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The Observatory of the Slovak Academy of Sciences at Skalnaté Pleso was the destination of the excursion program at the IMC in Stará Lesná. The observatory is situated at an altitude of 1780 m and lies at the foot of the 2634-m Lomnický Štít, the second highest peak in the High Tatra Mountains. Particularly in the winter, the mountains are often above the low clouds covering the surrounding region. Extensive visual meteor observations were carried out at the observatory between 1944 and 1953. Nowadays, the observatory hosts the easternmost station of the European Network for fireball patrol.

In this issue:

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Contents

Useful Information

The December Issue *(WGN 26:6)*

The *December issue* will be mailed around late November or early December. Contributions are due on *November 18* at the latest. They should be sent to *Marc Gyssens*.

Administrative Correspondence

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

From the Editor-in-Chief

Marc Gyssens

First, a small point concerning the previous issue. Upon preparing the copies of the issues for mailing, we discovered a printing error in that the table of contents, which normally figures on the inside front cover, was replaced by the address list, which also figures on the inside back cover. Since we discovered this before the copies were sent out, we copied the table contents on a separate page of the same color as the cover, so that, by cutting off the right margin, readers can glue the table of contents over the inside back cover. We were in a rush then, so it was not until a little later that we found out that not all copies of the magazine suffered from this printing error; so if your copy of the August issue did have the table of contents on the inside front cover, please ignore the insert—you know now why it was there!

Since sending out the previous issue, we had the IMC *in Stará Lesná, Slovakia, which was (once again) a very successful one. A special aspect of this conference, however, was the presence of several professional astronomers, who spoke very encouragingly about our work, and actually expressed the opinion that the terminology "amateurs" and "professionals" does not do justice to our work!*

At the IMC, *a lot was said, of course, about the 1997 Leonids, the recent June Bootid outburst, and the 1998 Perseids, which continue to distinctly show the "new" peak. Of course, also the prospects of the 1998 Leonids were discussed, but there was also mention of the possibility of a Draconid outburst this year. As if this were not yet enough excitement, David Asher, who could not make it to the* IMC, *communicated to us the possibility of enhanced Taurid activity this year. So, 1998 may well turn out to be one of the most spectacular years of the century, meteor-wise!*

To get all this information to you in time, especially if you were not at the IMC, *we decided to publish the October issue earlier. Please watch the fall's meteor activity vigilantly, and, meanwhile, enjoy reading this issue!*

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Ina Rendtel

General information

Please help us in keeping our records straight by renewing right now. In this way, you insure that your subscription is processed well in time before the February issue has to be sent out and you save the already overloaded *IMO* officers to have to run on and off to the post office to mail back issues. All relevant information is concisely summarized below. Despite what we expected, we did *not* have to raise prices this year!

International payments invariantly involve costs. Therefore, if you also wish to buy other *IMO* publications (outside back cover), it is a good idea to combine this with your renewal in one order and one payment. *New* IMO *publications* are Report 10 containing the 1997 visual observations, and the Proceedings of the 1997 and 1998 *IMC*s, the latter of which will appear shortly and can already be ordered. You can also pay your subscription for *two* years, which is particularly interesting this time, because with the introduction of the "Euro," we will probably have to change prices in 2000!

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The 1998 International Meteor Conference

Stará Lesná, Slovakia, August 20–23, 1998

Dragana Okolić

I am sitting on the train Bratislava-Budapest-Belgrade. It is Sunday, August 24, 1998, a sunny day. Marc Gyssens, the editor-in-chief of *WGN*, asked me yesterday if I would write an article about the *IMC* for WGN. I said "yes" without thinking, because the furthest thing from my mind was to refuse Marc and, besides, the *IMC*s are a great thing. Now I wonder why I did it. Well, it is not hard at all to write a story about the *IMC*, on the contrary, it is a real pleasure to do something like that. It is hard to make the story short, because it is hard to decide what is important and what is not at all those glimmering impressions... Hm, if I start from the beginning and try to follow the flow of time and space, maybe I will succeed.

I arrived at Stará Lesná on Thursday around noon. Very warmly welcomed and quickly and comfortably accommodated by the host, I threw the backpack into my room and went out into the beautiful August sun which shone on the High Tatra Mountains. The first ones I said hello to, not counting the hosts, were the participants from Romania, whom I know ever since my first *IMC* in Belogradchik in Bulgaria in 1994. They told me about their Perseid observing camp: about observing of course, but also about some side-activities and interesting guests they had. Some of them informed me that the poster session was about to begin in the congress hall of the nearby Academy Hotel. There, the International Conference *Meteoroids 1998* was still ongoing. I found Eva Bojurova and Henry Hendriks, and, in the next moment, we were sitting among all these important faces from the *International Astronomical Union*-Commission 22. I found out what the posters represented. During the poster session, I scanned the lecture hall and found some more familiar faces smiling at me. I did not realize then, but now I know what the basic difference is between the professionals and the amateurs: the smile. I am not exaggerating. Pay attention next time you have a chance!

The last sentence led my stream of thoughts away from the line of the time continuum. I started to think about the *IMC* in general terms. Each *IMC* is a both a little bit the same and a little bit different. The same, because each time the *IMC* starts, wherever and whenever it is held, a similar atmosphere is created, which lasts with the same intensity until the end of *IMC* and even further. It lasts even on the trains, planes, cars, ... our homes, until we wake up in the everyday reality. This *IMC* was also different for me, because it brought about many new faces. It put the professional and amateur astronomers together and made them all excited about the plans for this year's Leonids.

The new faces I referred to above are primarily the ones from Poland and the Czech Republic. I did not yet have a chance to meet them on previous *IMC*s. I met four young people from Warsaw, friendly and smiling—whence, amateurs ;-)—with plenty of fresh observers' enthusiasm. Among them were Marcin Gajos, Urszula Majewska, Arkadiusz Olech, and Marek Samujłło. I should add here a piece of information that Rainer brought up at the *IMO*'s General Assembly, as the Director of the Visual Commission: Poland has become the top country in the amount of observing hours this year! As for the observers from the Czech Republic, actually, there was only one. But he is so interesting and so experienced, that the time I spent talking with him went by extremely fast. Mr. Miloš Weber is from Prague. He already observed meteors back in the time my parents were born (!). I think this tells enough about his experience. It was really a pleasure hearing at least one bit of every aspect of meteor astronomy he has been involved in.

But let me get back now to the chronology of events, that is back to the poster session on *Meteoroids 1998*. When I mentioned the meeting of professional and amateur meteor astronomers, a little bit earlier, I should have added that the *IMC* was placed exactly between *two* professional meetings. The first one, *Meteoroids 1998* took place from August 17 to 21, and the Academy Hotel where it took place was only 500 meters away from the location of the *IMC*. The other one, *Sources of Asteroids and Comets*, took place from August 24 to 28, right after the end of the *IMC*. As for the posters, two of them especially caught my attention. One was about the spectrum of TV meteors and the other was a shiny picturesque poster about NASA's plans for Leonid observing. I copied the references from the first one, because I have a plan to try to do something in that area. From the second poster, I learned the meaning of "MAC." If you want to know yourselves, here is what it is: Multi-instrument Aircraft Campaign. Is it clear now how and wherefrom (!) they will observe the Leonids?

The time for the poster session ran out and the dinner was about to be served. We returned to the Stará Lesná Hotel, and, all of a sudden, everyone was there. Now the *IMC* got things under control and I lost the sense for time. I am not sure if I am capable to describe the events which followed chronologically. That is why it is hard for me to separate the important from the unimportant. I am positive that the opening of the *IMC*, with the welcoming words of a local official and the organizers, happened before the closing. I also know that the lectures started on Friday, but I did not remember the schedule anymore. I have the program packed at the bottom of my backpack, and so I cannot take it out right now. Anyway, proceedings will be printed, and it will include the detailed program and the content of the lectures. For those who are impatient, I will only say that, besides shower observations and analyses, and among other things, these were discussed:

- detection of minor streams by double-station TV observations;
- more on the forward scatter meteor year;
- Leonid expectations from modeling the stream;
- VISDAT—a database system for visual meteor observers;
- the ratio of start and end heights of meteors; ...

In the evenings, the time of day reserved for less formal topics, we saw some slides and videos. Some were from Perseid observing in Slovenia, and some were from the preparations for the observing of the total solar eclipse in Bulgaria. One evening was reserved for the hosts and on that occasion, we heard more about the history of meteor expeditions in Czechoslovakia and Slovakia.

The obligatory excursion was organized on Saturday afternoon. The weather was sunny, but windy too. The fact that it was windy is especially significant, because we went to visit the Skalnaté Pleso observatory, which is at about 1700 meters above sea level. It was fascinating.

As usually, the *IMC* ended too soon. We all had to leave before we said, asked, or showed all we wanted. I hope you realize that it was wonderful, but, only if you have been at some *IMC*, you know just how wonderful it was. So, if, by chance, you missed this *IMC*, do not miss the next one! For me, the time between two *IMC*s is too long, so I regularly meet my meteor friends on various coordinates, on various occasions. So, see you, my known friends! And those still unknown? See you in Frasso Sabino, just north of Rome in Italy, on September 23 next year!

... I am already in Budapest. I hope that the train to Belgrade is somewhere around here!

The 1999 International Meteor Conference

Frasso Sabino, September 23–26, 1999

communicated by Massimo Calabresi and Roberto Gorelli

The *International Meteor Conference* in 1999 will be hosted by the *Associazione Romana Astrofili* in Frasso Sabino, some 50 km north of Rome, Italy, on September 23–26. The costs covering the conference and lodging from Thursday evening to Sunday noon, including all meals, will be 240 DEM. The participants will be accommodated in a newly built hotel, which is 3 km away from the conference site. The late-summer weather conditions are most inviting in this area in September. We anticipate to give more information in the December issue of *WGN*.

