *In the year of the Incarnation of our Lord 900 there appeared a marvelous sign in heaven. For the stars were seen to flow from the very height of heaven to the lowest horizon, well nigh as though they crashed one upon the other. And upon this marvel followed woeful calamities... frequent tempests... rivers also overflowing their banks... men boasting themselves against God. In this same year... I, (Bishop) Radbod the sinner, was judged worthy to be enrolled among the servants of the holy church of Utrecht...*

[7] The Director of the Meteor Section of the British Astronomical Association, William F. Denning, later revealed the high state of expectancy which accompanied the 1899 shower: *No meteoric event ever before aroused such an intense and widespread interest, or so grievously disappointed anticipation. The scientific journals and newspapers all contained references to the subject, and the occurrence was predicted in such confident terms to take place that the public became enthusiastic, and looked forward to its appearance as a certainty. Many people regard the prescience of the astronomer as something marvelous, he can foretell the moment of an eclipse that will occur generations hence, and no thought of questioning either his accuracy or veracity ever enters their heads. But the fiery storm did not appear.*

On a lighter note... at Cambridge University at the time and a porter was stationed outside to watch the sky and to report to the partygoers when the show began. When questioned at about 1 a.m. whether there had been any shooting stars he replied, *They had none of them shot yet, but some of them looked as if they were just going to.*

ALL ASTRONOMERS WAITING.

The Heavens, It Is Expected, Will Be Illuminated To-night by the Wondrous Meteoric Display.

Unless astronomers throughout the world are very much mistaken, there will take place in the heavens to-night a display of celestial fireworks such as has not been witnessed by spectators on this planet in sixty-six years, or since 1833. At the last grand exhibition in 1866 the display, according to the astronomers, was not quite up to the standard, but in 1833 some of the meteors were as bright as the full moon. If expectations are met, the display to-night will exceed in brilliancy and grandeur even that wonderful illumination.

Toward a certain part of the earth's orbit which now is but a few hours distant we are rushing at a speed of many miles a second; and, toward it also, from another direction, swooping along at half a hundred miles per second, is a tremendous swarm of meteors. The two ought to meet to-night, head on. The collision should occur about midnight. Unnumbered masses of meteoric matter are in the swarm, but each gigantic shape and boulder will be hurled into the earth's atmosphere. These bodies, which until they strike our atmosphere, have no light, are rendered incandescent by friction, and form what are commonly known as shooting stars. Having become heated to a white heat the meteors are disintegrated by the air through which they pass and fall as fine dust.

The advance guard of the great body is already upon us. Some who were watching the sky on Sunday night noticed a few falling stars in the eastern heavens in the neighborhood of the constellation Leo. Every astronomer in the world who amounts to anything will sit up nights for the next forty-eight hours ready with all sorts of delicate instruments to try and wring another secret from the universe. The observatory at Columbia University is at a disadvantage this year, because its instruments have not all been installed in the new building. However, Prof. Rees says that a number of photographs will be taken, and some interesting results are expected.

METEOR BORES A HOLE IN IOWA.

Terrestrial Vagrant Makes a "Loud, Roaring Noise When Descending."

MINNEAPOLIS, Nov. 15.—A dispatch from Webster City, Iowa, says: "A large meteor fell in the woods just east of this place last night. It made a hole about five feet square and was still seething and steaming so that its full size could not be determined. People in the vicinity say it made a loud roaring noise when descending."

Clouds Obstruct Chicago's View.

CHICAGO, Nov. 15.—Chicago and the Mississippi Valley went to bed this morning without catching a glimpse of the star shower of Leonids for which they have waited a third of a century. From Davenport east to New York, according to the dispatches received by the Weather Bureau, the sky was overcast to a degree which blotted out all the stars and made satisfactory observation of the meteoric shower an impossibility.

Figure 5 – Articles from the *New York Times* of November 1899. In the November 14 edition, a news story promoting the shower ironically began with the comment, *Unless astronomers throughout the world are very much mistaken...* In the November 16 edition, short stories appeared about "a large meteor" that landed just east of Webster City, Iowa (unrelated to the Leonids), while another item notes the unfavorable weather which prevented observation of the Leonids from Davenport, Iowa, through Chicago and on to New York.

Calculations by British astronomers J.C. Adams and G.H. Stoney demonstrated that the swarm of particles passed sufficiently near to Saturn in 1870 and to Jupiter in 1898 so that they might be deflected into another orbit. Indeed, by 1899, the orbit of the particles had been given a severe shift, passing 0.0117 AU inside of the Earth's orbit where likely they could not be seen. The failure of the shower to manifest itself undoubtedly led to a serious diminution of interest in meteor astronomy.

Following 1899, interest in the Leonids never revived. This was very unfortunate, since almost inexplicably the Leonids roared to life—albeit a year late—in 1900. On November 15-16 of that year, rates of over 1000 per hour caused "a panic" among people living at a small community near Hudson Bay, Canada. Then, in 1901, at Potmona College in Claremont, California, Leonids appeared for a brief interval to fall at almost 2000 per hour, while at Tucson, Arizona, and Tuape, Mexico, the meteors were described as ... *too thick to count*... Since most astronomers, as well as the general public, were "burned" at the lack of seeing any significant shower activity in 1899, only very few people were eye-witnesses to the spectacular displays that occurred in subsequent years.[8]

If the turn-of-the century years were disappointing, the 1930s were even worse. Even though hourly rates reached 190 in 1931 and 240 in 1932, nothing the least bit like the great showers of the past had been reported anywhere. In addition, for the second time since its discovery, the Leonids "parent" P/Tempel-Tuttle failed to be recovered despite a diligent search. The general consensus was that, like the ill-fated Biela's comet, P/Tempel-Tuttle had somehow been torn apart and had apparently vanished forever and had left its fragments behind. The fragments of Biela's comet had produced incredible meteor displays in 1872 and 1885 but had since diminished significantly. Now, it looked as though the once-great Leonids too had finally begun to peter out.

Observers generally ignored the Leonids during the 1940s and 1950s, and this state of neglect probably caused many to miss the unexpected arrival of enhanced Leonid activity in 1961, with rates climbing to over 50 per hour. Many of these were brilliant meteors with long enduring trains. From 1962 through 1964, hourly rates of 15 to 30 were recorded.

Then, in 1965, P/Tempel-Tuttle, lost for nearly a full century, was re-discovered (comet 1965 IV).[9] Revised calculations would later reveal that the comet passed closer to the Earth's orbit (0.0032 AU) than on any occasion since 1833.

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[8] A very similar scenario occurred in the 1970s. Remember Comet Kohoutek of 1973-74? It was discovered when still remarkably far from the Sun, 5 AU, suggesting it was a giant among comets and would become extremely brilliant. Brightness predictions ranged up to magnitude -10, and some astronomers announced that this could be the "comet of the century." The news media took them at their word and announced the approach of a comet so bright that it might be visible in broad daylight. The world prepared to watch a blazing celestial light show.

Kohoutek turned out to be very ordinary as naked-eye comets go, however. Most people missed it entirely because it was near the horizon. The recriminations were nasty, with astronomers and news media blaming each other and the public blaming both. Reporters shied away from comets thereafter, practically ignoring the much brighter Comet West in March 1976, which became a lovely sight in the dawn sky.

[9] About 1869, John Russell Hind put forth a theory that a comet observed by the Chinese in the year 1366 was P/Tempel-Tuttle. In 1932–33, S. Kanda's computations agreed with Hind's that the comet of 1366 was indeed P/Tempel-Tuttle, noting that the reason the comet appeared unusually bright that year (magnitude 3) was that it made a very close approach to the Earth (0.06 AU). An attempt to locate the comet in late 1932 was met with failure. In 1964, J. Schubart traced the 1866 orbit of P/Tempel-Tuttle backwards in time to 1366, and was able to match a 1699 apparition with the comet seen in October of that year by Gottfried Kirch. Schubart then progressed forward in time with his computations and predicted that P/Tempel-Tuttle would arrive at perihelion on April 25, 1965. Several photographic searches were conducted unsuccessfully and it appeared that the comet was destined to remain lost. However, in October 1965, Schubart announced his discovery of the 16th magnitude comet on plates exposed on June 30 and July 1 by M.J. Bester of the Boyden Observatory, South Africa. As it turned out, Schubart's prediction was 5 days too early. According to D.K. Yeomans, the next perihelion passage of P/Tempel-Tuttle is scheduled for 1998 February 28.0110.

Indeed, the 1965 Leonids produced rates of up to 120 meteors per hour as seen from widely separated locations as Hawaii and Australia. From the Smithsonian tracking stations at Maui and Woomera came reports of Leonids as bright as magnitude −5, at times several in the sky together, accompanied by luminous trains lasting several seconds. These reports were reminiscent of the brightness, if not the numbers, of the objects seen in 1799 and 1833.

One year later, on November 17, 1966, a storm of tens of thousands of Leonid meteors fell for a short interval over the central and western United States. It was a display that apparently rivaled the historic Leonid showers of 1799 and 1833. Within a time span of just two hours, meteor rates increased sharply from about 40 per hour to 40 per second! (Figure 6).

From the San Gabriel Mountains in southern California, one observer noted that, ... *we saw a rain of meteors turn into a hail of meteors and finally a storm of meteors too numerous to count.* From Kitt Peak Observatory in southern Arizona, another observer stated that, ... *the meteors were so intense that we were guessing how many could be seen in a one-second sweep of the observer's head. A rate of about* 150 000 *per hour was seen for about* 20 *minutes.* Many commented on how looking directly at the Leonid radiant gave an impression of the Earth moving trough space toward Leo. One person watching from northern Colorado later noted that, ... *I had the feeling that I should be hearing something.* Still another said, ... *instinctively we sought to shield our upturned faces from imagined celestial debris.*

In the aftermath of this incredible display, Canadian meteor expert Peter M. Millman utilized radar data to determine the width of the Leonid shower as 35 000 kilometers (Figure 8); now generally regarded as the width of the swarm that contained the greatest concentration of meteoroids. The Earth swept through this dense, yet narrow filament of debris in just one hour.

The Leonids provided one more surprise as the decade of the 1960s came to a close: on November 17, 1969, a brief interval (less than an hour) of intense (four per minute) Leonid activity occurred over a limited geographical area in the northeastern United States. Yet, elsewhere, the shower was weak.

Now, with the scheduled return of P/Tempel-Tuttle just over two years away (February 1998), the cycle is about to fall due once more. What will it produce?

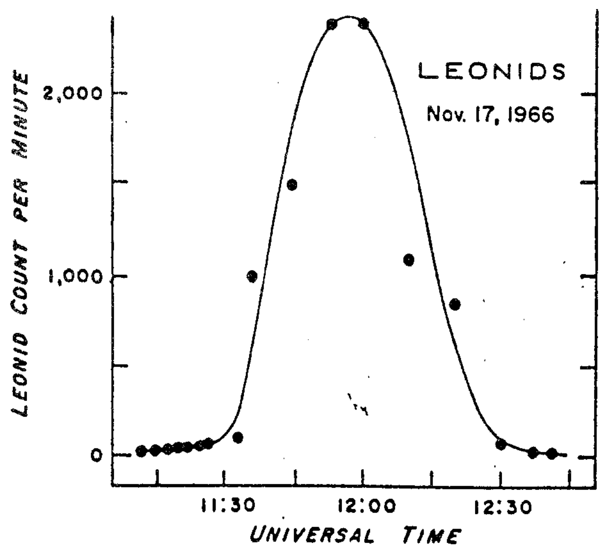

Figure 6 – The Leonid rate per minute for a single observer at Kitt Peak Observatory in Southern Arizona. A maximum of 2400 per minute (40 per second) was attained near 11^h55^m UT.

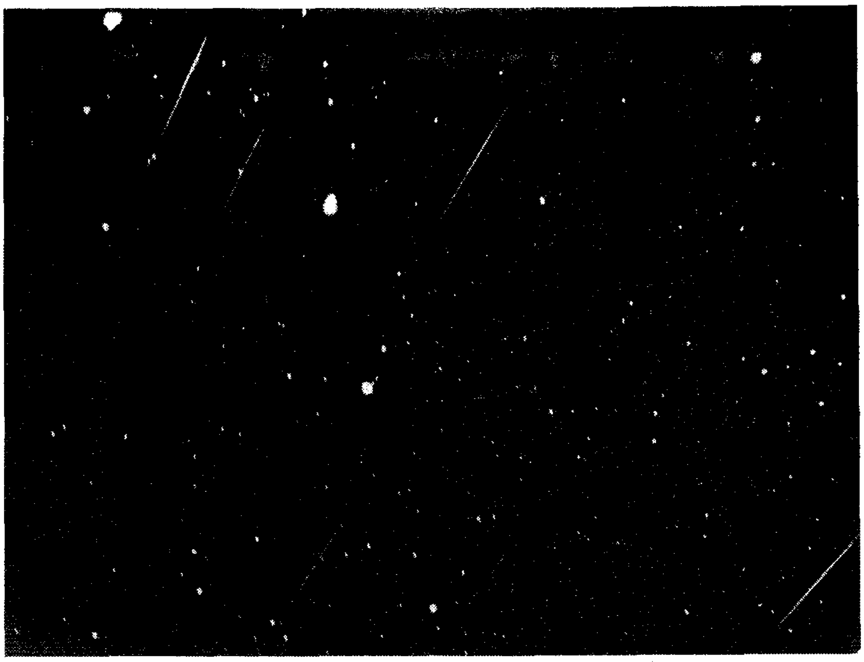

Figure 7 – The Leonids on November 17, 1966, as photographed from Arizona.

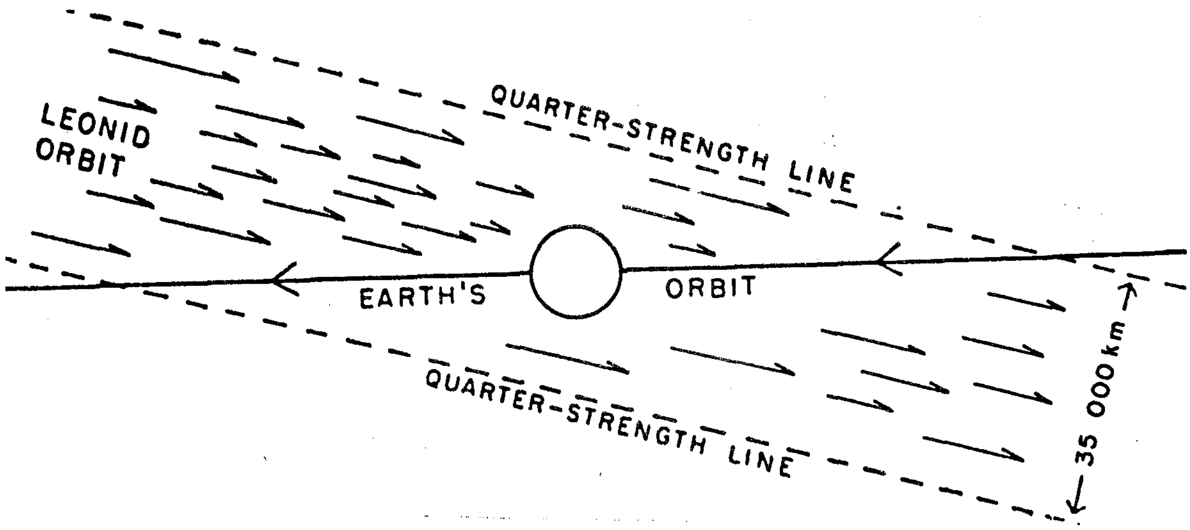

Figure 8 – The width of the 1966 Leonid shower, according to radar studies by Dr. Peter Millman.

3. The future

Like most comets, P/Tempel-Tuttle is a cosmic litterbug, leaving a "river of rubble" in its wake. Like the comet itself, every tiny particle in this particular meteor stream orbits the Sun in a roughly 33-year period. These particles—ranging in size from dust grains to small pebbles—are what produce the Leonids. Even though many Leonid meteoric particles have become scattered along the comet's orbit, stretching all the way out to the orbit of Uranus, the densest swarm of them are apparently clustered closely around the comet itself. It is this dense swarm that would graze the orbit of the Earth at about the same time the comet would, at approximately 33-year intervals. For this reason, the Leonids are recognized more as a periodic rather than an annual shower.