Erratum

Meteorite Craters Discovered by Means of Examining X-SAR Images—Part II

communicated by Roberto Gorelli

Notice that the Internet site of DLR is `http://isis.dlr.de/XSAR/catalog.html` (on p. 137 of *WGN* 26:3, "`dlr`" was erroneously written as "`dir`." Furthermore, in the table identifying the images containing the craters discussed, the quicklook for crater 24 (the last in the table) is located in the *southern* hemisphere, so please change "N" into "S." Finally, the readers must be warned that DLR is changing the number of quicklooks. However, the quicklooks can also be found back utilizing time, orbit, and coordinates.

Ongoing Meteor Work

Prospects for Two Upcoming Periodic Meteor Showers

Joe Rao

A capsule history of the science of meteor astronomy is presented, beginning with the unexpected appearance of a storm of Leonid meteors in 1833. The overview of the evolution of meteor science continues up to the most recent stupendous Leonid display in 1966. The return to the inner solar system in 1998 of two well-known periodic comets—21P/Giacobini-Zinner and 55P/Tempel-Tuttle—has brought hope among meteor observers that a recurrence of their respective spectacular meteor showers—the October Giacobinids and November Leonids—will soon occur. An examination of both displays is provided.

Giacobinid activity in the 20th century has varied dramatically due to the changing orbit of 21P/Giacobini-Zinner. A close approach to Jupiter in 1910 eventually led to significant meteor activity from this comet by 1926 and full-fledged meteor storms in 1933 and 1946 (the latter being the first case to be observed by radar-echo techniques). The comet's orbit was again perturbed by Jupiter in January 1958, preventing further interaction between the Earth and the Giacobinid stream. Another Jovian perturbation in September 1969 brought the Giacobinids back to the Earth's vicinity with a very strong showing being observed in 1985. Prospects for another Giacobinid shower in 1998 are discussed.

The years 1998 and 1999 are the years for the long-awaited return of the Leonid meteors. As to which year might bring any spectacular Leonid shower, opinions from several experts are voiced. The best Leonid showers seem to occur when the Earth follows their parent comet, 55P/Tempel-Tuttle to the latter's descending node—a situation that will occur in 1998–1999. Yet, there have also been two cases (1799 and 1832) of a Leonid storm taking place when Earth has led the comet to the node. Such a geometry also took place in 1997, but only produced a moderately strong display.

Based on Leonid performance during their past six cycles (dating back to 1799), the author suggests that only modest Leonid showers occur with Earth following 55P/Tempel-Tuttle to the nodal crossing point at 200 days or less, while when the Earth arrives at the node from approximately 300 days or more there is a greater likelihood of more substantial meteor activity. The Earth will arrive at the node 257.3 days behind the comet in 1998 and 622.5 days in 1999, implying that heavy Leonid activity may be an "iffy" proposition in 1998 with better overall odds for 1999. Regions of possible visibility of the impending Leonid showers are depicted and are determined from a compromise between when Earth arrives at the nodal crossing point and when Earth is passing across that part of its orbit where the Leonid storm of 1966 occurred.

Finally, a look ahead to the 21st century seems to indicate that observing circumstances for the Giacobinids seem to improve considerably by the year 2018, whereas, for the Leonids, perturbations wrought by Jupiter on 55P/Tempel-Tuttle in August 2029 should preclude any storm activity for future returns of this comet in 2031 and 2065.

1. Introduction

Meteor observing can be relaxing and enjoyable—yet also potentially dramatic. One fascination of meteor observing is its unpredictability. It is impossible to predict what will happen next. On any given night there is always a chance that you will observe something new and different, rare, or unique, whether it be a new stream, a long-enduring train, or a spectacular bolide. Currently however, an air of anticipation exists revolving around something predictable: the return of two well-known periodic comets, with each possibly bringing with them some unusual meteor activity.

When a comet nears the Sun, its nucleus sheds clouds of rubble that spread out along its orbit, creating a continuous "river of dust" moving in the same direction as the comet. Each time Earth passes through one of these rivers, it stops millions of orbiting particles, and—over the course of a night's watch—an alert observer may see the few dozens or hundred that rain from the air over his location. A comet nucleus releases meteoroids when some of its icy material—water ice, carbon dioxide, and other sublimated gases—is warmed and vaporized by the Sun. This gas pushes dust and larger bits of rocky matter and ice chunks off the nucleus, with their initial direction of motion most always toward the Sun and lighter material being turned in an anti-solar direction. The particles responsible for most of the streaks of light we see are quite small, ranging in size from large grains of sand to small pebbles. Usually arriving at many (up to dozens) of kilometers per second, they vaporize at altitudes of about 60 to 120 kilometers in the upper atmosphere. About a dozen major annual showers highlight the meteor watcher's calendar—"major" meaning those that display more than 10 meteors per hour under ideal observing conditions.

Then there are the stupendous "storms" of meteors, where the entire sky becomes ablaze with celestial pyrotechnics. On very rare occasions, a shower may intensify to produce thousands of shooting stars per hour. Usually, such a show lasts only a few hours or less, meaning that it is visible from only a small fraction of the Earth. It occurs when Earth passes through a thin, extra-dense ribbon of debris inside the much larger dust river. Such dense filaments are typically found relatively near the parent comet and are assumed to have been shed from it only in recent centuries, as they diffuse outward over time. A large meteoroid particle's position relative to the parent comet depends upon the nucleus spin direction and the location of its out-gassing region. However, small particles are immediately pushed away from the Sun by radiation pressure—independent of what direction they leave the nucleus. These latter particles will, sooner or later, wind up outside of, and behind the parent comet. Again, in most years a particular shower may be weak or nonexistent, but especially when the parent comet is nearby, meteor storms can occur.

2. The ups and downs of meteor astronomy

The science of meteor astronomy began with a meteor storm, and chances are that this same storm might soon make a return appearance. On November 12-13, 1833, across much of North America, anyone under a clear sky in the pre-dawn hours may have seen hundreds of meteors every *minute*, a rate of perhaps fifty thousand per hour. In the days that followed, wild theories involving electrified air or flammable gases filled the popular press. Those who witnessed this incredible display lost, conclusively, their childhood belief in stars falling from their fixed positions in the sky. Stars after all, could not pour down by the thousands! Also the belief that meteors were some sort of purely terrestrial combustion process in the atmosphere was put to rest. For the entire barrage in this storm of 1833 seemed to come from a single spot in the constellation of Leo. Some accounts of the storm describe a "black cloud" overhead where the meteors shot—an illusion caused by the hard-to-see meteors closest to their radiation point.

This dark void was, in fact, an optical illusion—as a Yale mathematics professor, Denison Olmsted, promptly demonstrated. He established the storm's geographic extent and, observing from Boston, found the number of particles at the moment of maximum, to be about half the number of flakes which we perceive in the air during an ordinary shower of snow. When the shower had considerably diminished, he counted 650 meteors in fifteen minutes, although he confined his observations to a zone which was not a tenth of the visible horizon; and he estimated 8660 for the total number over the whole sky. This latter number would have given 34 640 meteors per hour. Since the phenomenon lasted more than seven hours, the number of those visible at Boston probably exceeded 240 000! Olmsted determined that the meteors had originated beyond Earth and that they entered the atmosphere traveling in parallel paths. He concluded that this meteor blizzard had been shaken out of a swarm whose path crossed the Earth from the direction of Leo. Moreover, if the Earth passed through such a swarm on November 12-13, 1833, it would presumably do so on nearly the same days every year. It might not necessarily run right through the core of the swarm every time, yet some sort of meteoric display might be expected annually.

Olmsted's prognostication was beautifully confirmed. Once astronomers' attention had been called to it, they were able to observe these November meteors[1] annually, although in subsequent

[1] 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 AD 933 and 10 days in AD 1533. Another part is due to the sidereal year being $20\frac{1}{2}$ minutes longer than the tropical year, this excess accumulating to $14\frac{1}{2}$ 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.

years they were never as impressive as in 1833. With this realization, the meteors were given the Latin family name for their apparent place of origin: *the Leonids*. After 1833, many astronomers researched 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 cycles of 33 or 34 years. The great storms of meteors had come in November at these intervals, and, he suggested, they could be expected to continue as long as the meteor swarm remained intact (*"Perhaps,"* he later wrote, *"we shall have to wait until 1867 before seeing this magnificent spectacle return."*). Astronomers soon found other swarms whose dates of reappearance were fixed. Apparently the solar system was sprinkled with clouds of cosmic debris. If indeed the Earth on its annual trek around the Sun encountered dozens of them, how many must be scattered throughout the solar system? Evidently, here was a new group to be added to the population of our system, and a group seemingly far more numerous than any other.

In 1863–1864, Hubert Anson Newton of Yale established a time interval of 33.25 years for the major Leonid showers and predicted their next significant recurrence would come in November 1866. Indeed, there were very good Leonid showers not only in 1866, but in 1867 and 1868 as well, although none as impressive as the "Blizzard of '33." Great expectations for a spectacular shower were aroused when the next thirty-three-year cycle came up in 1899. Passing almost unheeded in the general excitement was a last-minute prediction by two British astronomers that a brilliant Leonid shower seemed unlikely, thanks to the disturbing action of Saturn and Jupiter on the meteor swarm.[2] Unfortunately for the reputation of most other astronomers, the promised celestial pyrotechnics display failed to occur, severely setting back the science of meteor astronomy. American meteor expert Charles P. Olivier would later write: *"... the failure of the Leonids to return in 1899 was the worst blow ever suffered by astronomy in the eyes of the public."* Adding to this, the Director of the Meteor Section of the British Astronomical Association, William F. Denning, noted: *"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."*

There was, of course, no use trying to explain to the average person that trying to predict a meteor shower was quite a different proposition from predicting an eclipse. The meteors were supposed to fall, but they did not. The next Leonid cycle of 1932–1933 failed to produce a meteor storm, and so it was too with the display of 1965. By then, even the most enthusiastic meteor observers might have been ready to give up on the Leonids, but on the morning of November 17, 1966, they roared to life once again: the western United States in particular were treated to an extraordinary meteor storm, dramatically demonstrating that the Leonids were far from dead, which brings us to the present.