Typically, the Leonids are nothing to get very excited about. Ordinarily, at their peak on November 17-18, they usually produce no more than about 10 meteors per hour. Since, like their parent comet, Leonid meteoroids orbit the Sun backward, or in a retrograde orbit, they collide nearly head-on with our Earth (Figure 9). They rush through our atmosphere at over 70 kilometers per second, faster than any other major shower, producing bright, swift streaks of white, green and blue, many of which leave long-enduring trains. In those Novembers in the years leading up to or just after P/Tempel-Tuttle passes by, however, we stand a "chance" of careening through the densest part of the Leonid swarm, enhancing the possibility of seeing a storm of meteors.

In 1981, Dr. Donald K. Yeomans of NASA's Jet Propulsion Laboratory put forward what many have considered to be the definitive study concerning the orbit of P/Tempel-Tuttle and its implications on future Leonid activity. By studying historical data for the millennium between the years 902 and 1969, he was able to map the distribution of meteoric material surrounding the comet. Figure 10 summarizes this distribution as determined by a calculation of the minimum distance between the Earth and particles ejected from the comet on dates near the time of the comet's perihelion passage. The points are empirically derived and thus do not represent a continuous distribution of material.

The four quadrants of the diagram represent locations where the particles are either ahead of or behind the comet in its orbit and inside or outside (relative to the Sun) of it. If the ejection velocities of the dust particles driven from the comet controlled their dynamic evolution, quadrant IV would be heavily populated. In fact, that quadrant is nearly empty. This has led Dr. Yeomans to conclude that it is solar radiation pressure, plus planetary perturbations that cause the Leonid particles to rapidly evolve to a position behind the comet and outside its orbit.

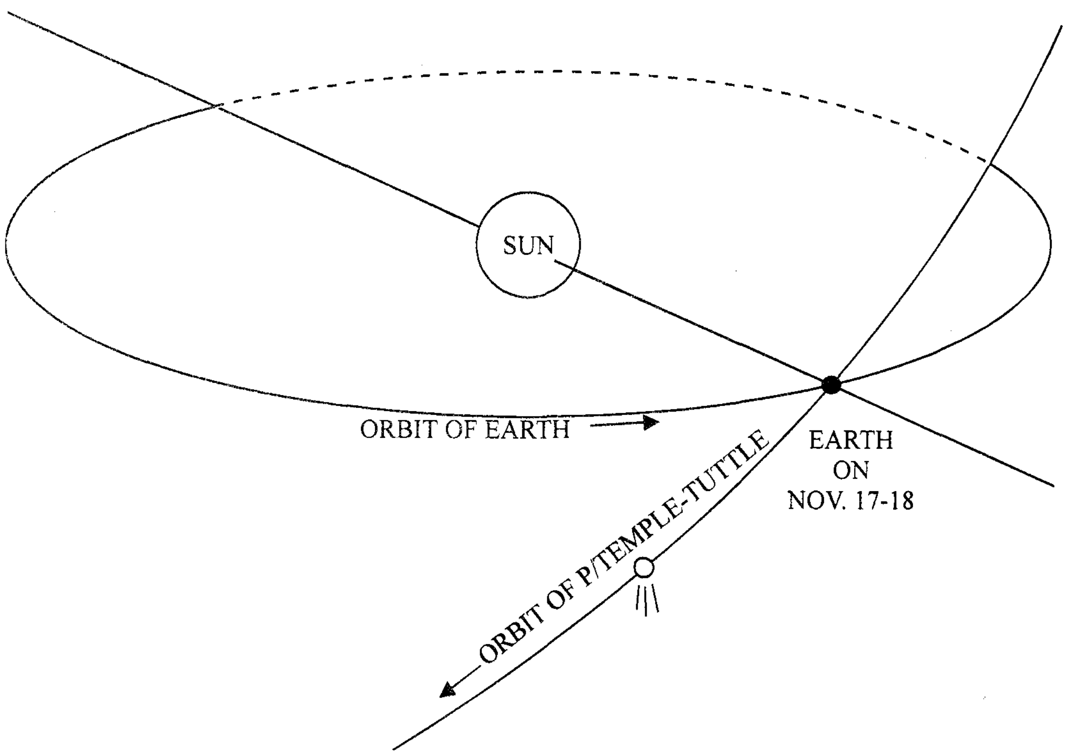

Figure 9 – The Leonid Meteor Stream, as pictured in a three-dimensional diagram which is correctly drawn according to the orbital characteristics of the stream. Inclination of the Leonid orbit to the Earth is 162°7, so that in effect the meteoroids move in a direction opposite to that of the Earth. According to the *Observer's Handbook of the Royal Astronomical Society of Canada* the geocentric or entry speed into the Earth's atmosphere is 71 km/s, a velocity faster than that of any other known meteor shower. The actual orbit of the Leonids practically coincides with that of the Earth on November 17-18.

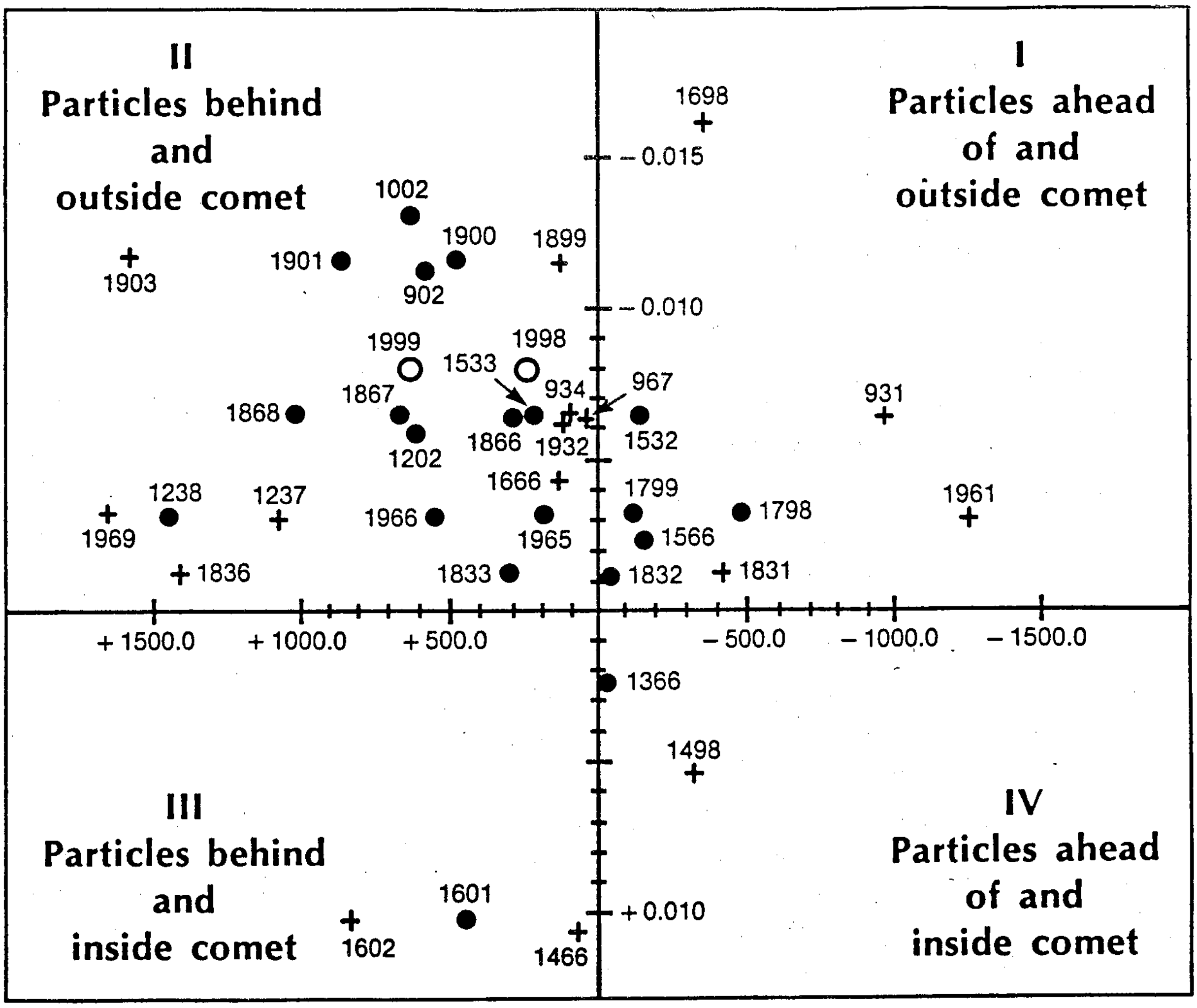

Figure 10 –The distribution of dust particles surrounding Comet Tempel-Tuttle is depicted in this diagram based on the work of Dr. Donald K. Yeomans. For the dates near the time of the comet's perihelion, calculations were done to determine the location of the dust particles relative to the parent comet at the time of their closest approach to the Earth. The horizontal axis gives the time in days that particles lag behind (+) the parent comet or precede (–) it. The vertical axis is the distance in astronomical units that the particles are outside (–) and farther from the Sun, or inside (+) the comet's orbit. Solid circles indicate dates when major meteor storms occurred at the time of the Leonids, while crosses are for dates of showers of lesser intensity. Conditions for 1998 and 1999 are plotted as open circles. (From *Comet Tempel-Tuttle and the Leonid Meteors* by D.K. Yeomans, *Icarus* 47, 1981, pp. 429–499.

Strong meteor displays, with hourly rates in excess of 100, appear to be possible for about six or seven years before and after P/Tempel-Tuttle's perihelion when it passes up to 0.025 astronomical unit inside or 0.010 AU outside the Earth's orbit. Indeed, there are signs that this is happening now, for despite a Full Moon, both visual and radio observations of the 1994 Leonids suggested very strong activity—perhaps zenithal hourly rates (ZHRs) of 80 to 100 per hour—having briefly taken place between 6^h and 7^h UT on November 18, 1994. Shelby Ennis, a ham radio operator (W8WN), has monitored meteor showers on radio for over three decades. About the 1994 Leonids, he noted, *While not a great shower, they (the Leonids) were very good... better than I can remember from "way back." They were more like the "normal" peak of the Perseids or Geminids.*

The likelihood of a *stupendous* display (a meteor storm) appear best when the Earth encounters particles found in quadrant II, as will be the case in 1998 and 1999. Yet, it should also be noted that the great meteor storm of 1799 occurred when the Earth brushed past P/Tempel-Tuttle's orbit less than four months *before* the comet itself (within quadrant I), and very similar circumstances regarding this particular situation will again exist in 1997.

However, as we have already seen, while the Leonids have the potential to storm every 33 or 34 years, they do not always do so. Recall that when storm conditions appeared favorable in 1899 and 1932, the hoped-for Leonid blizzards failed to materialize.[10] This leaves the spectacular Leonid displays that many have predicted for the close of this century somewhat uncertain. *That is the way it is with meteor showers*, says Yeomans. *You can say "probably," but if you say "definitely" they will get you every time.*

In addition, trying to predict exactly at what time the peak of the Leonids will occur in any given year will probably give astronomers additional headaches. This is because we would be trying to anticipate intercepting not just a single stream along the orbit of P/Tempel-Tuttle, but possibly one of several: each stream having evolved from the solid debris that crumbled off the comet's nucleus at previous perihelion passages.

Likely, these consist of irregular clouds of dust, perhaps spewed by outbursts on the comet. (The 1966 and 1969 Leonid displays, for example, might have been caused by particles ejected by P/Tempel-Tuttle as far back as 1767—six revolutions ago). If, as in 1966, we are again lucky and pass through a dense filament of cometary material, we will get a storm; if not, we will see considerably less to perhaps almost nothing at all.

Furthermore, you will have to be in the right place at the right time: Leo does not begin to rise until after midnight during mid-November, and the time for viewing Leonids is thus limited to the hours between midnight anddawn.

As it is, one-quarter of the Earth is between midnight and dawn at any given moment. And as we have already seen, the dense meteoroid filaments are typically narrow with the Earth likely sweeping through one in only about an hour's time. If during that hour you are in daylight, you are out of luck (as was the case for the eastern United States in 1966, see Figure 11). On the other hand, if the peak storm activity comes before midnight, the bulk of the meteors will be below your horizon.

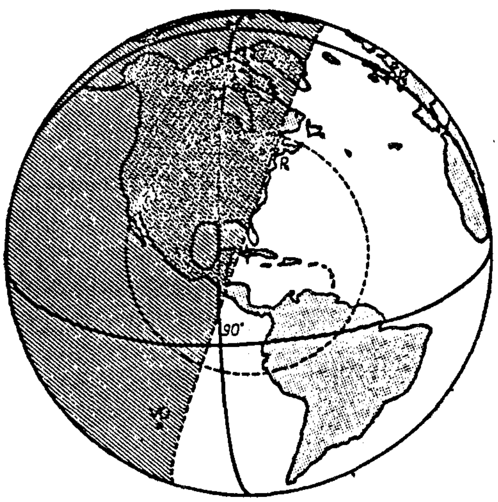

Figure 11 –The Earth as seen from the Leonid radiant at 11^h55^m UT on November 17, 1966. The shaded area is on the night side.

[10] Actually, when comparing the Earth-comet geometry of 1932 to 1866, it would appear that the prospects for a meteor storm would be better for the former rather than the latter year. In 1866, the Earth followed P/Tempel-Tuttle to the grazing point (descending node) of the two orbits by 299.4 days, with the comet passing 0.0065 AU inside the orbit of the Earth. In 1932, the comet passed slightly closer to the Earth's orbit at 0.0062 AU, with the Earth arriving at the node just 121.4 days after the comet—less than six months earlier than in 1866. Yet, the Leonids stormed in 1866, but not in 1932!

So just when might we go through any prospective filaments in the coming years? If we knew in advance what the orbital plane of the Leonid particles are, then the calculation is quite simple, for the encounter must take place when the Earth goes through this plane. Assuming that the meteoroids are moving in exactly the same plane as P/Tempel-Tuttle, Yeomans recently re-calculated this comet's orbit as well as re-computing the times when the Earth will arrive at the grazing point with the comet's orbital plane.[11] At this upcoming apparition, the comet passes 0.0080 AU inside of the Earth's orbit.

Yeomans data are presented in Table 1, which also includes the time difference, in days, between when the Earth either follows (+) or leads (−) the comet to the grazing point. In addition, based on Yeomans's times, I have included those regions of the Earth that would be in the best position to view any prospective enhanced Leonid activity as well as the corresponding age, in days, of the Moon. Note that interfering moonlight will be minimal in 1995 and 1999, and will not be a factor at all in 1996 and 1998. Only in 1997 is the Moon a serious hindrance appearing as a bright waning gibbous, near Orion's upraised club.

Table 1 – Nodal crossing data according to Yeomans.

Year	Earth crosses comet's orbital plane (UT)	Comet's distance	Region of visibility	Moon's Age
1995	November 18, 01^h15^m	−838 days	Europe/Africa/W. Asia	24.6
1996	November 17, 07^h20^m	−473 days	Eastern N. America/ S. America/Atlantic	6.6
1997	November 17, 13^h35^m	−108 days	Western N. America/Pacific	17.9
1998	November 17, 19^h45^m	+257 days	Asia	28.3
1999	November 18, 01^h50^m	+623 days	Eastern Atlantic/ Europe/Africa/W. Asia	9.0

What if, however, the Leonid particles for a given year are shifted somewhat in their position with respect to the orbital plane of the comet? In such a situation, the prospective time of maximum could come minutes, or even hours earlier or later. In 1965, for example, the strong Leonid display seen from Hawaii and Australia came approximately *13 hours before* the Earth arrived at the comet's orbital plane.[12] The great Leonid storm of 1966 came about an hour after the Earth passed the comet's orbit, while the 1969 shower occurred about 4 hours later.