For devoted sky gazers, ardent amateur astronomers and especially for those who assiduously scan the sky for meteors, these are now exciting times. First and foremost on everyone's mind, of course, are the November Leonids, now approaching yet another possible peak in their 33-year cycle. But as a preliminary to the possible main event, there is another famous periodic shower that is scheduled to reach its peak in early October and perhaps can be called the 1998 dark horse. These are the Giacobinids, or Draconid meteors; another meteor shower with a storied history of its own.

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[2] The two British astronomers, G. Johnstone Stoney and A.M.W. Downing, utilized an orbit for the Leonids that was computed by John Couch Adams. It was then 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. Stoney himself addressed the Royal Astronomical Society of London on November 10, 1899 and stated that a shower could be expected only if the particle stream radius extended at least 0.014 AU from the central orbit path. Unfortunately, this announcement came only five days before the predicted peak of the 1899 Leonids!

3. The Giacobinids of October

Some observers reported a count of a meteor per second.
My own count was only about a dozen per minute.
Somehow, meteors never fall so fast for me.

Robert S. Richardson, former Associate Director of Griffith Observatory, Los Angeles, commenting on the 1946 Giacobinid Shower.

With so much interest focused on the November Leonids, it is easy to overlook another periodic display that might possibly show some activity in early October of this year. The Giacobinid meteors are this year's "wild card." The Giacobinids have produced two of the greatest meteor displays in this century in 1933 and 1946, while lesser showers occurred in 1926, 1952, and 1985. Most years produce no Giacobinids at all. An intense shower seems to occur only when the Earth passes just inside the orbit of Comet 21P/Giacobini-Zinner shortly after the comet itself has gone by (Figure 1).

Apparently, the associated meteoroids are of relatively recent cometary origin and have not dispersed over the entire orbit, but rather move along close to their parent comet. It is for this reason that meteor-observing organizations always plan special meteor watches in those years when Comet 21P/Giacobini-Zinner comes to perihelion and also passes near the Earth. In such cases, enhanced Giacobinid activity seems possible. You *might* be treated to a spectacular meteor display around the time of the comet's perihelion, but it is also possible that you could come away without seeing a single Giacobinid! In November 1998, this comet will pass through perihelion, "possibly" producing a short-lived revival of the currently dormant Giacobinid stream.

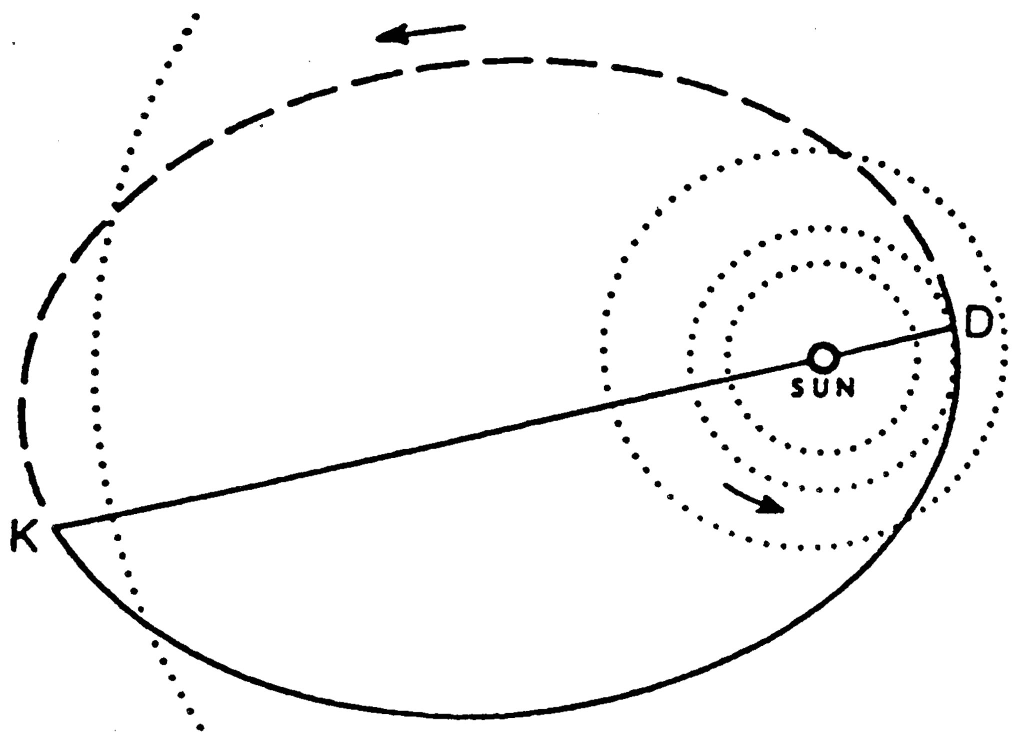

Figure 1 – The elliptical orbit of Comet 21P/Giacobini-Zinner. In this figure, K is the ascending node of the orbit, D the descending node. The orbit south of the ecliptic is drawn in a dashed line. The line KD, through the Sun, is the nodal line of the comet's orbit and not the major axis. The dotted orbits are the planets Venus, Earth, Mars and Jupiter. This particular example reproduces the orbital geometry for the year 1985 with both the descending node and the perihelion lying just outside the orbit of the Earth. (Diagram from *Handbook for Visual Meteor Observations* by Paul Roggemans (1989, Sky Publishing Corporation.)

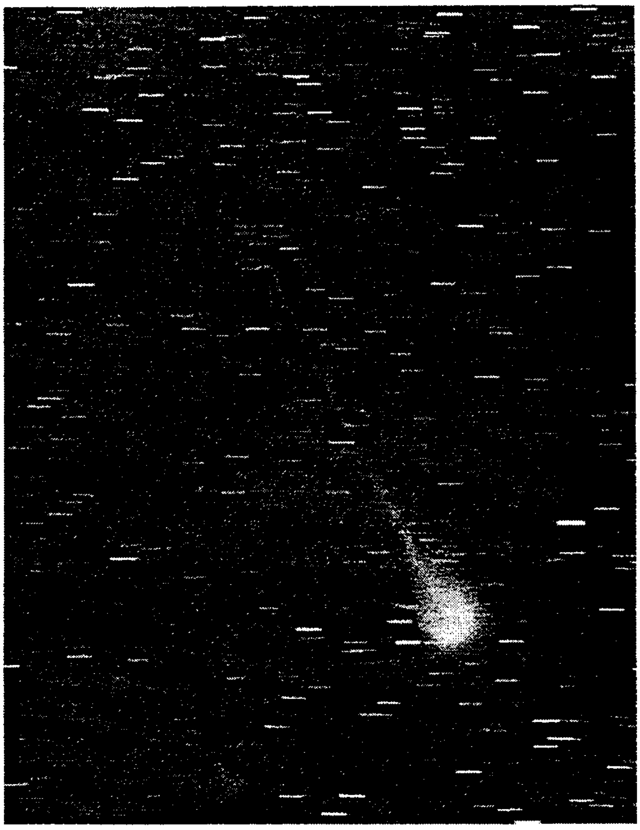

Figure 2 – Comet Giacobini-Zinner—October 26, 1959. This official US Naval Observatory photograph was taken by Elizabeth Roemer.

This will be the thirteenth observed apparition of 21P/Giacobini-Zinner (Figure 2). It was discovered on December 20, 1900, by M. Giacobini at the Nice Observatory in France and independently discovered on October 23, 1913, by Ernst Zinner at the Remeis Observatory in Bamberg, Germany. At its upcoming perihelion on November 21, 1998 it should be accessible to amateurs as a ninth-magnitude glow in western Capricornus, low in the southwest sky after sundown. This comet also holds the distinction of being the first comet ever to be explored by a spacecraft, when it was successfully intercepted by the International Cometary Explorer (ICE) on September 11, 1985. This space probe traversed the plasma tail of the comet, at a speed of 21 kilometers per second, some 7800 kilometers from the nucleus. The comet's nucleus was presumed to be an oblate spheroid with an estimated equatorial diameter of 2.5 kilometers.

A game of push and pull

Comet 21P/Giacobini-Zinner has an orbital period of approximately 6 1/2 years and, as such, is a member of Jupiter's family of comets, with its aphelion located just outside Jupiter's orbit. Periodically, the orbit of this comet can be perturbed by Jupiter's strong gravitational field. Calculations by the author indicate that during the 20th century, 21P/Giacobini-Zinner has suffered three serious perturbations that have played significant roles in determining whether or not the Earth could encounter its associated meteor shower. The first, in February 1910, occurred when the comet approached to within 1 AU of Jupiter. This caused its perihelion distance to increase, gradually pulling its orbit outward toward Earth and making meteor activity from this comet possible.

Then, in January 1958, the comet swept to within 0.93 AU of Jupiter, subsequently pushing the comet closer toward the Sun.

As a consequence, the distance between the comet orbit and the Earth increased considerably in the years that followed, and the Giacobinids completely vanished from the scene.

However, in September 1969, 21P/Giacobini-Zinner approached to within 0.58 AU of Jupiter, its closest Jovian pass of this century. This newest round of push-and-pull actually resulted in a positive twist: the comet was hurled back toward Earth's orbit and once again the Giacobinids returned.