4. Conclusion

More than three decades ago in *Sky and Telescope*, Charles P. Olivier wrote the following: *Any prediction as to what the Leonids will do in a given year cannot be much more than an intelligent guess.* All these years later, Olivier's words still ring true.

[11] Another method to determine the time of a shower's maximum is to refer to its solar longitude. The 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 comparing meteor rates observed in different years. So far as the Leonids are concerned, Alastair McBeath of the International Meteor Organization and Robert L. Hawkes in the Celestial Handbook of the Royal Astronomical Society of Canada utilize $\lambda_\odot = 235\overset{\circ}{.}6$. In 1995, this corresponds to November 18, 8^h UT. This is about seven hours after the nodal crossing time given by Yeomans and, as McBeath notes, ... *will favor sites across North America.*

[12] It certainly seemed that 1965 was the ideal year to anticipate a Leonid storm. The Earth passed the nodal crossing point just 195.5 days after P/Tempel-Tuttle—the moment when the comet's orbital plane would be crossed was November 17 near 5^h UT—apparently near perfect conditions for Africa, Europe, and the eastern Atlantic. Yet, as already noted, there was no storm and the shower peak actually came more than half a day earlier, and half a world away over the western Pacific.

About the only thing that *is* predictable about the Leonids, is that they are *unpredictable*! Suffices to say, nobody really knows what to expect from them as we move into the later part of the 1990s. While the oft-quoted figure of 10 per hour is not particularly conducive to getting amateurs out on a cold November morning, the upcoming years hold the potential of some truly exciting observing. Monitoring various stages of the shower in 1995, especially on the peak night of November 17-18, could offer the possibility of a far-better than average shower—perhaps presaging another historic display later in the decade. The *International Meteor Organization* (*IMO*), which coordinates the activities of a global network of amateur observers, has already begun its *International Leonid Watch* and will monitor the shower through at least the end of this century.

Based on what has been observed at the previous six Leonid epochs, it would appear that there is a possibility of a "storm" in any year from 1997 through 2000, with the odds especially favoring the years 1998 and 1999. The circumstances in those two years certainly seem very favorable, but no one can guarantee a spectacular shower as the Earth plays a cosmic game of blindman's buff with these tiny particles. But even if a meteor storm fails to materialize, the Leonids still could produce a shower with rates far higher than any of the other annual streams—even outdoing the Geminids and Perseids. In short, all-night observing sessions world-wide should be planned for the night of November 17-18 through the end of this century. For those who cannot participate in an all-night meteor watch, Dr. Edward Brooks of Boston College suggests that astronomy clubs attempt to organize a *Leonid hotline*. In this way, he says, should meteor activity increase precipitously or unexpectedly, hotline members would quickly alert others by phone. *In the past, for example, this method has worked rather well in the aftermath of major solar flares that had the potential to spawn a sudden burst of auroral activity.*

To be sure, so far as the ever-erratic Leonids are concerned, all that can be said is that those who are out looking when and if it happens, will see it!

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Ongoing Meteor Work

The Makings of Meteor Astronomy: Part X

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Experimental meteor astronomy began in 1798 with two students, Heinrich Brandes and Johann Benzenberg, at Göttingen University. Inspired and encouraged by George Lichtenberg, Professor of Experimental Physics at Göttingen, the two students collected simultaneous observational data on shooting stars, demonstrating for the first time that meteors most probably had an extraterrestrial origin.

1. Introduction—meteor heights

As we noted last time, Ernst Chladni closed his 1794 treatise on meteoric stones with a plea for observations. In particular, he called for two-station observations of meteor heights to be made.

Two-station observations of a meteor trail are useful since the parallactic shift in the meteor's apparent path, with respect to the background stars, can be exploited to find its beginning height, end height, and trail length. If the duration of a "two-station meteor" is also noted an estimate of its velocity can be found.

It was through the influence and continued encouragement of George Lichtenberg (1742–1799), professor of experimental physics at the University of Göttingen, that the first systematic two-station observations of shooting stars were eventually made. Indeed, Lichtenberg persuaded two of his then students, Heinrich Wilhelm Brandes (1777–1834) and Johann Friedrich Benzenberg (1777–1846) to make simultaneous observations of the sky between September and early November in 1798. Before, we discuss the work of these two students, it is constructive and informative to consider a few brief biographical details [1].

2. George Christoph Lichtenberg

George Lichtenberg was born in the town of Ober-Ramstadt, Germany on July 1, 1742. His father was a Protestant pastor, and he was the seventeenth, but fifth surviving, child born into the family. His early schooling was overseen by his father, and, while a sickly child—Lichtenberg had a permanent spinal deformity—he showed early promise as a scholar, excelling in mathematics and natural history.

Lichtenberg first entered the University of Göttingen under the patronage of Ludwig, the 8th Duke of Hesse-Darmstadt. There, he studied a wide range of subjects including literature, history, and natural sciences. Of the latter, Lichtenberg was to later write, *I have covered the path that leads toward science like a dog accompanying his master on a walk... I have covered it over and over again in all directions.* His avid interest in the sciences soon made Lichtenberg the leading German authority in such fields as geophysics, astronomy, chemistry, statistics, and geometry. Lichtenberg's prime interest, however, was experimental physics.

Following a distinguished undergraduate career, Lichtenberg was appointed, at the tender age of 27 years, *professor extraordinarius* at the University of Göttingen in 1769. He was promoted to *professor ordinarius* in 1775. Lichtenberg was later honored by his peers by being elected a fellow of the Royal Society (London) in 1793, and a fellow of the St. Petersburg Academy of Sciences in 1795.

Lichtenberg was an avid astronomer and personally investigated several meteorite falls and he made observations of new comets. He also observed the Venusian transit of June 1769. Lichtenberg also wrote a biography of Copernicus, and edited and published the works of Johann Tobias Mayer, the founder of the Göttingen Observatory. In spite of his many and indeed catholic interests, it was in the area of natural science, or as we would call it physics, that Lichtenberg excelled. Indeed, the first chair of experimental physics to be established at a German University was that created for Lichtenberg at Göttingen.

Through his electrostatics experiments, Lichtenberg is often accredited with the discovery of the process that modern day xerographic machines exploit to copy images. Lichtenberg also discovers the, so called, Lichtenberg figures, which are formed when fine dust is sprinkled on an electrically charged plate. Interestingly, the Lichtenberg figures and the acoustic patterns of E.F.F. Chladni [2] were ceased upon by the Romantic Natural Philosophers as examples of hieroglyphs, or revelations of the Creator. This group of philosophers believed that experimental phenomena, such as that displayed by the Lichtenberg figures, were secret symbols, the deciphering of which would reveal the true nature and purpose behind God's many creations [3].

By all accounts, Lichtenberg was an influential and well-liked teacher at Göttingen. He encouraged both scholarship, and the furtherance of new scientific investigations. Lichtenberg made no memorable contributions to the development of meteor science, but his influence was all important. It is through Lichtenberg, for example, that Chladni was encouraged to begin his meteoric studies, culminating in the former's influential thesis of 1794, and it was through Lichtenberg that Brandes and Benzenberg were encouraged to make their observations, hence establishing for the first time a truly experimental aspect to meteoric studies.

After a long and distinguished scientific career, Lichtenberg passed away, at age 57 years, in Göttingen on February 24, 1799.

3. Johann Friedrich Benzenberg

Johann Benzenberg was born in the town of Schöller, near Düsseldorf, Germany on May 5, 1777. As a young student he initially studied theology in Herborn and Marburg. Later, however, upon moving to the University at Göttingen, he turned his attention to the study of natural sciences. He received his doctorate from the University of Duisberg in 1800, and became professor of mathematics at the Lyceum in Düsseldorf in 1805.

Benzenberg joined forces with Heinrich Brandes in 1798, while still a student at Göttingen. Encouraged by Lichtenberg, the two young observers set about making the first systematic and simultaneous study of shooting stars (see below). While the observations collected by Benzenberg and Brandes were taken as supportive of Chladni's extraterrestrial hypothesis of meteoroid origins, Benzenberg later adopted the viewpoint that meteors were stones "shot" from lunar volcanoes. Indeed, Benzenberg was to write a text supporting the lunar origins hypothesis in 1834.

Most of Benzenberg's later years were concerned with studies in ballistics and astronomy. Indeed, Benzenberg arranged a series of experiments in which lead spheres were dropped from church towers (and down mine-shafts) with the intention of measuring their lateral displacement towards the east, thereby demonstrating the revolution of the Earth. In this respect Benzenberg's experiments predated those of Foucault by some 50 years.

Benzenberg died, after reaching the age of 69 years, in Bilk, near Düsseldorf, on June 7, 1846.

4. Heinrich Wilhelm Brandes

Brandes was born in the town of Groden, near Cuxhaven in Germany, on July 22, 1777. Few details are known about his formative years, but it is certainly known that he studied natural sciences under Lichtenberg at Göttingen. Brandes was appointed professor of mathematics at the university in Breslau in 1811, and later became professor of physics at Leipzig in 1826.

We know that, as a student at Göttingen, Brandes spent some time studying meteors, but his later works centered on the theory of refraction in the Earth's atmosphere. Brandes also published works on the theory of cometary tails.

Brandes published several popular scientific works and was widely read as a popularizer of science. Brandes died at age 57 years in Leipzig on May 17, 1834.

5. The observations

Brandes and Benzenberg were not the first observers to calculate the height and velocity of meteors by the method of triangulation. Edmund Halley, for example, had used such methods in the early 1700s to determine the height and velocity of several bright fireballs [4]. Brandes and Benzenberg, however, were the first observers to set about systematically collecting simultaneously observed meteor data. Their data, which formed the basis of their pioneering paper, were collected between September 11 and November 4, 1798.

Working from a baseline of just a few kilometers, Brandes and Benzenberg soon found that shooting stars formed at high altitudes. During the 54 days between September 11 and November 4, the two observers deemed a total of 21 meteors to have been observed simultaneously. In fact, all of their coincidence data were collected on just six separate nights—their best night was October 9, when seven meteors were simultaneously observed. Their second best night was November 4 (the final night of the study) when six meteors were simultaneously observed [5].

Of the 21 simultaneously observed meteors, Brandes and Benzenberg calculated the beginning and end heights of just four meteors. The remaining 17 meteors were assigned end heights only. The distribution of end heights is shown in Figure 1. The maximum and minimum end heights determined by Brandes and Benzenberg were 132 and 6 geographical miles (a distance equivalent to 1/60 of one degree of longitude at the equator). These extreme values are clearly in error, but the average meteor end height of 50.1 ± 29.1 geographical miles (that is, about 93 km) is about correct on the basis of modern day estimates.

The details surrounding the four meteors ascribed beginning and end heights by Brandes and Benzenberg offer some interesting food for thought. Two of the meteors were observed to move downward through the atmosphere, that is, their beginning heights were greater than their end heights. On the other hand, the other two meteors, and indeed the first two meteors for which both beginning and end heights were calculated, moved nearly vertically upwards in the atmosphere.

In other words, their was a fifty-fifty split in the apparent direction in which meteors moved through the atmosphere.

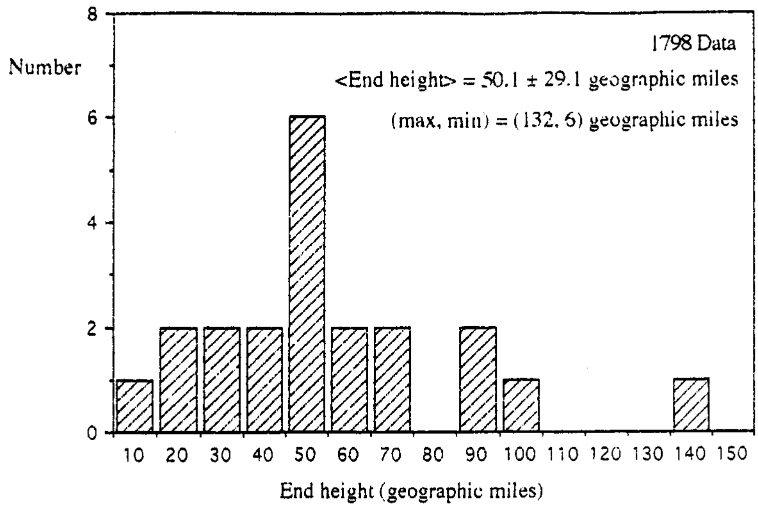

Figure 1 – Distribution of meteor end heights as deduced by Brandes and Benzenberg in 1798.

Interestingly, Benzenberg reported three more simultaneous meteor results in his book published in 1834. The meteors described by Benzenberg were collected during the nights of September 15 and October 3, 1801, and on the night of August 10, 1802. Only one meteor, that of September 15, 1801, yielded beginning and end heights—and yes, it apparently moved upward in the atmosphere.

Clearly, the data on beginning and end heights collected by Brandes and Benzenberg was (from a modern perspective) in error. This observational error can easily be accounted for by the short baseline separation that the two observers used. Indeed, the great mathematician Friedrich Bessel demonstrated this very fact in 1839 [6]. What is interesting, however, is that at face value, Brandes and Benzenberg had not unambiguously established the extraterrestrial hypothesis of meteor origins. Indeed, by 1802, more meteors (with reduced beginning and end points) had been observed to move upwards in the atmosphere than downward; a result that is more consistent with a terrestrial origin for the meteors. As we saw in a previous column [2], Chladni did suggest, in 1817, that there may be two kinds of meteors, with one group forming in the Earth's atmosphere and the other group entering the Earth's atmosphere from outer space. It was also suggested that the apparently ascending meteors might have resulted from a reflection phenomena caused by strongly compressed air. Indeed, Von Humboldt [6] felt that the topic of ascending meteors still required some discussion when he wrote his monumental thesis, *Cosmos*, published in 1849. Von Humboldt, however, argued that such meteors could be explained purely on the basis of experimental errors. In light of Bessel's analysis of 1839, Von Humboldt concluded his discussion with the comments, *the assumption of an ascent of shooting stars was rendered wholly improbably, and inadmissible as a result of observation.*

Trail lengths were computed for just two of the four meteors for which Brandes and Benzenberg calculated beginning and end heights. These two meteors both moved downward in the atmosphere and had trail lengths of about 14 km. The estimated velocities for these two meteors were 8 and 10 km/s. It was the discovery that shooting stars (all be it just two cases) entered the Earth's atmosphere with near planetary velocities (10 km/s is about 1/3 that of the Earth in its orbit about the Sun) that proved to be the most important result to come out of the whole observing campaign. We have seen that Brandes and Benzenberg height measurements offered no clear evidence that all meteors entered the Earth's atmosphere from above, but what they did show was that in the two cases where a meteor apparently entered the Earth's atmosphere from outer space, the entry velocity of the meteoroids was akin to that expected for objects in orbit about the Sun.

The Brandes and Benzenberg meteor observing partnership apparently dissolved in 1802, and the 1798 campaign was the only long term project that the two observers completed together. While Benzenberg did not continue his observational work on meteors, Brandes eventually embarked upon another series of meteor observations; these new observations were not attempted, however, until 1823 [7].

Simultaneous observations of meteors were collected by Brandes and his students between April and October 1823. During this interval of time a total of 63 simultaneously observed meteors were recorded. Thirty six of the meteors were ascribed both beginning and end heights, and 26 of these doubly observed meteors were deemed to have moved downward in the atmosphere, nine apparently moved upwards, that is, from the lower to the upper atmosphere, and one traveled horizontally (see Figure 2). The extreme beginning and end heights (for all observations) deduced by Brandes and his students were, maximal and minimal beginning height, 339 km and 7.5 km, and, maximal and minimal end height, 184 km and 10 km. The average beginning height was (99.7 ± 58.4) km, while the average end height was (78.4 ± 37.8) km. These average results are in good agreement with modern day estimates, all though, once again, the extreme values are in obvious error.

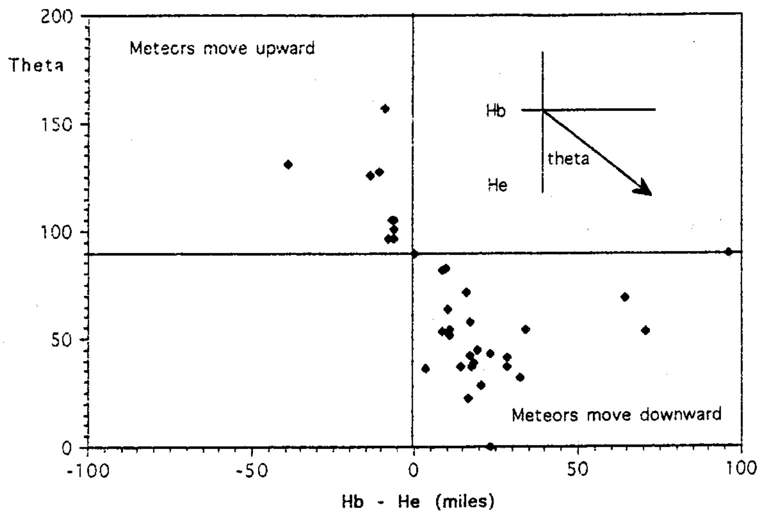

Figure 2 – Direction of flight versus meteor trail length, as deduced by Brandes from his 1823 observing campaign.

While some meteors (25%) were still observed to move upward in the atmosphere, the collected observations were now beginning to indicate that meteors really did enter the Earth's atmosphere from outer space. Once again, however, it was the implied "planetary" velocities of the meteors that presented the strongest argument for an extraterrestrial origin. Brandes found that the observations suggested that meteors enter the Earth's atmosphere with relative velocities between 29 and 58 km/s.

6. Conclusions

Brandes and Benzenberg were pioneers of experimental meteor astronomy. Following their campaign of 1798, and the later studies by Brandes in 1823, the idea that meteors were produced by the entry of extraterrestrial bodies into the Earth's atmosphere became reasonably well established as an observational fact.

It was not until circa 1840, however, that the problem of apparently ascending meteors was resolved in terms of experimental error. This is not to say, as we shall see next time, that every one believed that meteors entered the Earth's atmosphere from outer space.

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Some Notes from Old Journals

Tony Markham

Scattered through old astronomical magazines and journals are many entries which give insights into how meteor observing has developed over the years. This article gives some examples from two UK based sources: *The Astronomer* Magazine (*TA*) and the *Journal of the British Astronomical Association* (*JBAA*).

1. Meteor shower naming

This is a topic which does not seem to greatly concern observers nowadays. However, the 1952 February *JBAA* included a letter from Dr. J.G. Porter [1] which raised the question of how meteor showers should be named. He objected to the use of names such as *Bečář's stream* and *Umids* for the December shower in Ursa Minor that had been reported by Bečář in 1946, arguing instead for names such as *December Ursids* or *Beta Ursa Minorids*. In comments following Porter's letter, however, *BAA* Meteor Section Director J.P.M. Prentice, while referring to the shower as the *December Ursids*, stated that he did not object to the name *Bečář's stream*. We, of course, now call this shower the Ursids.

2. Credit for discoveries

As part of his objection to the name "Bečář's stream," Porter included a copy of a 1916 letter of W.F. Denning that had been published in the magazine *Observatory*. In this letter, Denning had reported his observations of activity from a radiant at $\alpha = 218°$ and $\delta = +76°$ during December 18–25, and had noted that this was close to the expected radiant for activity associated with Comet Tuttle (referred to by Denning as "Mechain-Tuttle's comet"). However, in his comments following Porter's letter, Prentice argued that the name "Bečář's stream" was not unfair to Denning since Bečář's observations of the 1945 outburst had been more significant than Denning's work in drawing attention to the shower.

3. New showers

Possible new meteor showers are reported from time to time. It is usually the case, however, that having been reported in one year, such showers are never heard of again. Among such showers have been a radiant at $\alpha = 10^{h}00^{m}$, $\delta = +47°$ on March 7-8 [2], a radiant near β Pegasi in mid/late July [3], a radiant near Polaris in late August [4], and a radiant near 30 Cephei on Aug 11-12 [5].

4. Comet-meteor shower relationships

Denning's letter in [1], which was written following the June 28, 1916 outburst of the Pons-Winneckids, also speculated about finding meteor activity associated with some other comets. Three possible radiants were listed: near γ Librae on September 7 and near ξ Sagittarii on October 24, both associated with Comet Finlay, and near γ Draconis on October 10, associated with *Giacobini's comet of 1900*.

Whereas Denning clearly accepted a relationship between comets and meteor streams, a review [6] of Dr. J.G. Porter's book *Comets and Meteor Streams* in the 1953 January *JBAA* showed that others continued to doubt the relationship. Referring to Whipple's model, the reviewer commented that ... *it is now even less convincing since Lovell has shown that neither the Aquarids nor the Orionids can be associated with Halley's comet.* He later added *Porter's view about meteors associated with comets is that a common origin for both is more probable than the assumption of a direct connection*, but then questioned even this, adding ... *in some cases at least, the similarity of the elements is only fortuitous...*

5. Sporadic meteors

In the early 1950s, the question of the origin of sporadic meteors was nearing its resolution. However, whereas the above review stated that Dr. Porter *showed conclusively that hyperbolic meteors were the exception, not the rule...*, a review [7] of Lovell's book *Meteor Astronomy* in the 1955 June *JBAA* gave both sides of the argument and stated that at the date of publication (1954), the final answer was still awaited. Even after accepting sporadic meteors as Solar System members, the reviewer of Porter's book added ... *their origin remains unsolved. Were they formed with the planets, or have they originated in some other way...?*

6. Quadrantid and Geminid rates

The 1953 April *JBAA* included a paper by J.P.M. Prentice entitled *The Hourly Rate of the Quadrantid Meteor Shower at Maximum* [8]. While accepting that richer returns had occurred in 1864, 1909, and 1922, with weaker returns in 1901, 1927, and 1940, the paper concluded that the normal ZHR was around 45. The possible 13 year cycle suggested by the above years was discussed. Prentice accepted that the orbital period was not 13 years and described two possible ways of generating an apparent 13 year periodicity from a combination of shorter orbital periods.

Most interesting is a footnote which states *Denning's comparison of Quadrantid and Geminid rates in... 1909 is misleading. He was certainly unaware that the Geminids are the finest (visual) shower of the year, for he treats them as equivalent to the Lyrids and the Orionids.* With hindsight, of course, we can explain Denning's results. We now know that Geminid rates are being altered due to gravitational perturbations of the Geminid orbit. It is interesting, however, to note that Prentice regarded the Geminids rather than the Perseids as the finest visual shower. Prentice also commented that radar determinations had shown the Quadrantids to be richer than the Geminids and Perseids. He accounted for this "discrepancy" as being *probably due to a difference in the infra-visual content of the three streams.*

7. The 1966 Leonids

Our impression of the 1966 Leonids nowadays is largely influenced by the reports of the high rates that were seen from the USA. Minutes of the *BAA* meetings of October 26, 1966, [9] and November 30, 1966, [10] in the 1967 February *JBAA* give an indication of what had been expected beforehand and the initial accounts of what had been seen.

At the October meeting, Meteor Section Director Harold Ridley had noted that the Leonid hourly rate had reached about 100 in 1965, and he predicted an *exceptionally strong display* for 1966 reaching, perhaps, a rate of 200–300 per hour of November 16-17.

At the November meeting, he described how UK weather conditions had been variable in the south and in East Anglia, better in the midlands, but more cloudy in the north. For UK observers, the display had certainly not been as spectacular as he had hoped. The maximum hourly rate seemed to have been between 30 and 40. Reports from South Africa and Western Australia had described the display as disappointing. However, observers at Kitt Peak in the USA had seen rates of 15–20 per minute at around 11^{h} UT and 20 per second at 12^{h} UT. He noted that, whereas a broad maximum had been expected, a sharp narrow maximum had been seen instead, suggesting that the outburst was due to material that had only recently parted company with the comet. However, one *BAA* member present at the meeting argued instead that the results supported Lyttleton's accretion theory of comets.

8. Perseid subcenters

Little attention is paid to possible Perseid subcenters nowadays. However, during the mid/late 1970s, several observers reported in *TA* on the results of their monitoring of Perseid subcenters. Four had been reported by Martynenko in 1974, based on Soviet observations in 1970. These were at $\alpha = 02^{\mathrm{h}}25^{\mathrm{m}}$ and $\delta = +57°$ (Sword Handle); $\alpha = 03^{\mathrm{h}}00^{\mathrm{m}}$ and $\delta = +55°$ (γ Per); $\alpha = 03^{\mathrm{h}}05^{\mathrm{m}}$ and $\delta = +41°$ (Algol); and $\alpha = 03^{\mathrm{h}}15^{\mathrm{m}}$ and $\delta = +49°$ (α Per). A possible fifth subcenter was reported at $\alpha = 01^{\mathrm{h}}30^{\mathrm{m}}$ and $\delta = +58°$ (δ Cas) by Jim Craven in *TA* 1976 September [11].

9. Meteor simulations

How accurately do observers record the details of meteors that they have seen? In *TA* of July 1970 [12], G.S. Pearce reported the results of an experiment in which members of *Plymouth A.S.* had attempted to record the details of simulated meteors. Among the conclusions reached was that there was a tendency for the brightness of fast meteors to be underestimated. The results for the first meteor were particularly inaccurate—the observers had not been told about the nature of the test in advance. This highlighted the need for caution when interpreting observations of "casually observed" meteors.

10. Meteor sounds

Sounds simultaneous with the passage of meteors have occasionally been reported in *TA*, although such reports seem to have been rare in recent years. Descriptions of such sounds have included *oscillating hiss*, *distinct swishing sound*, *distinct fizz sound*, and *faint crack*. Sceptics have argued that such sounds are purely psychological and based on analogies with fireworks, whereas supporters have usually argued that some (unidentified) part of the electromagnetic spectrum must be involved.

11. Nebulous meteors

The December 1969 issue of *TA* included three reports of nebulous meteors [13] from Colin Henshaw, Graham Winstanly, and Paul Sutherland, the latter observer describing an accompanying *oscillating hiss*. The Editor was somewhat sceptical, suggesting that such observations were usually really of owls or bats. Despite this comment, further reports appeared in subsequent issues. In the issue of January 1970, S. Miller reported a group of four nebulous objects seen in binoculars [14] and in the issue of April 1970, Martin Ince described a magnitude 2 elliptical object [15] which he stated was definitely not a bird.

12. Spurious meteors

During meteor watches, our attention is sometimes caught by something meteor-like which we subsequently realize was not a real meteor. In the June 1976 issue of *TA* [16], Jim Craven described five types of *optical delusions* that can appear similar to meteors.

They were as follows:

- Black meteors—the short sudden "movement" of a streak of sky, blacker that the background.
- Shortish faint meteors, about 1 magnitude above the limiting magnitude, usually seen when changing the center of the field of view.
- Faint fast meteors, with paths directly between two adjacent stars up to 10° apart and usually off-center of the field of view.
- Short faint meteors, magnitude 3 or 4, apparently originating from a star off-center of the field of view.
- The sudden brightening of a bright star, off-center of the field of view, by 2–3 magnitudes.

13. Satellites and Aircraft

Often during meteor watches, objects initially seen as meteors turn out to be satellites or aircraft. The problem is worse for photographers who have to decide whether or not a trail that tye have recorded is that of a meteor—in some cases without having seen the object visually.

For example, in the issue of April 1982 of *TA* [17], Robert McNaught described how the first 50 hours of operation of his new fish-eye system had yielded no bright fireballs, but had recorded Salyut 6 at magnitude −2, magnitude −5 flashes from an aircraft passing overhead and a magnitude −3 aircraft at low elevation.

The November 1983 issue of *TA* included a cover photograph by J.A. Burger which included two meteor trails from August 12-13, 1983. However, in the issue of December 1983 [18], Russell Eberst suggested that, given the brightness variations, one of them might be the trail of a satellite. He suggested that the satellite might be 82-111A, an American surveillance satellite. By chance, the object had also been photographed by Noel White and his photograph was published on the cover of the January 1984 issue. Analyses of these photographs by Roy Panther [19] and J.A. Cooper [20] (also taking into account his own photograph) gave heights for the brightest point in the trail of 225 miles and 365 km respectively, heights clearly much larger than would be expected for a meteor. Cooper suggested the Big Bird satellite as a possible candidate.

On the cover of the October 1988 *TA* was a photograph taken by Nick James on 1988 August 9 that apparently showed four parallel meteor tracks. Once again, satellites proved to be responsible. Russell Eberst identified them as four of the six "whitecloud" secret USA satellites which were orbiting in formation [21].

14. Conclusion

The above notes cover only a selection of the topics that these publications have covered. My collection of the publications is, in any case, far from complete.

In some cases, the accepted view has changed over the years. For example, the link between Comet Halley and the η Aquarids and Orionids is now generally accepted and the Quadrantid ZHR quoted nowadays is usually much higher than 45.

Other topics, such as meteor sounds and nebulous meteors, remain controversial and probably will do for many years to come.

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Geometrical Circumstances of the Movement of Meteors and the Definition of the Radiant

A. Grishchenyuk, V. Lopata, V. Gulyaev

The geometrical peculiarities of the meteor's motion in the atmosphere in dependence on different brightnesses and showers are shown. These characteristics help in accurately identifying meteors with their showers.

1. Calculations

One of the most uncertain parameters of meteors (when they are counted without plotting the paths onto a map) is the shower association. This holds especially for meteors of minor showers. For example, parallel observations carried out in Crimea in August 1994 showed that for different groups observing independently the percentage of coincidences in the shower association was 100% for Perseids, whereas for meteors of minor showers this percentage was 30% only. Usually, different groups prolonged the same meteor backward to neighboring constellations: the one group prolongs the meteor towards Pegasus and the other, to Aquila, or towards Pegasus and Cygnus. Several factors lead to such mistakes : firstly, the observers pay their attention mainly to Perseids; secondly, they do not know the geometry of the motion of a meteor; and thirdly, they do not know the characteristics of meteors of minor streams being active at this time and the positions of their radiants.

The goal of the present paper is to study the geometrical characteristics of the meteor's motion in the atmosphere and to give a quantitative figure for the ratio of meteor distance from the radiant (elongation) to the meteor length dependent of both the zenithal distance of the radiant and the meteor magnitude. I.S. Astapovich [1] gives such a formula for this relationship.

Let us suppose that a meteor appeared in point A and disappeared in point B. Then the distance AB is the linear length of the meteor L. The angle AOB (Figure 1) in the angular length of the meteor λ. The angle AOR is the elongation (E) of the beginning point from the radiant.