In 1926, the orbits of the Earth and 21P/Giacobini-Zinner virtually touched, being separated by just 0.0005 AU (75 000 kilometers). The Earth arrived at the grazing point first, 69.1 days ahead of the comet. Observing for 3 hours from Stowmarket, England, the assiduous British observer J.P.M. Prentice reported an hourly rate of 17. What stole the show over the British Isles however, was a great Giacobinid fireball noted by many hundreds of people. The meteor moved slowly and lit up the sky, leaving a persistent train that lasted *about 30 minutes*!

Stormy times

The first of the great Giacobinid meteor storms took place on the European evening of October 9, 1933. On that date, the Earth was passing 0.0054 AU (808 000 kilometers) inside the orbit of 21P/Giacobini-Zinner, just 80.2 days after the comet itself passed this region of space. Astronomers in Europe were not prepared for what was in store for them, but as darkness fell, observers noted the beginnings of something unusual. Within just an hour, the number of Giacobinids increased dramatically. By $20^{h}08^{m}$ UT, one of the best meteor displays of this century was reaching its peak (Figure 3).

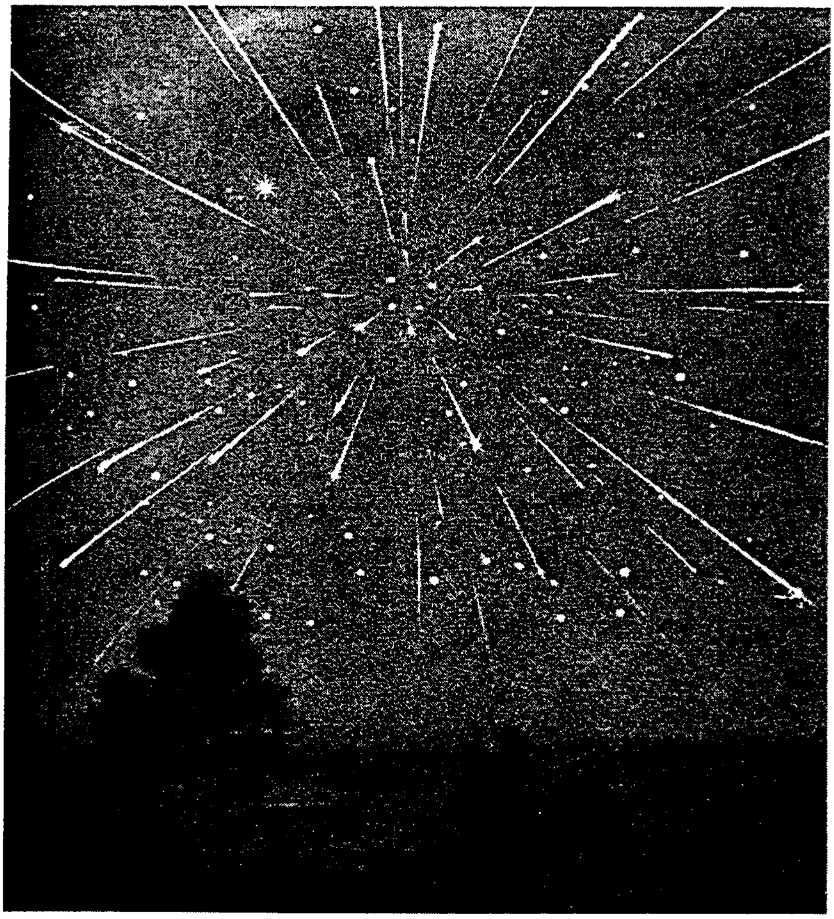

Figure 3 – The Great Giacobinid Meteor Storm of October 9, 1933, visible primarily across Europe. Alert and experienced meteor observers from the British Astronomical Association were unable to observe, the weather being too bad. At other sites, however, the hourly rates were spectacular, varying from observer to observer, from 50 to 480 meteors per minute. The total duration was limited to 4½ hours and the shower was extraordinarily rich in faint meteors. Illustration by Lucien Rudaux, *Larousse Encyclopedia of Astronomy* (1959).

The average hourly rate was estimated by most to be in excess of 6000, with the highest rate estimated at an astonishing *480 per minute* by R. Forbes-Bentley at Birchircara, Malta. An hour later, the rates had fallen to 1/10th of these extremes, and the shower was all but gone about 3 hours later as night came to the eastern United States. The meteors were described as slow, generally faint and yellowish.

As Comet 21P/Giacobini-Zinner approached perihelion in February 1940, some were hopeful that another meteor storm would materialize in October 1939, since the Earth would pass a mere 0.0013 AU (194 000 kilometers) inside the comet's orbit. However, Earth would reach this point in space 136.2 days before the comet and as a result no storm—or even a weak shower—appeared. Finally, in 1946, the stage was set for another tremendous outburst: on October 10, Earth was 0.0015 AU (224 000 kilometers) inside the comet's orbit and would be following the comet to this point in space by only 15 days!

Unfortunately, a Full Moon would also be in the sky, likely drowning out many of the fainter meteors. *"The Moon will probably kill off a majority of the meteors,"* wrote Roy K. Marshall in the October 1946 *Sky and Telescope*, adding sarcastically, *"... maybe we'll see only a thousand per hour!"* This time, the Giacobinids were best placed for observers in the Western Hemisphere. The impending shower garnered considerable publicity in the press, as evidenced by a front-page story in *The New York Times* on Monday, October 7, two days before the big event (Figure 4).

"All the News That's Fit to Print"

The New

VOL. XCVI..No. 32,398.

SOX VANQUISH
DS IN 10TH, 3-2,
HOMER BY YORK

First Baseman's Blow
2 Out Decides First
World Series Contest

Tie Score at 2-2 in
on 3 Singles—Johnson,
Hughson's Relief, Wins

By JOHN DREBINGER

Shower of Stars To Fall This Week

By The Associated Press.

CAMBRIDGE, Mass., Oct. 6—Harvard astronomers set up their telescopes today in anticipation of a heavenly fireworks display due to start Tuesday night in the form of thousands of falling meteors.

The university observatory said that the display would be "one of the largest in astronomical history" and would extend through Thursday.

Easterners, the observatory added, would probably get their clearest view of the phenomenon about 10 P. M. on Wednesday, while other parts of the United States would see the display if it lasts three or more hours.

With good weather, the scientists said, the "shooting stars" should be in view without the aid of instruments.

The observatory said that the display would be caused by the nearness of the earth to the orbit of the comet Giaconini-Zinner, with a proximity during the three-day period of 131,000 miles, as compared with the 238,000-mile distance to the moon.

VOTE REGISTRATION
OPENS HERE TODAY

OPA AND WAA ACT
TO SPEED HOUSING;
BUILDERS CRITICAL

Surplus Materials Ordered Into
GI Plan in Sixty Days—Rise
for Pine Millwork, Doors

NAIL SHORTAGE DENOUNCED

Need for Simple Articles Perils
Program, Association Says
—U. S. Claims Discounted

By JOHN D. MORRIS

WASHINGTON, Oct. 6—The Government took action on two fronts today to spur the housing program, but the National Association of Home Builders reported that progress was still being "drastically" curtailed by shortages of some needed materials.

The War Assets Administration ordered all war surplus building materials moved into the housing program within sixty days. The Office of Price Administration, as an incentive to increased production, raised ceiling prices on pine-stock millwork and Douglas fir doors.

City
As

Figure 4 – Announcement of the impending 1946 Giacobinid Meteor Storm. Front page of *The New York Times* for October 7, 1946.

For many, the weather posed the biggest concerns. The remnants of a Florida hurricane brought generally cloud-filled skies to the eastern United States, with scattered-to-broken clouds plaguing the central states, while the West enjoyed mainly fair weather. Those eager sky watchers who were blessed with fair skies and anxiously awaiting nightfall were not disappointed.

Meteor activity rapidly increased, reaching a sharp peak near 3^h50^m UT, with many of the estimates indicating rates—despite the bright Moon—of 50 to 100 meteors per minute! According to one correspondent to *Sky and Telescope*: *"There was no quarter of the heavens untouched by the fireworks."* In Chicago, Wagner Schlesinger, director of the Adler Planetarium, counted 149 *"flashing projectiles"* in ten minutes. Not bad, considering that the sky was more than 80% cloud-covered! Schlesinger said he had even seen two meteors blaze by *"... through the clouds."* In St. Louis with Edwin E. Friton, Regional Director of the American Meteor Society, Edward M. Brooks, St. Louis University, saw many flashes of light through holes in an altocumulus cloud deck, *"... like white snowflakes in a minor snowstorm."* For five hours, some Canadian observers under the supervision of Isabel K. Williamson counted over 2000 meteors. Since they observed only through specially made rings that allowed viewing of only selected areas, the count was far below what the actual number could have been.

As was the case for the 1933 display, maximum intensity of the Giacobinids of 1946 only lasted about an hour, so the stream width was determined to be less than 150 000 kilometers in the direction of the Earth's motion. Visually, the meteors appeared at abnormally high altitudes in the Earth's atmosphere, and displayed large atmospheric decelerations and abnormally short trails. From these observations, we have since deduced that the Giacobinids consist chiefly of very brittle, low-density material.

A milestone of the 1946 shower was the first-ever detection of a meteor shower by radar-echo techniques. Most of the observations were made on World War II radar instruments that were specially adapted just for this purpose. During the war, it had been discovered that meteors made characteristic whistles on radio receivers. Electromagnetic pulses can be beamed into space from a radar transmitter. As a meteoroid rushes through the atmosphere it drags a long train of ionized air behind it. What we observe is the long column of ionized particles formed by collisions with the meteoroid. This column is vastly larger than the object that produces it. Perhaps a few meters in width initially, it expands rapidly so that, within a second or two, it has attained a diameter of a kilometer or more. Electromagnetic waves from the radar transmitter, encountering such a train of ionized particles, set the electrons into vibration. The vibrating electrons emit waves that are picked up and recorded by a receiver at the same station that emitted the pulses. From the time elapsed between the instant a pulse was transmitted and received, and the velocity of light, the distance to the meteor can be determined.