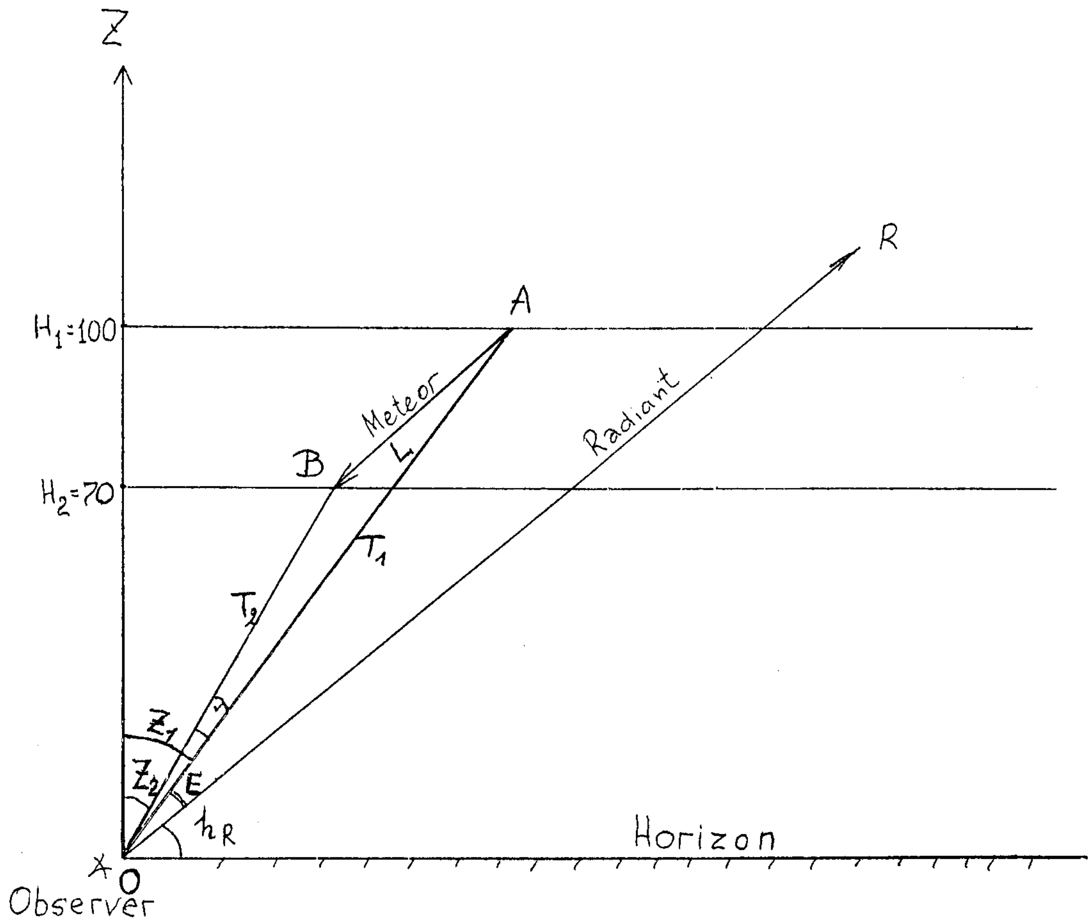

Figure 1 – Geometrical conditions of the meteor motion in the Earth's atmosphere.

Let T_1 be the distance of point A from the observer O, and T_2 the distance of point B. Then

$$H_1 = T_1 \cos Z_1, \qquad H_2 = T_2 \cos Z_2, \qquad \frac{H_1 - H_2}{L} = \sin h_R,$$

where Z_2 is the zenithal distance of the meteor's end, H_1 and H_2 are the linear altitude of the meteor's start and end point, and h_R is the height of the radiant above the horizon. Taking into account that the direction from O to the radiant R is parallel to the meteor path L, we get

$$\frac{L}{\sin\lambda} = \frac{T_2}{\sin E}, \qquad T_2 = \frac{H_2}{\cos Z_2}, \qquad L \sin E = \frac{H_2 \sin\lambda}{\cos Z_2},$$

and hence

$$\frac{E}{\lambda} \approx \frac{\sin E}{\sin\lambda} = \frac{H_2 \sin h_R}{(H_1 - H_2)\cos Z_2}.$$

Let us consider the ratio E/λ for different magnitudes of the meteors, whence for different masses of the meteoroids. The altitudes of meteors having different brightnesses were taken from [1] and are given in Table 1. The ratios E/λ are given in Table 1 with 15°-steps for the zenithal distance of the radiant and the end point of the meteor. Figures 2 and 3 show the results for different zenithal distances of the radiant graphically. As meteor heights were applied without differentiation in the showers, the given results represent average values.

The altitudes of meteors of different showers without differentiation in the brightness were also taken from [1] and are presented in Table 2. Table 2 and Figures 3–6 show the results of the calculations. Figure 7 shows the trajectory of the meteor projected onto the celestial sphere.

Table 1 – The ratio E/λ of the meteor distance from the radiant to the angular length of the path for different magnitudes.

m	−3	−2	−1	0	+1	+2	+3
H_1 (km)	107	115	117	112	107	102	103
H_2 (km)	65	70	70	75	65	83	77
				E/λ			
Z_2				$Z_R = 80°$			
80	1.548	1.556	1.489	2.027	3.478	4.368	2.962
65	0.636	0.639	0.612	0.833	1.429	1.795	1.217
50	0.418	0.420	0.402	0.548	0.940	1.180	0.800
35	0.328	0.330	0.316	0.430	0.737	0.926	0.628
20	0.286	0.287	0.275	0.375	0.643	0.807	0.547
Z_2				$Z_R = 65°$			
80	3.767	3.786	3.625	4.933	8.465	10.632	7.208
65	1.548	1.556	1.489	2.027	3.478	4.368	2.962
50	1.018	1.023	0.979	1.333	2.287	2.872	1.947
35	0.798	0.803	0.768	1.046	1.795	2.254	1.528
20	0.696	0.700	0.670	0.912	1.564	1.965	1.332
Z_2				$Z_R = 50°$			
80	5.729	5.758	5.513	7.503	12.875	16.170	10.963
65	2.354	2.366	2.265	3.083	5.290	6.644	4.504
50	1.548	1.556	1.489	2.027	3.478	4.368	2.962
35	1.214	1.221	1.169	1.591	2.729	3.428	2.324
20	1.059	1.064	1.019	1.387	2.379	2.988	2.026
Z_2				$Z_R = 35°$			
80	7.301	7.338	7.026	9.562	16.408	20.607	13.970
65	3.000	3.015	2.887	3.929	6.742	8.467	5.740
50	1.972	1.982	1.898	2.583	4.433	5.567	3.774
35	1.548	1.556	1.489	2.027	3.478	4.368	2.962
20	1.349	1.356	1.298	1.767	3.032	3.808	2.582
Z_2				$Z_R = 20°$			
80	8.375	8.418	8.060	10.969	18.823	23.640	16.026
65	3.441	3.459	3.312	4.507	7.734	9.713	6.585
50	2.262	2.274	2.177	2.963	5.085	6.386	4.329
35	1.775	1.784	1.709	2.325	3.990	5.011	3.397
20	1.548	1.556	1.489	2.027	3.478	4.368	

The results of the calculations were checked by a graphical construction of the motion of the meteors having different zenithal distances with a scale of 1 : 100 000.

A comparison shows good coincidence within the errors of the graphic representation and measurements.

2. Conclusions

1. The ratio E/λ is not a constant value, but varies from 0.5 to 30 for different streams and zenithal distances of meteor and radiant. To identify the stream it is necessary to know this ratio for different star magnitudes. Taking into account the velocity, brightness, and zenithal distance of the meteor's end point, one can calculate the zenithal distance of its radiant.

2. To identify the radiant more precisely, it is necessary to know the physical characteristics of the meteors of a given stream (color, velocity, linearity) and an approximate position of the radiant of the given stream.
3. It is necessary to note the star nearest to the suspected radiant or several stars along the backward prolonged meteor path.
4. It is necessary to organize a special program for the investigation of minor meteor streams being active at the same time as major ones (for example, κ-Cygnids during the activity period of the Perseids or Aurigids during the Geminids).

The realization of these recommendations will help the observer to identify the positions of minor streams more precisely, especially during periods of high activity of another shower. The experience shows that the determination of minor stream radiants without plotting the meteors onto maps during major showers' activity periods gives small reliability.

Table 2 – The ratio E/λ of the meteor distance from the radiant to the angular path length for several showers.

Shower	Cap	Tau	δ-Aqr	Per	Ori	Leo
V_∞	24	27	38	62	66	72
H_1	96	102	101	120	120	126
H_2	85	78	89	101	101	94?
			E/λ			
Z_2			$Z_R = 80$			
65	3.436	1.336	3.022	1.926	2.205	1.227
50	2.259	0.878	1.987	1.266	1.450	0.807
35	1.773	0.689	1.559	0.994	1.138	0.633
20	1.545	0.601	1.359	0.866	0.992	0.552
5	1.458	0.567	1.282	0.817	0.936	0.521
Z_2			$Z_R = 50$			
65	12.719	4.945	11.187	7.130	8.163	4.544
50	8.363	3.251	7.355	4.688	5.367	2.987
35	6.562	2.551	5.772	3.679	4.211	2.344
20	5.720	2.224	5.031	3.207	3.671	2.043
5	5.396	2.098	4.746	3.025	3.463	1.928
Z_2			$Z_R = 20$			
80	45.255	17.593	39.803	25.370	29.043	16.166
65	18.595	7.229	16.355	10.424	11.934	6.642
50	12.226	4.753	10.753	6.854	7.846	4.367
35	9.593	3.729	8.438	5.378	6.157	3.427
20	8.363	3.251	7.355	4.688	5.367	2.987
5	7.888	3.067	6.938	4.422	5.063	2.818
Z_2			$Z_R = 5$			
65	19.713	7.663	17.338	11.051	12.651	7.042
50	12.961	5.038	11.399	7.266	8.318	4.630
35	10.170	3.954	8.945	5.701	6.527	3.633
20	8.866	3.447	7.798	4.970	5.690	3.167
5	8.363	3.251	7.355	4.688	5.367	2.987

References

[1] Astapovich, I.S., "Meteors in the Earth's Atmosphere", Moscow, 1958, pp. 234–235.

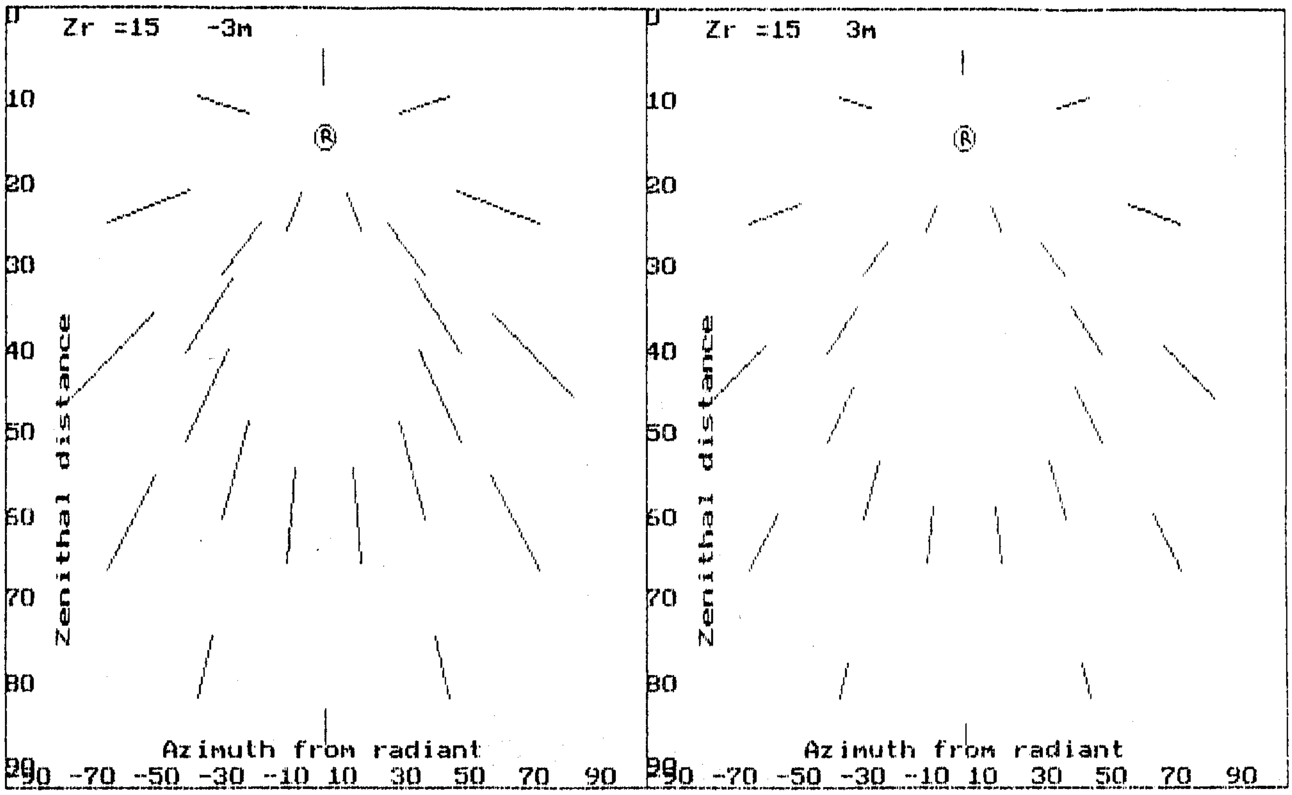

Figure 2 – Trajectories of meteors of −3 and +3 stellar magnitudes for $Z_R = 15°$.

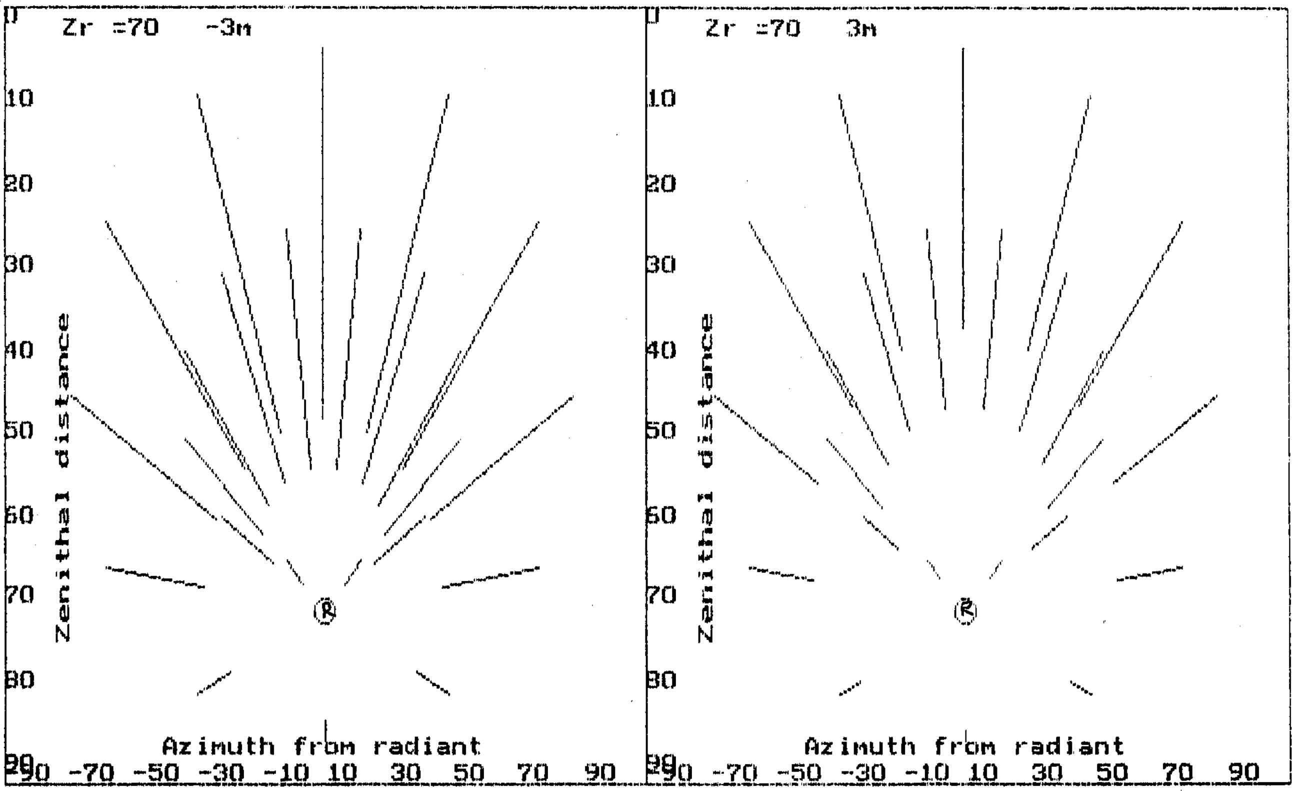

Figure 3 – The same as Figure 2 for $Z_R = 70°$.