Apparatus that was earlier used in a January 1946 attempt to make radar contact with the Moon was trained on the Giacobinids from the Evans Signal Laboratory of the Army at Belmar, New Jersey. Despite the fact that the sky was completely overcast, the machine registered a response after 3^h20^m UT that was described as an indication that *"an unusual condition existed."* At that same moment, Joint Army Air Forces Signal Corps watchers at White Sands, New Mexico, were reporting numerous "pips" on their radar screens representing meteors appearing *"... at distances of 45 to 180 miles."* Similarly, in London, radar work was being carried out by the British Ministry of Supply Operational Group.

It was also radar that was responsible for the detection of a surprisingly strong Giacobinid display in 1952. In that year, Earth would precede the comet by 195.5 days, so it seemed logical not to expect any significant activity with the Earth that far ahead of the comet. Visually, only the barest hint of activity could be detected, but, at Jodrell Bank in England, radio-echo apparatus indicated a sudden 2-hour burst of activity during the daylight hours of October 9. At one point, hourly rates peaked at 174..., to be sure, far less than 1946, yet—considering the geometry between Earth and comet—still remarkable.

Cosmic paradox

Giacobinid activity has been most recently observed in 1972, and again in 1985. The 1972 display was looked for with high anticipation. Not only were the orbits of Earth and 21P/Giacobini-Zinner separated by only 0.00074 AU (111 000 kilometers), the Earth was going to pass closest to the comet's orbit 58.5 days after the comet itself. Many confidently expected a recurrence of the storms of 1933 and 1946. Eastern Asia was expected to be in the best position to view the display, but fog and low clouds were widespread. Nonetheless, the Hiraiso Branch of the Radio Research Laboratory employed a 27.1-MHz radar, which detected a peak of 84 radar echoes in 10 minutes.

Elsewhere, despite all the promising statistics and advance build-up, the shower visually turned out to be a huge disappointment, with very few meteors being observed. Perhaps the fact that, on this particular occasion, the orbit of the comet was ever-so-slightly inside the Earth's orbit— as opposed to being on the outside in the case of the major showers of 1933 and 1946— had something to do with the paucity of meteor activity.

In contrast, the outlook for the 1985 Giacobinids was not at all promising. Although the Earth was going to pass closest to the comet's orbit a mere 26.5 days after the comet, our respective orbits at that time were six times farther apart than in 1933, and 20 times farther than in 1946. The overall consensus from most meteor experts was that, because the meteor stream seemed so narrow, it would probably miss us altogether. Indeed, most of the world saw little activity, but observers in Japan just happened to be in the right place at the right time and witnessed an impressive outburst near $9^{h}40^{m}$ UT on October 8 (Figure 5). This corresponded to $18^{h}40^{m}$ local time in Japan. In Tokyo, for instance, sunset was at $17^{h}18^{m}$ local time with astronomical twilight ending at $18^{h}43^{m}$ local time. One of the world's most assiduous meteor observers, Yasuo Yabu, gave a rapidly declining rate of approximately 200 per hour at $9^{h}40^{m}$ UT, which was already down to 100 just twenty minutes later. Corrected zenithal hourly rates suggested a sharp peak in the 600 to 800 range![3] Ichiro Hasegawa of the Nippon Meteor Society would later comment that the 1985 Giacobinids *... were one of the most impressive events I ever saw."*[4] Daylight radar results from the United Kingdom also indicated significant activity.

Giacobinid analysis

Table 1 presents the Giacobinid meteor shower data for various years computed by D.K. Yeomans. For each year listed, the successive columns give the following information:

1. the date (UT) the Earth arrives at 21P/Giacobini-Zinner's descending node, corresponding to the predicted time of maximum shower activity;
2. the distance (in AU) between the comet's and the Earth's orbits at the comet's descending node (a "−" sign indicates that the comet is on the inside of the Earth's orbit, while a "+" sign indicates that the comet is on the outside of Earth's orbit);
3. the number of days before or after the comet that the Earth arrives at the comet's descending node; and
4. meteor activity (if any) noted; based on data compiled by G.W. Kronk, A.C.B. Lovell, P. Roggemans, and D.K. Yeomans. Bright moonlight seriously hindered observation of the 1946 shower. An asterisk indicates that the associated activity was detected by radar techniques.

[3] As is well known, introducing correction factors to calculate ZHRs also introduces uncertainty, and even the corrections themselves contain uncertainties because they were based not on measurements but on estimates (guesstimates?). Caution must be taken with too optimistic calculations which often ignore the statistical meaning of a ZHR. For these reasons, computing a ZHR for short observing periods and/or poor observational circumstances (like for the 1985 Giacobinids) is not really advisable. Or, as Daniel Green of the Minor Planet Center, Cambridge, Massachusetts remarks, it is *"...sort of like computing a comet orbit with only visual astrometry!*

[4] From "An Interview with Dr. I. Hasegawa" by Jürgen Rendtel in *WGN* 21:2, April 1993, p. 74.

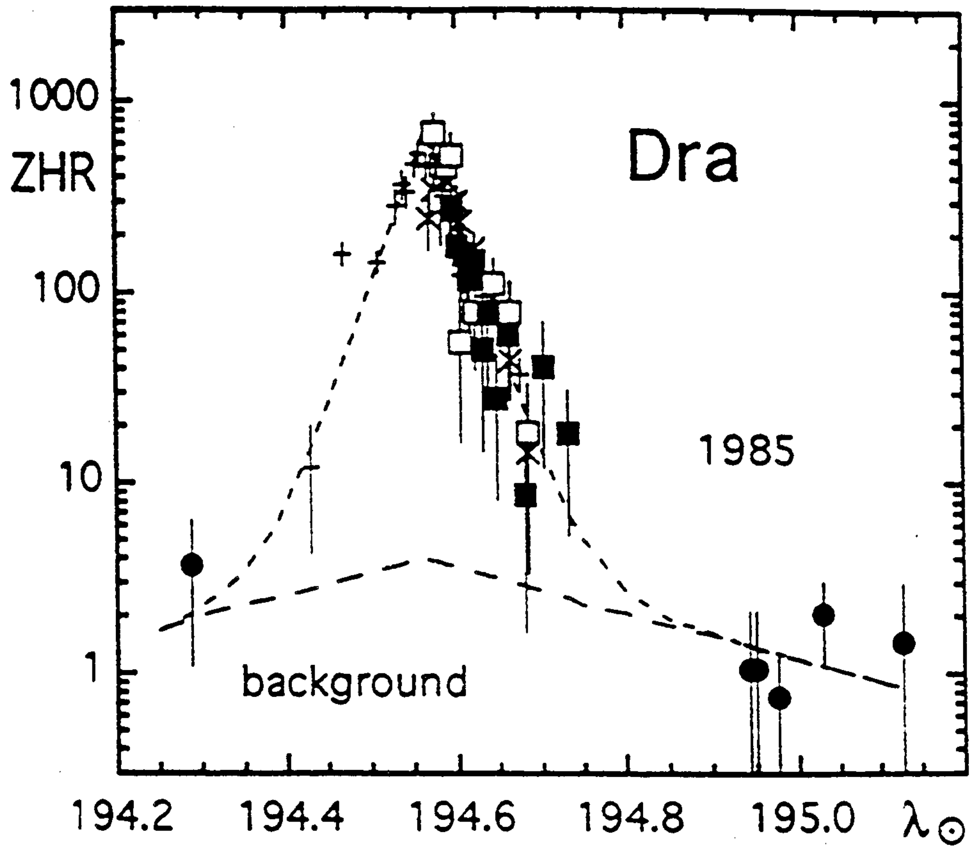

Figure 5 – Activity curve of the Giacobinid outburst of October 8, 1985, based on visual Nippon Meteor Shower data and radar data by Lindblad. At the bottom of the graph, solar longitude (eq. 2000.0) is utilized to define the moment of the outburst. For the 1985 Giacobinids, $\lambda_{\odot,\max} = 194^\circ\!.565$, which corresponds to October 8 at 9^h40^m UT. Apparently, as seen from Japan, the sky was not fully dark when maximum activity occurred (about an hour after sunset). The actual visual hourly rate was over 200 per hour, but when corrections were made for twilight and other factors, the zenithal hourly rate (ZHR) corresponded to 600 to 800. The outburst apparently lasted less than an hour.

Table 1 – An analysis of Giacobinid meteor showers.

Year	Date (UT)	C–E (AU)	Earth at node	Activity
1900	Oct 10.52	−0.0617	55.2 before	
1913	Oct 09.77	−0.0179	30.2 before	
1926	Oct 09.98	+0.0005	69.1 before	17
1933	Oct 09.77	+0.0054	80.2 after	3000–28 800
1939	Oct 10.32	+0.0013	136.2 before	
1946	Oct 10.16	+0.0015	15.4 after	3000–6000
1952	Oct 09.65	−0.0057	195.5 before	174*
1959	Oct 10.22	−0.0595	21.7 before	
1966	Oct 09.95	−0.0621	190.7 after	
1972	Oct 08.65	−0.0007	58.5 after	0–3; 84*
1978	Oct 09.12	+0.0013	133.2 before	
1985	Oct 08.55	+0.0329	26.5 after	600–800
1992	Oct 08.32	+0.0390	172.0 after	
1998	Oct 08.87	+0.0383	49.5 before	?

In 1985, Donald K. Yeomans of NASA's Jet Propulsion Laboratory in Pasadena suggested that, in order for significant Giacobinid activity to occur, the following criteria should be met: (*i*) the Earth closely follows the comet to the comet's descending node; (*ii*) the Earth passes close to the comet's orbit; and (*iii*) the Earth passes inside the comet's orbit at the comet's descending node (i.e., when C–E is both small and positive). For the 1985 apparition, it was thought that the orbital separation of 0.0329 AU (4 921 000 kilometers) would be far too wide to allow for much meteor activity. However, the surprising outburst observed from Japan, seemed to indicate that the Giacobinid stream was at least 0.033 AU wide—at least for that particular occasion.

Mixed prospects for 1998

For the impending return of the Giacobinids in 1998, there is some good news and bad news. The good news is that the Earth is still on the inside of 21P/Giacobini-Zinner's orbit at the comet's descending node. The gap between the respective orbits has widened since 1985, but not that much, to 0.0383 AU(5 728 000 kilometers). But the most important difference is that the Earth will reach the nodal crossing point 49.5 days before the comet. *"It is very difficult to assess what effect this difference will have,"* notes Dutch meteor expert Marco Langbroek, adding, *"... it might very well be the difference between all or nothing."* To gain a better perspective of what might be expected, refer to Figure 6, which is a plot of C–E (column 3 of Table 1) against Earth at node (column 4 of Table 1) for 19 entries.

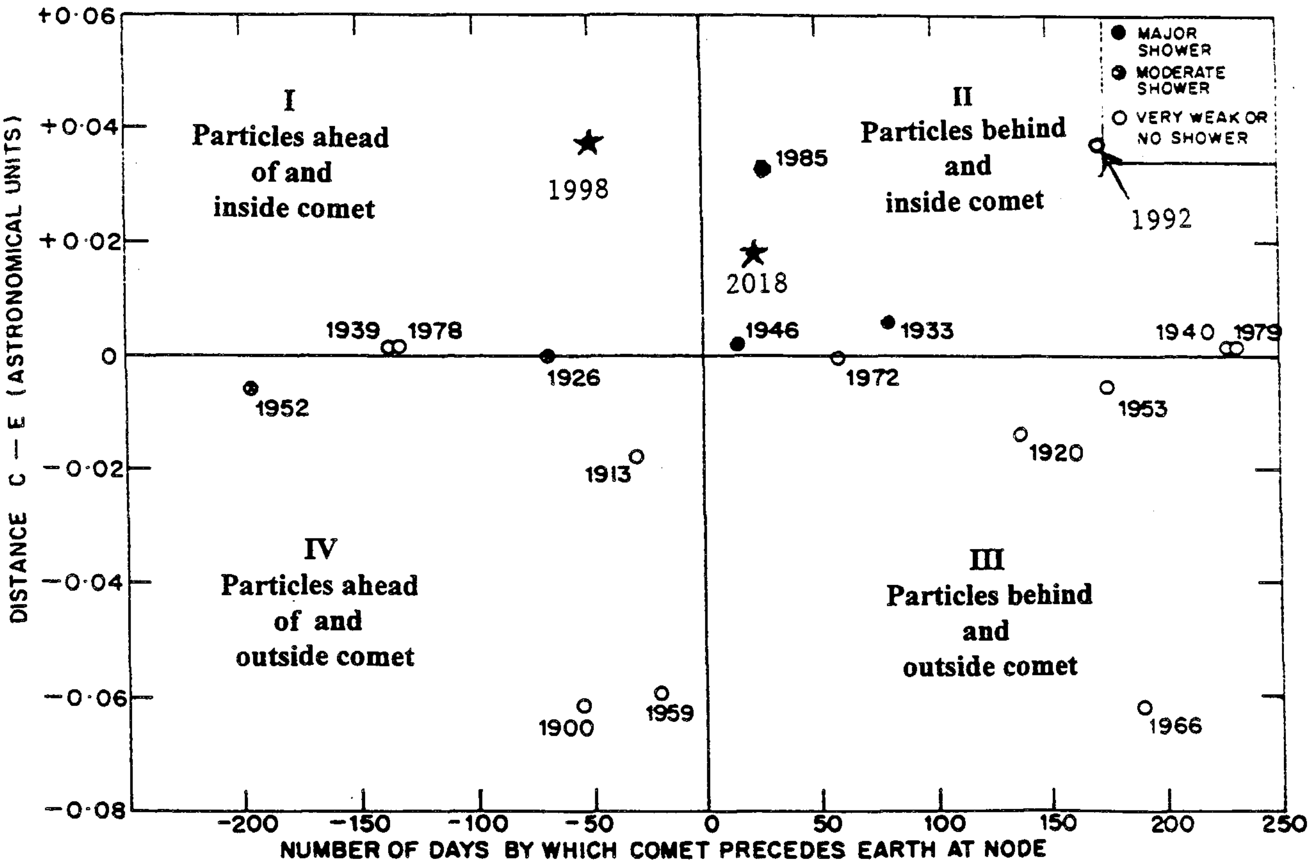

Figure 6 – The distribution of dust particles surrounding Comet 21P/Giacobini-Zinner, adapted from a similar diagram by D.K. Yeomans for Comet 55P/Tempel-Tuttle. The locations where meteoroids have been thickest around Comet 21P/Giacobini-Zinner, as revealed by Earth getting an unusually rich Giacobinid shower on passing through the comet's orbital plane (the plane of the paper). The meteors are closely confined to this plane. 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 AU that the particles are outside (−) 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. Stars mark the assumed location of dust particles in 1998 and 2018.

Four quadrants are depicted. The major showers of 1933, 1946, and 1985 are shown as filled dots; lesser showers in 1926 and 1952 are indicated by crosses. In the other years shown here as open circles, the shower activity was either insignificant or very low. Plots for 1998 and 2018 are depicted by stars. While some may argue that, like 1998, the showers of 1926 and 1952 also occurred with the Earth leading the comet to the nodal crossing point, it is only by closely examining the diagram in Figure 6 that one can see there is a difference: the showers of 1926 and 1952 are within quadrant IV, which not only depicts the Earth passing the node before the comet, but the Earth intersecting the orbital plane from outside the comet's orbit. The plot for 1998 however, falls within quadrant I, where little or no past activity to date has been observed. Yet, Figure 6 also shows that the upcoming 1998 event will be in a quadrant region where observations have not yet been available. Even no activity will serve as a useful constraint on the shower model, while if cometary debris runs well out ahead of the parent comet on the inside of its orbit, some sort of shower may yet be possible.

When and where?

Unlike most other meteor showers, the Giacobinids are at their best during the evening hours rather than after midnight. Their radiant ($\alpha = 17^{\rm h}22^{\rm m}$, $\delta = +57°$) is in the sky all night at mid-northern latitudes; high in the northwestern sky when darkness falls; it moves closer to the horizon throughout the night and is only a few degrees above the northern horizon by $4^{\rm h}$ a.m. local daylight time. As their radiant is close to the ecliptic north pole (in effect, the north pole of the solar system), Draconids are coming down into our orbit from the north, perpendicularly to the plane of the solar system and slightly behind the Earth. As such, the meteors appear to move slowly, their entry speed among the slowest of any shower, at just 20 km/s. In 1998, the Earth will pass the descending node of Comet Giacobini-Zinner on October 8, at $20^{\rm h}53^{\rm m}$ UT. Yet, in 1985, peak activity actually occurred more than $3\,^1\!/_2$ hours prior to the nodal crossing (these meteors must have been moved off the orbital plane by some perturbation). Were this to recur in 1998, the peak would take place closer to $17^{\rm h}15^{\rm m}$ UT.[5] This would be ideal timing for western Asia, the Balkans and the eastern Mediterranean. Were it to occur closer to the $20^{\rm h}53^{\rm m}$ nodal crossing time, much of Europe would be favored. North Americans will probably get their best shot at any Giacobinid activity several hours later, during the evening hours of the 8th. The Moon is waning, 86% illuminated, and rises near $21^{\rm h}$ local daylight time. Fortunately, between the time of the end of evening twilight and moonrise, there should be a 60 to 90 minute window of dark sky for most prospective meteor watchers. Begin watching the sky overhead as soon as it gets dark.

As the radiant is located near the lozenge-shaped head of Draco, the shower is sometimes called the *Draconids*. Notes British meteor astronomer Alastair McBeath: *"Poets among us might like to think of these as the 'Dragon's Tears' or its fiery breath."* Asks McBeath, *"Will the Dragon flame in 1998?"*

4. The Leonids of November

Did you stay up last night (the Magi did)
To see the star shower known as Leonid
That once a year by hand or apparatus
Is so mysteriously pelted at us?
It is but fiery puffs of dust and pebbles,
No doubt directed at our heads as rebels
In having taken artificial light
Against the ancient sovereignty of night.

Robert Frost

With the possible exceptions of the 1986 return of Halley's Comet and the total solar eclipse of July 1991, no celestial spectacle has been so eagerly awaited during these past three decades as the impending end-of-the-century return of the Leonid Meteors. Ever since their epic per-

[5] In a 1993 publication "Meteoroids and their parent bodies," the late meteor astronomer Lubor Kresák predicted $17^{\rm h}$ UT as the possible peak location.

formance in 1966, when meteors appeared to fall at rates estimated by many to be in excess of 100 000 per hour, sky watchers have been waiting for the end of the 1990s, when the conditions for another strong Leonid showing again appear to be favorable. The operative words here are "*appear to be favorable*," for the Leonids are famous not just for their periodic meteor blizzards, but for a schedule that has tantalized astronomers by blending elements of unpredictability and regularity for nearly two centuries.