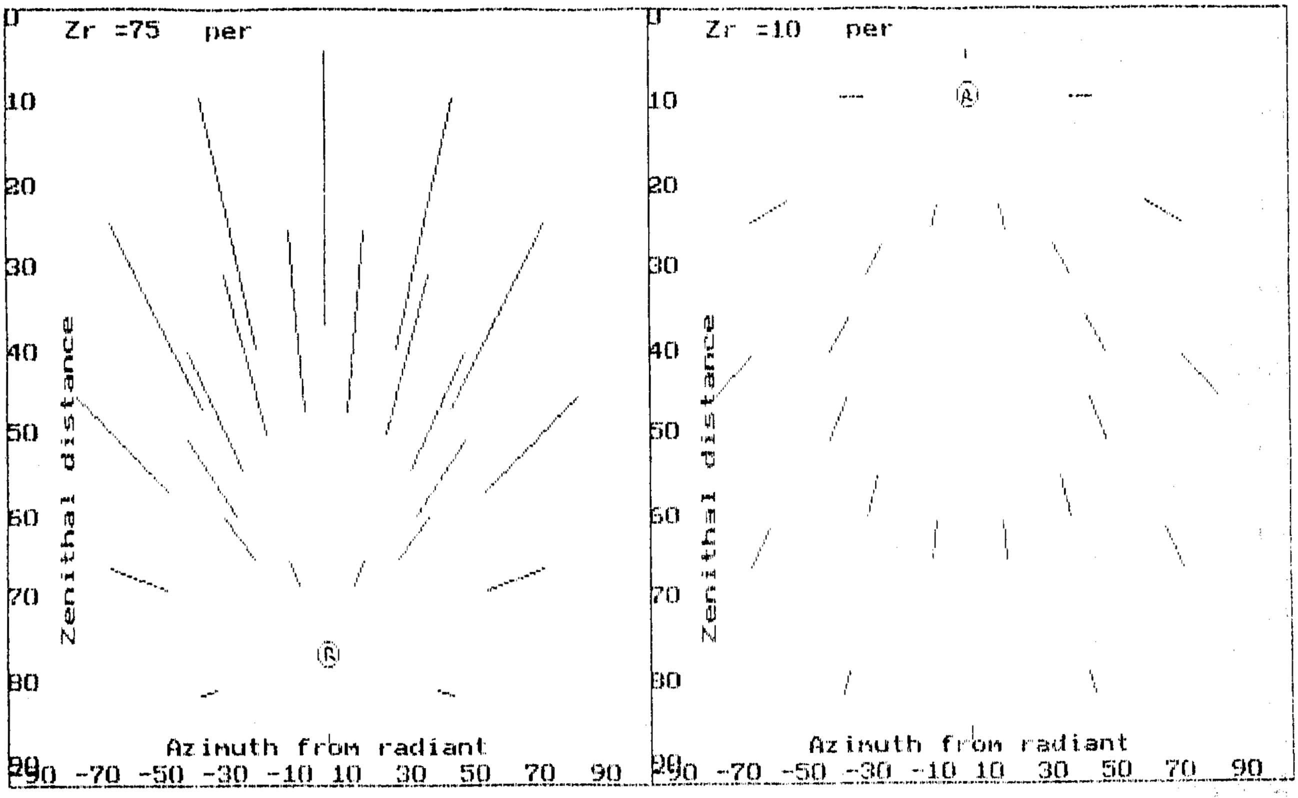

Figure 4 – Trajectories of Perseid meteors for $Z_R = 70°$ and $Z_R = 10°$.

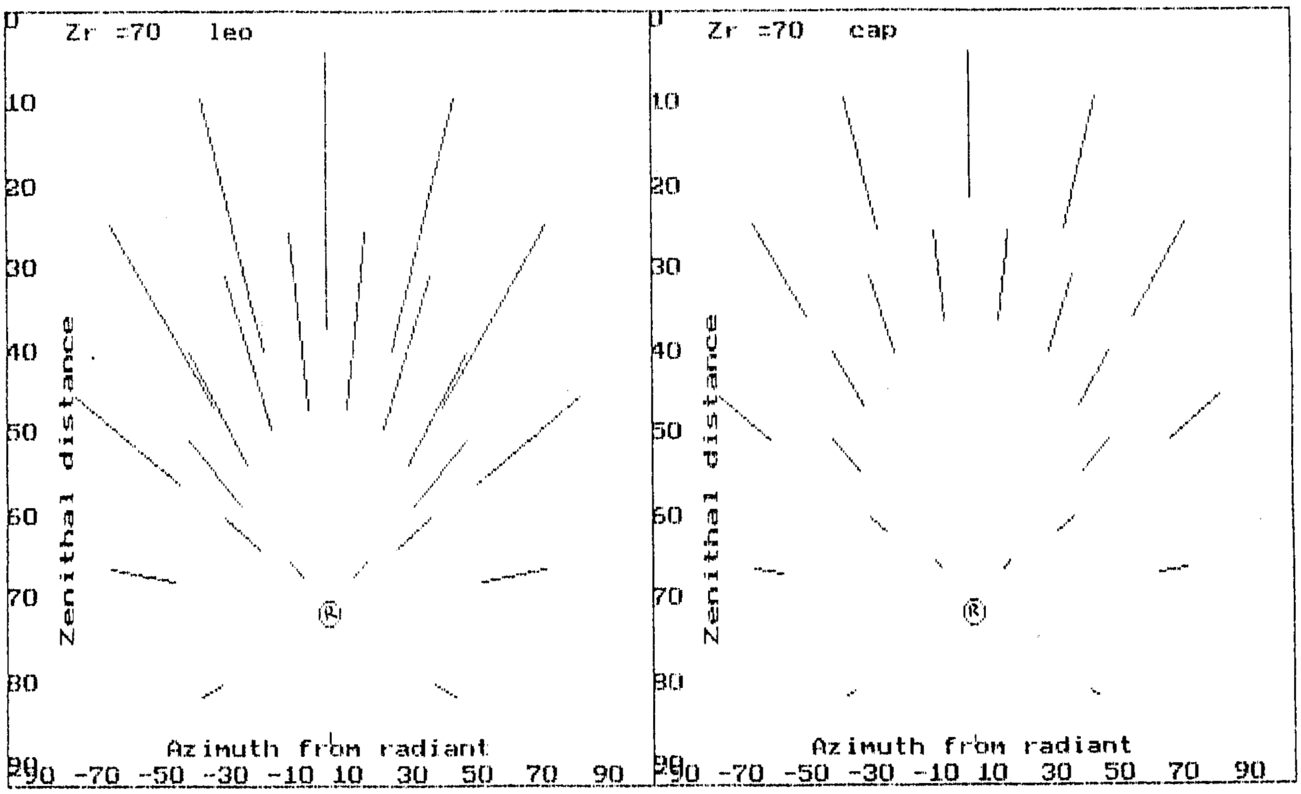

Figure 5 – Trajectories of Leonid and Capricornid meteors for $Z_R = 70°$.

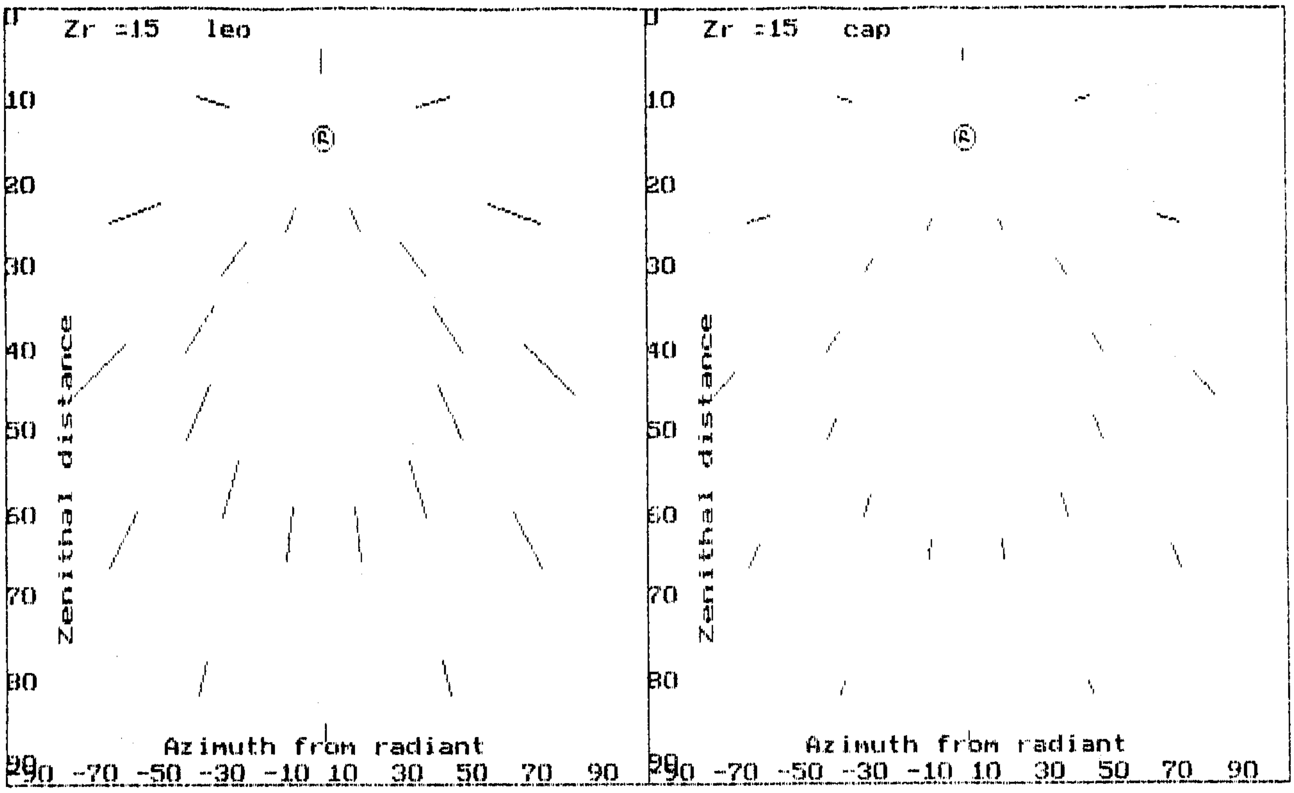

Figure 6 – The same as Figure 5 for $Z_R = 15°$.

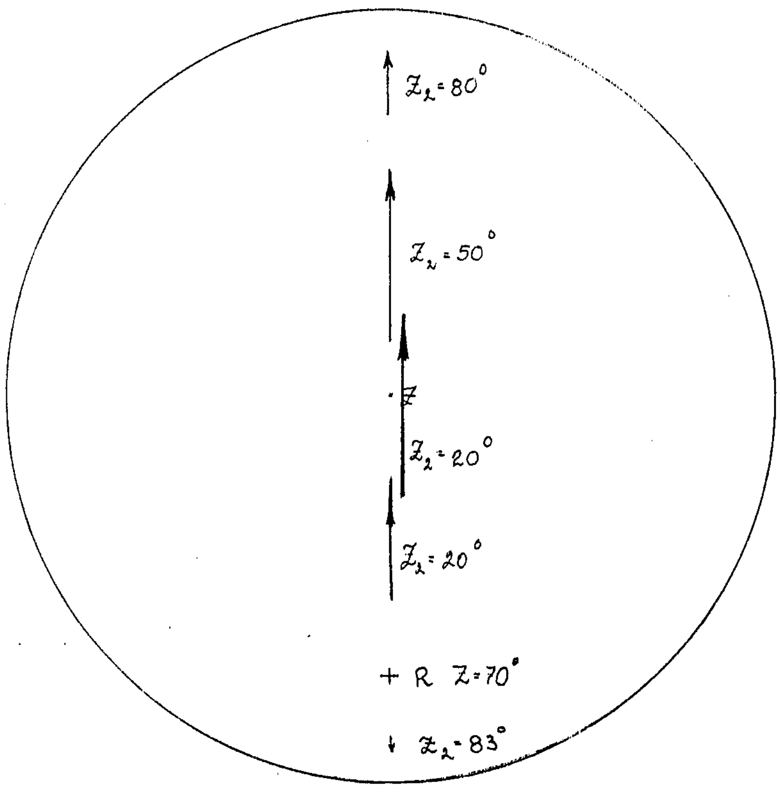

Figure 7 – Trajectories of meteors on the celestial sphere taken into account the phenomenon of decreasing meteor numbers toward the anti-radiant.

A Short-Duration Telescopic Shower

Malcolm J. Currie

My telescopic observations of March 6-7, 1995, ($\lambda_\odot = 346°$) shows the presence of a strong short-duration shower of slow meteors radiating from $\alpha = 154\fdg7$ and $\delta = +14\fdg7$, with an apparent full-width half-maximum radiant size of approximately $2\fdg2$. Fifteen of 41 meteors seen during $\lambda_\odot = 346\fdg00$ to $346\fdg19$ appeared to be members of this shower. Additional observations of the nights before and after only showed minimal evidence for this shower being active on the previous night. An archive search back to 1983 yielded few data for this solar longitude and could neither confirm nor deny the existence of this shower. A tentative shower identification is the κ-Leonids of Terentjeva.

1. Observations

One of the most enjoyable aspects of watching telescopic meteors is that one is often confronted by the unexpected. During the first two watches of a series on March 6-7, 1995, ostensibly for the Virginids, I noticed a preponderance of slow meteors coming from a common location—the eastern side of the "Sickle" of Leo. During the interval 23^h29^m–0^h58^m UT ($T_{\rm eff} = 1.25$ hours), 7 of the 14 meteors seen could have this common origin. Three were seen near $\alpha = 151°$ and $\delta = +22°$, and then the remainder around $\alpha = 150°$ and $\delta = +8°$. A further two watches in different fields situated to the east of the putative radiant (near 93 Leonis and the Leo group of galaxies) revealed a further seven candidates for this possible shower. These helped to pinpoint the radiant's declination, indicating that it was compact and about 4° north-east of Regulus. Up to this point, 14 of 33 meteors seen during $T_{\rm eff} = 3.06$ hours appeared to emanate from this radiant. One final watch began at 3^h15^m UT. By this time the radiant was starting to sink towards the west, and the chosen field was in southern Coma Berenices, some 2.5 times the average distance from the radiant of the first four fields. Not surprisingly, the shower rate diminished: there was only one additional shower candidate of the eight meteors recorded before twilight curtailed the session at 4^h05^m UT.

All the observations were made with a 127-mm refractor at 19.5× magnification with a $2\fdg6$ field of view from Grove, Oxfordshire, UK ($\lambda = 1°26'$ W, $\varphi = +51°37'$). The sky conditions were excellent for this site with an average field limiting magnitude of 12.8.

On the previous day, I had undertaken an all-night session (20^h03^m–4^h44^m UT, $T_{\rm eff} = 5.75$ hours, lm = 12.7) punctuated by cloud, netting 52 meteors. Of these, two or three were possible shower members. Chris Hall (HALCH) attempted to watch the following night but was beaten back by cloud. None of his 3 meteors seen in 0.51 hours were candidate shower members. Perhaps one or two of Chris's 14 meteors seen on March 3-4 when extended back do go through the radiant if allowance is made for daily motion. Chris and I both observed on March 8-9 and again no possible shower members were seen amongst the 21 meteors recorded in 3.1 hours.

2. Analysis

An analysis using the RADIANT software shows the radiant clearly (Figure 1). The radiant is located at $\alpha = 154\fdg7$ and $\delta = +14\fdg7 \pm 0\fdg2$ ($\lambda_\odot = 346°$) and has an apparent dimension of $2\fdg2$ (FWHM). The position includes a correction for zenithal attraction. In this analysis, the four pixels in the central degree square were ten-sigma detections, indicating that this was not a chance alignment of sporadic meteors, and a strong shower by telescopic standards.

In order to produce Figure 1, a stream velocity had to be supplied. The slow angular speed suggested $V_\infty = 20$–25 km/s, and 20 km/s was used to produce the figure. However, the identification of the radiant is not in jeopardy even if the true velocity were as large as 35 km/s. The assumed value is in line with the velocities of other ecliptic showers in the vicinity.

At first, I thought that this might be a new shower, but some further reading elicited a κ-Leonid shower in Alexandra Terentjeva's compilations [1].

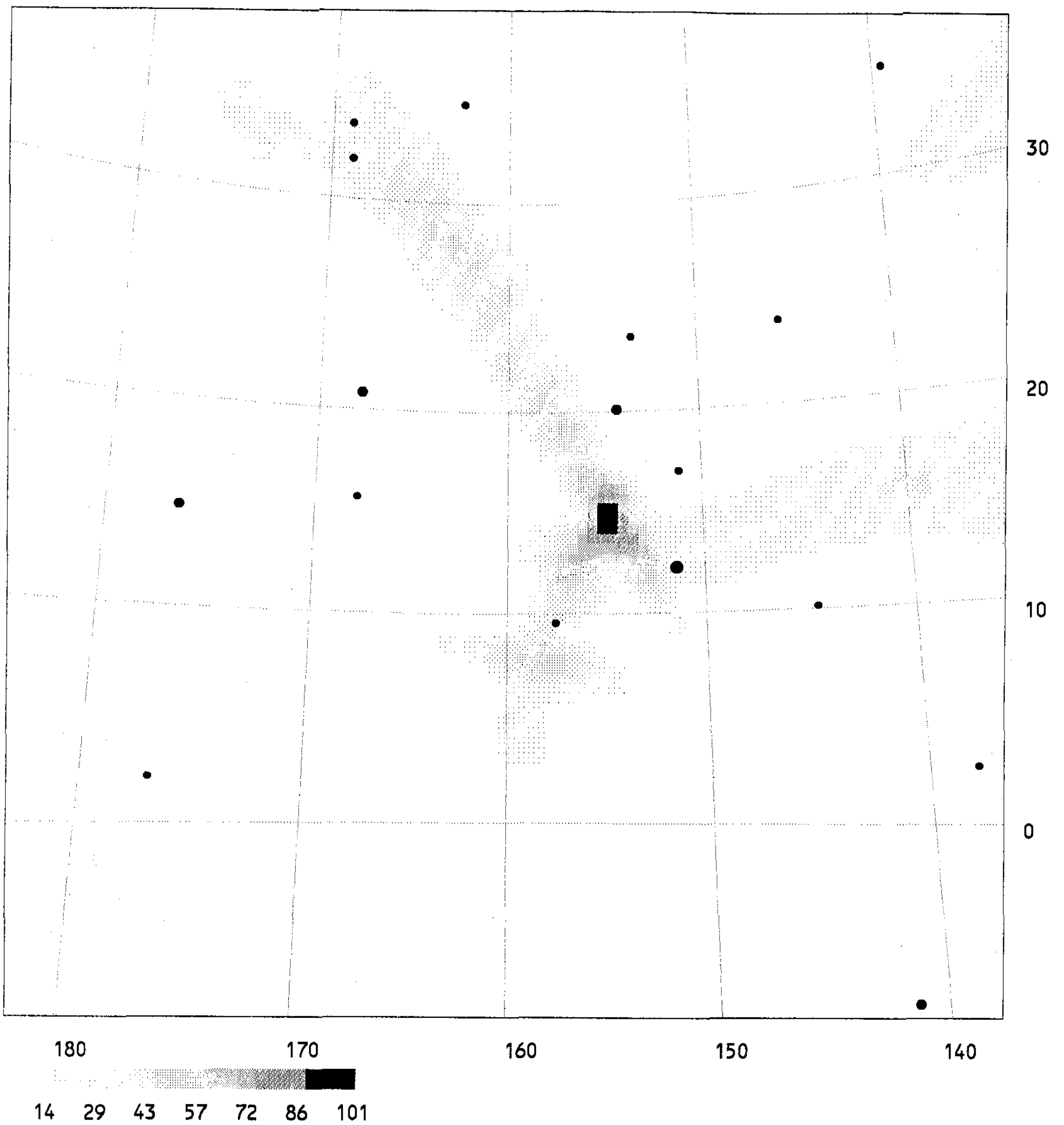

Figure 1 – A RADIANT probability analysis for March 6-7, 1995. The assumed shower geocentric velocity was 20.3 km/s, the reference longitude is $\lambda_{\odot} = 346°$ (2000), the pixel size is 0°5, the daily motion is 1°0 per day, scale corrections and zenithal attraction are applied, and stars brighter than magnitude +4 are marked. In total, 37 meteors are plotted.

This shower has two radiants listed for the duration March 5–6 located at corrected positions $\alpha = 158°$, $\delta = +16°$ and $\alpha = 160°$, $\delta = +15°$ (1950.0) with $V_\infty = 20.3$ km/s and $V_\infty = 23.4$ km/s respectively. These are just a few degrees from the observed shower and have velocities in agreement with observation. The κ-Leonid shower is also short duration, again matching what was observed. Contrary to this identification is that a double radiant is not observed. There is a slight asymmetry with enhanced probability a degree south and west of the center. In a plot combining both nights, there is weaker plateau at $\alpha = 156°5$ and $\delta = +13°2$. The latter matches the geometry of the catalogue positions. However, such "features" would not be mentioned without the *a posteriori* knowledge of the double radiant in Terentjeva's list. Given the uncertainties in the velocity scaling and the small number of meteors involved, the current data-set can neither rule out a close double radiant, nor can it support the hypothesis. A further caveat is that this region is rich in minor radiants at this solar longitude so that there is a significant probability that looking through large catalogues of radiants will evidence a nearby shower regardless of any genuine match (though my search was far from comprehensive). It is for convenience that I shall refer to this shower as the κ-Leonids in the rest of this report.

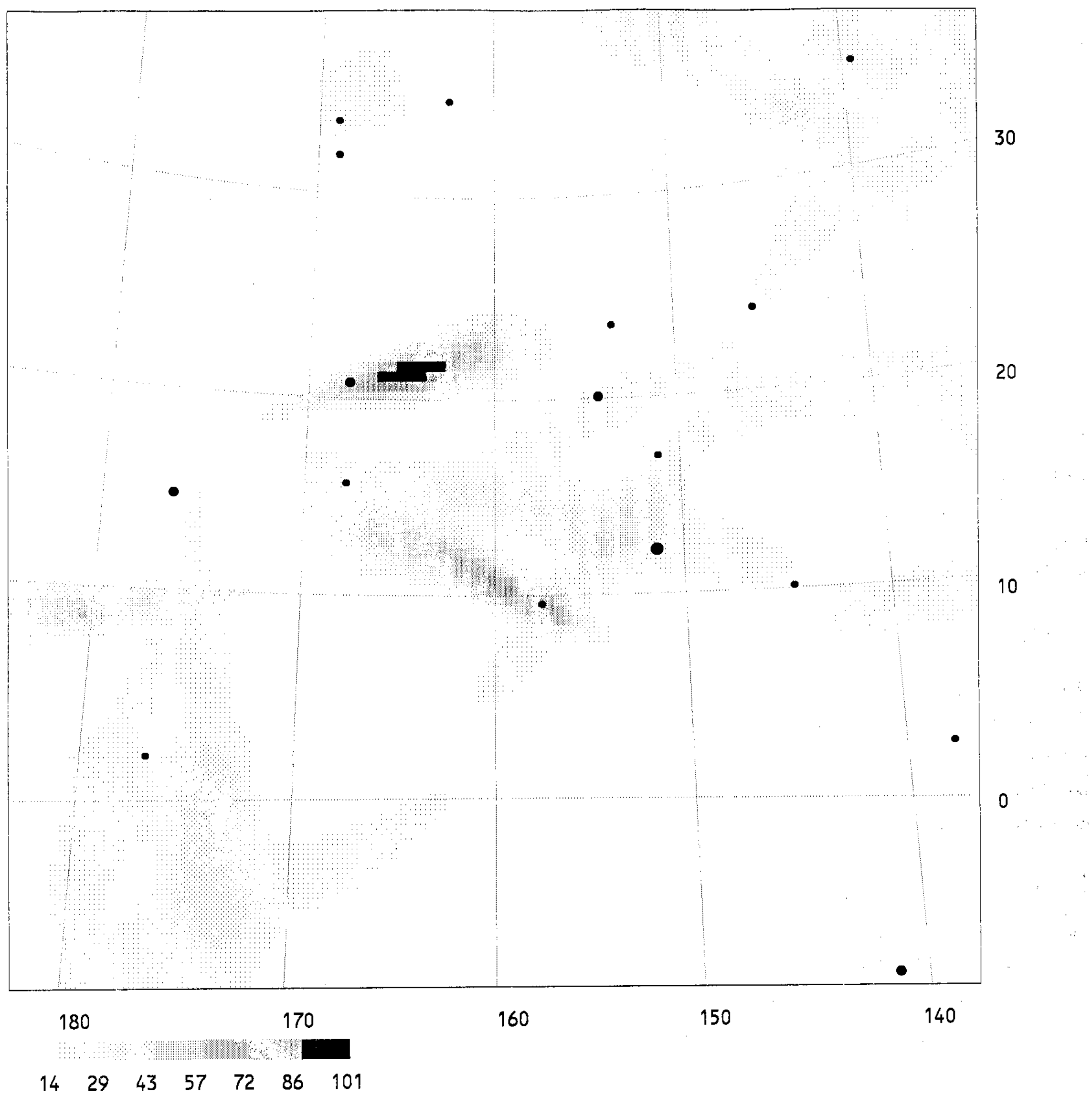

Figure 2 – As Figure 1, except that it is for March 5-6, 1995. In total, 35 meteors are plotted. The remaining prolongations lie outside the displayed region of sky.

Figure 2 shows the meteors plotted for March 5-6 using the same parameters as for Figure 1. Notice the strong contrast with the following night. The eye of faith would say that there is some very weak activity from the κ-Leonids on this date. I personally would not believe it.

In both figures there is also the suggestion of a weak radiant at $\alpha = 158°$ and $\delta = +9°$. A combined plot with $V_\infty = 23$ km/s has its peak pixels nominally at $4.3\,\sigma$ above the noise. My experience with RADIANT still warns me that there are too few prolongations forming this peak to be confident of it not being due to chance. If it is real, this could be part of the Virginid Complex. Also the first three meteors assigned to the κ-Leonids might then be part of this possible shower. Judging by the number of meteors seen from these two "radiants" in the other fields on March 6-7, the expected number of misclassifications is less than one. Therefore I have ignored this for the count and magnitude distribution of the κ-Leonids.

I have tried to find independent evidence for the existence of this shower by trawling the *BAAMS* and *IMO* archives back to 1982. There was only one set of short-duration observations for the calendar date in question, but more for each of the three days before March 5 and after March 7. In 1992, Bob Middleton of Brightlingsea, UK, saw two meteors between 18^h40^m and 19^h20^m UT, and neither were shower candidates.

On March 7-8, 1993, 19^h05^m–19^h45^m UT, Bob had one candidate of five recorded. His chosen field centers were not well placed for a radiant in Leo. At both of these times the radiant position would have been low in the east. So nothing conclusive can be said either way from the archives.

Table 1 – The apparent magnitude distributions of κ-Leonids and other meteors on March 6-7.

Shower	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	$\overline{m}$
κ-Leonids	1			1	3	3	5	2	10.47 ± 0.23
Others	1	1	2	5	6	7	3	1	10.00 ± 0.16

I should also welcome hearing from anyone who has made visual plotting or video recordings around these dates. However, given that the shower is rich in faint particles, as presented in Table 1, it seems unlikely that it is a naked-eye shower. If allowance for the apparent angular speed [2] is folded in, the difference in mean brightnesses is almost a full magnitude. This would be interesting from the stream-evolution point of view if it could be confirmed as significant.

3. Conclusions

This year, there appeared to be a strong but short-duration shower 4° north-east of Regulus at $\lambda_\odot = 346°$. The most likely candidate for this shower is the κ-Leonids. We shall need further independent observations to confirm this shower and to ascertain its properties. Moonlight will interfere strongly in 1996, so we shall have to await until 1997. I urge all telescopic and video observers to attempt to secure data then.

References

[1] Terentjeva A., "Meteor Bodies near the Orbit of Mars", *Proceedings of the International Meteor Conference, 1993*, Roggemans P., ed., 1993, pp. 97–105.

[2] Znojil V., "Occurrence of Minor Particles in Summer Meteor Streams of the Northern Hemisphere", *BAC* 33, 1982, p. 205.

Fireballs and Meteorites

The Río Cuarto Craters, Argentina

Carlos Francisco Sosa, Damian Wacker, and Hedy Matilde Teidons

A description is given of a crater complex in Argentina.

1. Crater characteristics and distribution

The Río Cuarto Craters are located between the towns of Carnerillo and Chucul, 40 km to the north-east of Río Cuarto City (Cordoba Province, Argentina), geographical coordinates $\lambda = 64°14'$ W and $\varphi = 30°52'$ S.

The group of craters consists of 10 oblong structures whose dimensions are in 4/1 proportion (length/width proportion), situated along a 50 km long line, oriented from north-east to south-west, just to the north-east of the above mentioned city of Río Cuarto. They have been named as follows:

Depresión del Norte (Northern Basin):

It is the biggest structure and the one located northernmost of that line, measuring 4.5 km by 1 km wide.

La Lágrima (The Tear-Drop):

This is a crater of small dimensions.

Los Mellizos (The Twins):

Next come The Twins, which, as their name indicate, are two near-identical structures parallel to each other, named the "Eastern Twin" and the "Western Twin", in view of their orientation. The "Eastern Twin" measures 3.5 km long by 0.7 km wide, its longitude causing a certain impression owing to the fact that the raised rim at one end disappears over the horizon when viewed from the other. Just alongside it is the "Western Twin," a near-identical depression parallel to its eastern companion.

Grupo de la Luna (Moon Group):

Always following the direction north-east to south-west, we find the so-called "Moon Group," consisting of three craters that are also parallel.

El Tándem (The Tandem):

Diverting to the south-west is the last group, called "The Tandem," consisting of two depressions placed one following the other.

In general, the craters are shallow, flat-bottomed depressions, surrounded by a raised rim that in some cases reaches 10 m high. One of them exhibits a central mound 10 m high, resembling complex-type impact craters. they are covered by local vegetations, and some of them show dunes, which are in continuous movement because of the wind. It must be noted that South American geologists knew about the existence of these craters, but they attributed them to erosion processes produced by water and wind.

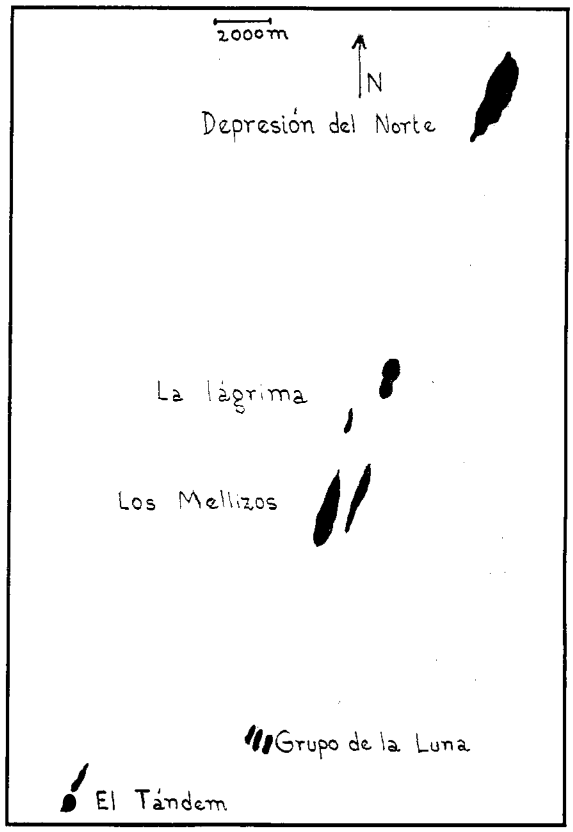

Figure 1 – Location of the Río Cuarto Craters. The dot on the map of South America is the approximate position of the crater complex within the province of Córdoba. The map at the right shows the lay-out of the crater complex.

2. Environment geology and physical aspects

The region is covered by a 20–25 m layer of loess, accumulated during the Pleistocene Period; crystalline outcrops and surrounding metamorphic mountain chains of the Córdoba ranges constitute the nearest bedrock expositions at 30 km to the north-west. Streams and rivers along the 50 km long chain of craters show evidence of blocking, deviation, and capture. The soil is flat, the main farming being sunflower and, to a lesser extent, peanut and corn.