Tempel-Tuttle: the "Mother of all Leonids"

It is well known that Comet 55P/Tempel-Tuttle is the progenitor of the Leonid meteors. On December 19, 1865, Ernst W.L. Tempel of Marseilles, France, discovered this comet in the evening sky near the star Kochab in Ursa Minor. He described it as a huge circular object at magnitude +5.5 to +6.0. On January 6, 1866, another independent discovery was made by Horace P. Tuttle, at the U.S. Naval Observatory, Washington, DC, when it had faded to near 7th magnitude. Thereafter, it faded, being last detected on February 9, 1866, when it was roughly magnitude +9 or +10.

Shortly thereafter, orbital calculations revealed this comet to be moving in an elliptical orbit with a period of 33 years, and on January 7, 1867, Theodor Ritter von Oppolzer published a definitive orbit that refined the period to 33.17 years. Almost immediately following Oppolzer's publication of his orbit, letters arrived at the publication *Astronomische Nachrichten* from two noted astronomers (Carl F.W. Peters and Giovanni Virginio Schiaparelli) suggesting a similarity to the previously determined 33-year orbit for the Leonid meteors by Urbain Le Verrier. Finally, in early February 1867, Oppolzer himself made the connection between his orbit for Comet Tempel-Tuttle and the Leonids.

Like their parent comet, each particle in the Leonid stream orbits the Sun independently in a roughly 33-year period, but in an orbit that is in the reverse or retrograde direction. So, in sharp contrast to 21P/Giacobini-Zinner, when we meet up with 55P/Tempel-Tuttle's dusty trail on November 17, the particles in it collide head-on with us at 71 kilometers per second—near the peak theoretical maximum speed for meteors belonging to the solar system (Figure 7). Because of their tremendous speeds, Leonids can become extremely bright and are usually tinged with hues of blue or green. Roughly half leave luminous vapor trains—some hanging in the air in excess of five minutes. The meteors begin to glow when they are still some 155 kilometers up, probably because they are of lightweight material.

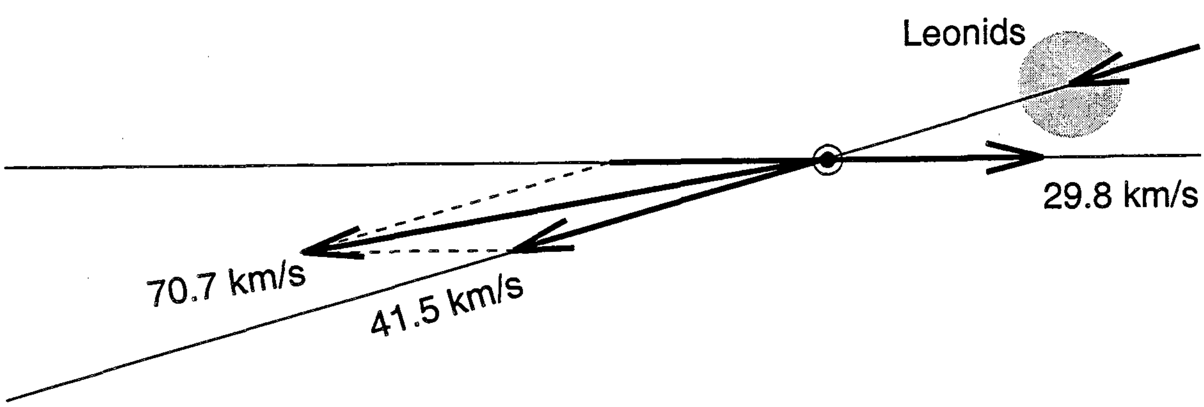

Figure 7 – Encounter between the Earth and Leonids. We measure the apparent velocity of the meteors and then combine this with the known velocity of the Earth to obtain the meteor's true velocity. Allowance must be made for the gravitational attraction of the Earth. As the meteoroid approaches the Earth, its motion is changed both in speed and direction. There is also a small correction for the velocity of rotation of the Earth. The orbital velocity of the Leonids of 41.5 km/s combines with the velocity of 29.8 km/s of the Earth. Since our encounter is in the nature of a head-on collision, the Leonids appear to move with a velocity of 70.7 km/s. (Diagram adapted from *Getting Acquainted with Comets* by Robert S. Richardson, 1967, McGraw-Hill Company.)

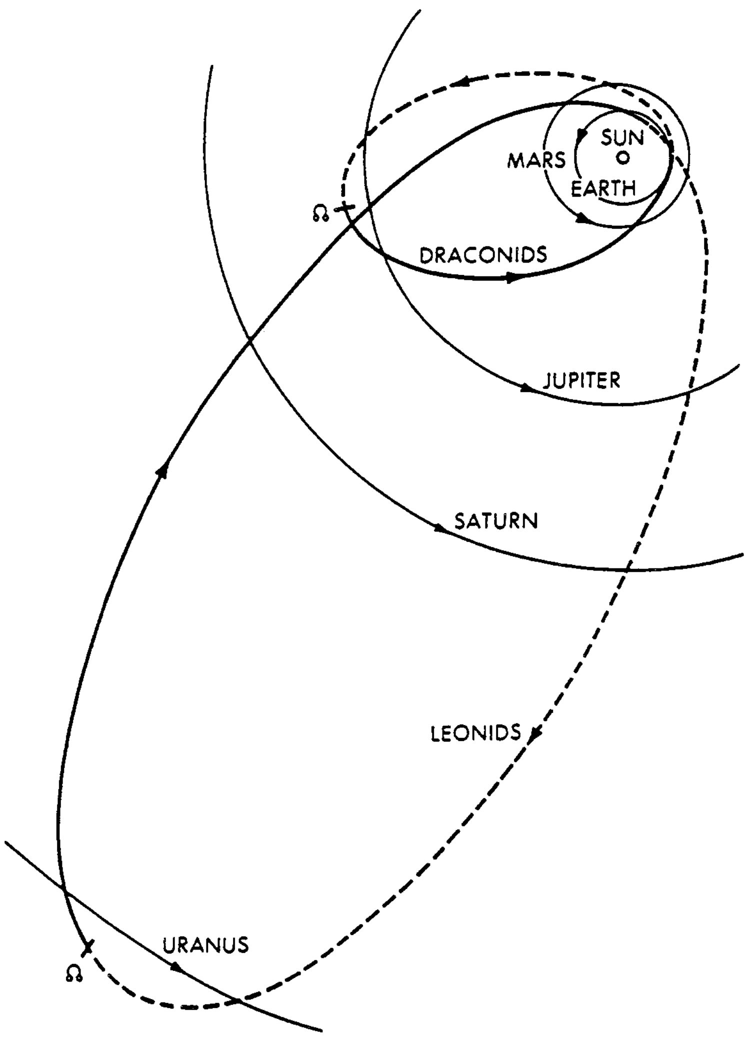

Figure 8 – Orbits of the Giacobinid (Draconid) and Leonid meteors. The Giacobinids are moving in the same general direction as Earth and appear to us as "slow." The Leonids, which we meet nearly head-on, appear to us as "very swift." Broken lines indicate sections of orbits below the plane of the diagram. (Diagram from *Getting Acquainted with Comets* by Robert S. Richardson, 1967, McGraw-Hill Company.)

Many Leonid meteoroids have become widely scattered along and away from the comet's orbit—a narrow ellipse that reaches all the way out to the orbit of Uranus (Figure 8). These stray particles are the ones that produce the ordinary, weak annual Leonid shower. The narrow, densest part of the swarm—probably no more than 35 000 kilometers wide—must be many astronomical units long: long enough to intersect the Earth's orbit for several years running, yet less than one ten-thousandth as thick. Besides this main stream, there must be scattered fragments stretched all around the orbit and spread out laterally at least 500 000 kilometers from the center line, to account for the lingering Leonid activity seen in off-years.

Before 1997, observations of 55P/Tempel-Tuttle have been identified in records for four previous apparitions (in 1366, 1699, 1865–1866 and 1965).[6]

[6] D.K. Yeomans suggests two other possible (but not definite) observations of this comet on October 30, 1234 (a notation of a guest star was found in Hyakurensho, a Japanese work) and on January 15, 1035 (a star with "vaporous rays" was noted by the Chinese). In the first case, Comet 55P/Tempel-Tuttle was about 0.1 AU from Earth at a solar elongation angle greater than 70°, which should have made it a naked-eye object. In the latter case, the Chinese sighting was made in Pisces, where the comet also was, but likely too faint to be seen with the naked-eye—unless, speculates Yeomans, the comet experienced a strong outburst, increasing its brightness considerably.

The most recent recovery of the then-approaching comet was made in early March 1997 at the observatories on Mauna Kea (Hawaii) and Cerro La Silla (Chile). Then, nearly a year from perihelion, it shone at a feeble apparent magnitude of +22.5. Early 1998 offered the best observing opportunity for this comet since late 1865. The comet was within 0.36 AU (54 million kilometers) of Earth on January 17 of this year, and less than 8° from the celestial north pole. In late January, the comet reached a peak brightness near magnitude +7.5. Current estimates of the nuclear radius of the comet based on its brightness at discovery suggest a value of 1.9 kilometers. Passing perihelion on February 28, 55P/Tempel-Tuttle crossed through the descending node of its orbit five days later, passing 0.0080 AU (1 197 000 kilometers) inside the orbit of Earth.