The material found in the craters includes chondrite fragments, besides impactites (stones with bubbles, whose inner parts are intertwined with quartz grains, indicating the enormous pressures developed during the impact of the body at issue). Also found were olivine crystals, a mineral that is present in various types of meteorites, like siderites and aerolites (chondrites and achondrites in several of its subdivisions). The collected samples were studied in the USA, Canada, and Austria.

According to the conclusions of Professor Peter Schultz, geologist of Brown University of Providence, Rhode Island, USA, and impact crater specialist—who studied this event—it appears that the Río Cuarto Complex was produced by a body approaching from the north-east, with an entry angle of no more than 15° with the horizon. Its diameter was estimated at about 150 m, three times bigger than its counterpart that produced the Meteor Crater in Arizona. Assuming an impact velocity of 23 km/s, typical of these objects, the estimated energy released at the impact site was the equivalent of a 350-Megaton bomb, 10 times greater than at the Arizona Meteor Crater and 30 times greater than the Tunguska event in Siberia. It is estimated that the impact took place between 2000 and 10 000 years ago.

The Northern Basin, also called Crater A, constitutes the first contact of the asteroid, while the majority of the remaining craters were being formed as the fragments were ricocheting. The low impact angle explains the oblong shape of these craters. It should be noted that such a low impact is very unusual.

3. Discovery

In October 1989, Captain Rubén E. Lianza of the Argentine Air Force—who resides in the USA owing to his profession—was flying over the impact zone when he saw some peculiar features on the ground that aroused his curiosity. Feeling that it might be low-angle-impact meteoric craters, he returned the next day to the same place. When climbing to a proper altitude, the view was spectacular, according to his own words: a series of oblong craters, in a chain. Later on, he took photographs that confirmed his earlier impressions. The shape of the depressions resembled remarkably the oblong pits produced in laboratory simulations of glancing impacts produced by hypervelocity projectile shots (more than 6 km/s).

As a result of this finding, he decided to get into contact with several foreign publications, among them *Sky and Telescope*, and through this last one, he got in touch with Professor Schultz. The next step was to organize an expedition in situ, the team consisting of the said professor, the geologist John Grant, and technician William Collins. In Argentina, Lianza himself would join them, together with meteorite specialist Alejandro Toselli of the Tucumán University and his graduate student, and some volunteer assistants. Large-size aerial maps of the region, obtained from the files of the Air Force at Parana, Lianza's home town, was of great help. With these maps and adequate instruments, the expedition could be started.

4. Conclusion

Since this may be one the only impact sites with the above-mentioned characteristics still visible on our planet Earth, subsequent detailed studies could allow us to evaluate and confirm, or modify, our present understanding on the formation processes of meteoric impact craters.

References

[1] *Sky and Telescope*, April, 1992.
[2] *Nature*, No. 6357, January 16, 1992.

Bright Fireball over the Czech Republic

August 4, 1995, $1^h17^m38^s \pm 16^s$ UT

Pavel Spurný, Ondřejov Observatory

On the night of August 4, 1995, a bright fireball of approximately −11 maximum absolute magnitude was photographed by four Czech stations of the European Fireball Network.

A bright fireball of −11 maximum absolute magnitude was photographed by four Czech stations of the European Fireball Network. The fireball traveled a 44.0-km luminous trajectory in 1.6 seconds and terminated its light at a high altitude of 66.7 km near the Czech town of Žamberk. Time of the fireball passage was determined from the combination of the records from Ondřejov fixed and guiding cameras, and it is in a good agreement with several visual observations. It is very important that all data, but most of all dynamic data, describing this fireball were obtained with a very good accuracy, because this fireball belongs to the fireball type IIIB. These fireballs are admittedly relatively frequent, but the determination of their especially dynamic data is from many reasons very difficult. They are among others distinguished for their very high terminal altitude, great value of the ablation coefficient, very small density and also for their assumed cometary origin.

The following precise results are based on three best records and are very close to the final values.

Table 1 – Trajectory data.

	Beginning	Maximum light	Terminal
Velocity (km/s)	26.88 ± 0.02	26.5	24.8 ± 1.0
Height (km)	84.0 ± 0.2	69.8	66.7 ± 0.2
Latitude (° N)	49.7917 ± 0.0013	50.066	50.1270 ± 0.0009
Longitude (° E)	16.212 ± 0.003	16.378	16.415 ± 0.003
Abs. magnitude	− 3.4 ± 0.7	−10.6 ± 0.6	− 3.5 ± 0.7
Photomet. mass (kg)	2.9	0.9	none
Z R (°)	66.68 ± 0.06		67.02 ± 0.06

Fireball type: IIIB

Ablation coefficient: (0.25 ± 0.03) s^2/km^2

Table 2 – Radiant data.

Radiant (2000.0)	Observed	Geocentric	Heliocentric
α (°)	327.74 ± 0.07	326.20 ± 0.07	
δ (°)	− 14.46 ± 0.02	− 17.80 ± 0.02	
λ (°)			266.00 ± 0.05
β (°)			− 2.84 ± 0.02
Initial velocity (km/s)	26.91 ± 0.03	24.61 ± 0.03	34.63 ± 0.03

Table 3 – Orbital data.

Orbit (2000.0)	
a	1.616 ± 0.006 AU
e	0.7508 ± 0.0008
q	0.4026 ± 0.0009 AU
Q	2.829 ± 0.011 AU
ω	113°98 ± 0°14
Ω	113°2971 ± 0°0002
i	3°99 ± 0°03

Observational Results

BAA Observations of the 1994 Ursids

Neil Bone

An overview is given of the *BAA* observations of the 1994 Ursids.

Clear, though slightly hazy conditions were found over many parts of the UK for the Ursid maximum on December 22-23. Observations were possible in a 4-hour interval from dusk to moonrise (around 21^h local time). The following 7 observers contributed 10^h31^m of watch time on the night, results from which are summarized in Table 1:

Roy Billington, Neil Bone, Steve Evans, James Lancashire, Nigel Rayner, George Spalding, and David Strachan.

Population index $r = 2.25$ has been used for Ursids, $r = 3.42$ for sporadics, in line with the typical value for shower meteors adopted by Spalding [1].

Table 1 – *BAA* Ursids results 1994 December 22-23.

UT	$\lambda_\odot$	T_{eff}	Lm	N Sp	HR Sp	N Ur	h	ZHR Ur
18^h02^m	270°74	1.00	6.10	5	8.2 ± 3.7	8	42°3	16.4 ± 5.8
19^h30^m	270°80	3.00	5.60	5	5.0 ± 2.2	15	39°3	16.4 ± 4.2
20^h21^m	270°84	3.00	6.03	10	5.9 ± 1.9	11	40°0	8.4 ± 2.5
21^h12^m	270°87	1.00	5.60	2	6.0 ± 4.3	3	40°2	9.6 ± 5.5
22^h15^m	270°92	1.00	5.50	4	13.7 ± 6.8	4	42°1	13.4 ± 6.8

These results do not support the view [2] that the 1994 Ursids showed unusually high activity close to maximum. Observed rates seem more consistent with the typically modest Ursid activity seen, for example, in 1992 [3]. Past instances of possible exceptional Ursid activity have been noted as, for example, in 1982 [4] and 1986 [5], but it would seem risky to derive any profound conclusions from the fewer than 20 hours' watch time comprised by the *BAA* and Japenese observations in 1994. What is perhaps most obvious is the need for the Ursids to be more thoroughly observed in future years to obtain more consistent coverage; 1995 presents an excellent opportunity.

Limited observations on December 23-24 and 24-25 showed only very low Ursid activity. Magnitude estimates from all 3 nights are summarized in Table 2. The solitary fireball was seen on December 22-23 at 22^h28^m UT by Roy Billington in Cheshire, and was a slow-moving white sporadic of magnitude −5. Persistent trains were shown by 6 Ursids, but none of the sporadics.

Table 2 – Sporadic and Ursid magnitudes.

Stream	−5	−4	−3	−2	−1	0	1	+2	+3	+4	+5	Total
Ursids	0	0	0	1	4	4	3	6	11	14	7	50
Sporadics	1	0	0	0	0	0	1	3	13	11	6	35

References

[1] Spalding G.H., *J. BAA* 98:1, 1987, pp. 26–34.
[2] Ohtsuka K., Shioi H., Hidaka E., *WGN* 23:2, April 1995, pp. 69–72.
[3] *BAA Meteor Section Newsletter* 45, 1993.
[4] *BAA Meteor Section Newsletter* 12, 1983.
[5] *BAA Meteor Section Newsletter* 23, 1987.

The 1994 Geminids in Bulgaria

Valentin Velkov

A ZHR profile and a mean value of the population index *r* are obtained based on the meteors recorded in 3 hours of observing time on the night of December 13-14, 1994 by members of *Astroclub Canopus* in Varna.

Encouraged by the successful Geminid observations in 1993 carried out by members of our Astroclub *Canopus*, we organized a new expedition in 1994, again in Avren village near Varna. Participants were Dilyana Antonova (Porozhanova), Lilia Porozhanova, Plamen Stoychev, Ivaylo Kolimov, and Valentin Velkov. The expedition lasted from December 8 to 14, but the weather was too bad, and we had only one observing night—December 13-14. We started our watch shortly before the moonset, which was as late as 3^h59^m local time, and we had no more than 3 hours of observing time.

The shower was expected to reach its maximum between 9^h and 10^h Bulgarian time, i.e., during the daytime. We were surprised by the exceptionally high activity of the Geminids, which was similar tot the activity typical for the time of the shower's maximum. In about 3 hours, 1457 meteors were recorded, 1123 of them being Geminids. Another thing that impressed us was the lack of bright meteors. Really, we obtained a rather high value of the population index *r* compared to that for the same period in 1993. This can be seen in Figure 1.

The lack of bright meteors prevented us from calculating *r* for short time intervals, as we did in 1993. A regression interval from magnitude −1 to +2 was used. The solar longitude interval to which the value of *r* for 1994 corresponds, is marked by dashed lines.

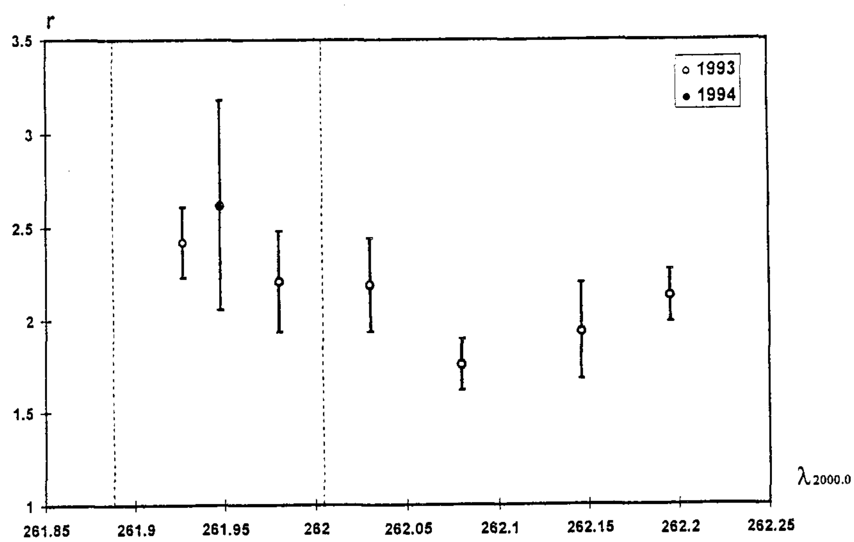

Figure 1 – Population index value computed for the 1994 Geminids compared to the values obtained for the 1993 Geminids.

Our *r* value was calculated using a collective magnitude distribution composed on the basis of the meteors recorded by all observers.

Using the obtained global *r* value, we calculated the individual ZHR values for each of the observers for 30 minute intervals. The results are shown in Figure 2.

In the second 30 minute interval there is a ZHR increase. Indeed, in some moments during that interval (2^h00^m–2^h30^m UT), we could see 2–3 meteors per minute! During the last two intervals a ZHR decrease is observed. Figure 3 presents the profile of the mean ZHR value. It can be compared with the 1994 ZHR profile, where a similar feature is seen, but for 1994 it seems to be shifted to the left with $\Delta\lambda = 0^\circ.03$, which corresponds to about 45 minutes earlier in time.

The same feature before the actual maximum in 1993 was also observed by two other Bulgarian Astroclubs—in Kardjaly and in Sliven. We suppose that the real maximum of the Geminids in 1994 occurred later in the daytime for our country.

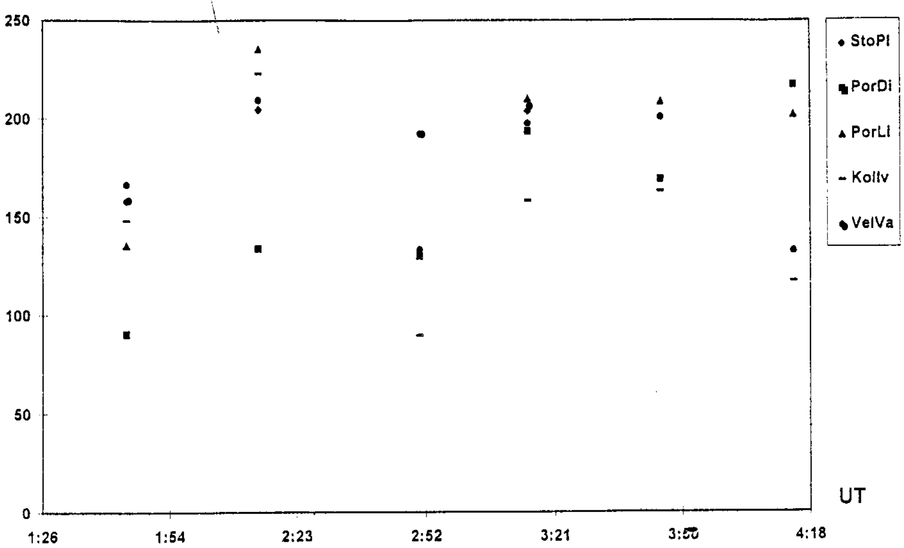

Figure 2 – ZHR values obtained for the 1994 Geminids.

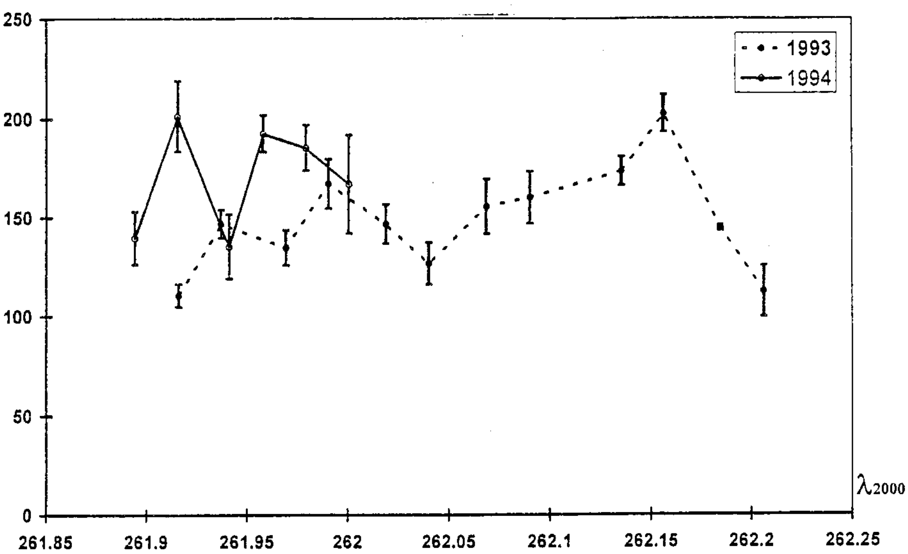

Figure 3 – Comparison of mean ZHR values for the 1993 and 1994 Geminids.

We could photograph only two meteors. Both were Geminids. We also observed some Monocerotids, Hydrids, and Puppid-Velids.

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