5. Name that year!

It has long been anticipated that 1998 and 1999 are the years that would offer the two best opportunities for a Leonid storm. But which will be the better year? Experts differ. NASA Ames scientist, Peter Jenniskens, thinks that the Leonid peak will be attained on November 17, 1998. In the March 22, 1996, issue of *The Astrogram* (the NASA Ames Employee Newspaper), Jenniskens is quoted as saying that on that day, *"... meteors may fall at the rate of three per second with occasional flares of up to 40 a second, but the storm will only last an hour."* Jenniskens indicates that *"... the odds seem best for observers in eastern Asia, where it will be deep into the night when the Earth is expected to hit the stream."* His calculations indicate that, in 1998, the time of the peak should occur within an hour of $19^{h}00^{m}$ UT, which indicates that the best observing locations would be China, Thailand, Vietnam, and the Philippines. Others, however, have less sanguine expectations. Brian G. Marsden of the Minor Planet Center, Cambridge, Massachusetts comments, *"My own personal opinion is that we shall not see much in the way of a meteor storm in either 1998 or 1999,"* but adds, *"... it would be nice if I am wrong!"*

Yeomans has published two detailed Leonid studies (in 1981 and 1996, the latter co-written with JPL colleagues Kevin F. Yau and Paul R. Weissman). Among other things, he has pointed out that the maximum likelihood of a storm would occur when the Earth runs into particles outside and behind the comet (which is precisely where Earth will be in 1998 and 1999). Yet, Yeomans also notes that there have been several cases in the past when similar circumstances failed to produce any significant activity. Good examples are 1899[7] and 1933, suggesting to him that *"... the particle distribution surrounding the comet is far from uniform in density."* And even if significant Leonid activity is encountered in 1998 and/or 1999, Yeomans suspects that it may not achieve epic storm proportions: *"In 1998–1999, the Earth will pass nearly three times as far from the comet's orbital path as it did in 1966 and more than six times further than it did during the great storm of 1833."* The 1998–1999 circumstances seem most like those for the 1866–1868 returns (about 5000 meteors per hour) and 1931–1932 returns (about 200 meteors per hour). *"Thus,"* he notes, *"the likelihood of an unusual Leonid shower event in 1998 and 1999 is very good but by no means certain. While it does not seem likely that the major 1966 Leonid storm will be repeated in either 1998 or 1999, the possibility cannot be ruled out. However uncertain the Leonid events may be... they are well worth an observational effort."*

Assuming that the peak of the Leonids is exactly or very closely aligned with the time when the Earth passes through the comet's orbital plane, Yeomans gives $19^{h}43^{m}$ UT on November 17 in 1998 and $1^{h}48^{m}$ UT on November 18 for 1999. The former case would favor Japan and eastern Asia, the latter, the eastern Atlantic, Europe, north Africa and western Asia.

[7] In a letter dated September 25, 1997, and published in *WGN* 25:5, October 1997, Marco Langbroek writes the following: *"Nodal passage in 1899 took place at* 18^{h} *UT on November 15. So, while the larger part of the public and professional anticipation would undoubtedly have been concentrated in Europe and North America, these people had no chance of observing a storm. A disappointment would have been their inescapable fate: any storm most probably took place above East Asia! For accounts of a possible 1899 storm, Hasegawa lists an entry (#218), taken from a Beijing Observatory compilation, for November 14.7, 1899, stating that* 'at 2 a.m., stars fell like rain.' *The mentioned time is exactly one day too early, but could this be a chronicler's (or translator's) mistake?!?"*

Celestial mechanics torn apart

Two studies on the distribution of particles associated with 55P/Tempel-Tuttle have been recently published, interestingly providing diametrically opposite solutions. At the University of Western Ontario (London, Ontario, Canada), Peter Brown and Jim Jones simulated the evolution of the Leonid stream via the numerical integration of 3 million test particles ejected from the comet nucleus during five perihelion passages. The years with no returns near the peak of the Leonid cycle in 1899 and 1933 were clearly portrayed in their model, and the strong return of 1966 was also verified. As there does not seem to be major recent planetary perturbations acting on the Leonid stream, as was the case in 1898 and 1732, they suggest that the impending Leonid showers from 1998 through 2000 will be strong, with the highest activity coming in 1999. The dust seems to be especially concentrated near nodal longitude $235^\circ\!.16$—which, as Brown and Jones are quick to point out, *"...is almost exactly the same position as that of the 1966 storm."* Using this logic, they suggest a Leonid peak in 1998 on November 17 at 17^h02^m UT (good for the western Pacific) and in 1999 on November 17 at 23^h02^m UT (good for Russia and China).

Similarly, Zidian Wu and Iwan P. Williams of the Astronomy Unit, Queen Mary and Westfield College, University of London (England) have also modeled the Leonid stream and have investigated its evolution on the assumption that most of the meteors observed in 1965–1966 were ejected from the comet at one of its last three returns. Like Brown and Jones, Wu and Williams were very careful in having their model reasonably account for the non-storm years of 1899 and 1933, as well as for the storm year of 1966. Yet, unlike Brown and Jones, Wu and Williams's forecasts for 1998–1999 are quite different. Their projections for 1998 are for a display perhaps similar to 1899 (40 per hour) or 1932 (240 per hour). As for the 1999 Leonids, Wu and Williams predict that *"...few will be seen."*

Perhaps the stark contrasts between these two studies echo a notion concerning prediction of meteor storms once offered by David Meisel, Executive Director of the American Meteor Society: *"Predictions of 'meteor storms' are notoriously unreliable. No one really knows how to do it properly."*[8]

Leonid analysis

Table 2 presents the Leonid meteor shower data, chiefly for those years when a meteor storm (with more than 1000 meteors per hour) was noted, computed by Yeomans.

Table 2 – An analysis of Leonid meteor showers.

Year	Date (UT)	C–E (AU)	Earth at node	Activity
1799	Nov 11–12	0.0032	116.9 before	30 000
1832	Nov 12–13	0.0013	50.7 before	20 000
1833	Nov 12–13	0.0013	307.9 after	50 000–150 000
1866	Nov 14	0.0065	299.4 after	2000–7200
1867	Nov 13	0.0065	664.4 after	2184–5000
1868	Nov 13	0.0065	1029.9 after	1000–1800
1900	Nov 15–16	0.0117	495.8 after	more than 1000
1901	Nov 15	0.0117	861.4 after	855–1800+
1965	Nov 16	0.0032	195.5 after	120
1966	Nov 17	0.0032	561.0 after	140 000–150 000
1997	Nov 17	0.0080	108.1 before	more than 100
1998	Nov 17.8	0.0080	257.3 after	?
1999	Nov 18.1	0.0080	622.5 after	?
2000	Nov 17.3	0.0080	988.7 after	?

[8] Comment was made in a letter to the author, dated September 6, 1985.

For each year listed, the successive columns give the following information:

1. the date (UT) of maximum shower activity. For showers yet to occur, the time that the Earth arrives at the comet's descending node is given to the nearest tenth of a day;
2. the distance (in AU) between the comet's and the Earth's orbit at the comet's descending node (in all cases the comet is on the inside of the Earth's orbit);
3. the number of days before or after the comet that the Earth arrives at the comet's descending node; and
4. storm activity noted; based on data compiled by P. Jenniskens, G.W. Kronk, A.C.B. Lovell, P. Roggemans, E.K.L. Upton, and D.K. Yeomans. Non-storm years (1965 and 1997) are included. For the years 1998–2000, the dates correspond to when Earth is predicted to arrive at the node of 55P/Tempel-Tuttle, to the nearest tenth of a day.

Getting a piece of the (big) rocks

From the study done by Brown and Jones, we can separate the Leonid particles shed from 55P/Tempel-Tuttle into three categories. The first contains particles with a mass of one gram that would correspond roughly to fireballs with a peak brightness of magnitude −5. Those with a mass of 0.01 gram would correspond to visual meteors with a peak brightness of magnitude 0, while the smallest particles of 0.0001 gram would be associated with radio meteors with a peak brightness of magnitude +5. From a review of records of past Leonid displays, it becomes readily apparent that whenever 55P/Tempel-Tuttle is within a few hundred days of its descending node, Leonid showers produce a much-greater proportion of fireballs and bolides. The larger particles that cause bolides hang around the nucleus because they leave the nucleus with less velocity than their small brethren and particularly because they are relatively unaffected by the radiation pressure that quickly sweeps away the smaller dust particles.

In fact, there are two unique cases (in 1799 and 1832) where storm activity occurred prior to the comet's arrival at its nodal crossing point. In 1799, a stupendous Leonid storm was observed by Friedrich Wilhelm Heinrich Alexander von Humboldt, the Prussian scientist and explorer. He was awakened by his partner, French natural historian Goujaud Aimé J.A. Bonpland, during the late hours of November 11-12 at their camp at Cumana, Venezuela. Von Humboldt wrote afterward:

> *"From half after two in the morning, the most extraordinary luminous meteors were seen in the direction of the East. Mr. Bonpland, who had risen to enjoy the freshness of the air, perceived them first. Thousands of bolides and falling stars succeeded each other during the space of four hours... From the first appearance of the phenomenon, there was not in the firmament a space equal to three diameters of the Moon, which was not filled every instant with bolides and falling stars... All these meteors left luminous traces from five to ten degrees in length... the phosphorescence of these traces, or luminous bands, lasted seven or eight seconds. Many of the falling stars had a very distinct nucleus, as large as the disk of Jupiter, from which darted sparks of vivid light... The light of these meteors was white, and not reddish... The phenomenon ceased by degrees after four o'clock, and the bolides and falling stars became less frequent; but we still distinguished some to the north-east by their whitish light, and the rapidity of their movement, a quarter of an hour after sunrise."*

This description is even more incredible when one realizes that all of this was observed on the night of a Full Moon! Moreover, this colossal display was also observed aboard a ship off Cape Florida near the edge of the Gulf Stream (Figure 9), where Andrew Ellicott commented that *at any one instant (the meteors were) as numerous as the stars."* Other witnesses were located in Labrador and Greenland as well as in parts of Europe. In England, two observers reported a *"sublimely awful"* shower of shooting stars as dawn was breaking, while *"bright streaks and flashes"* were seen through the daytime morning sky in Iserstadt, Germany!

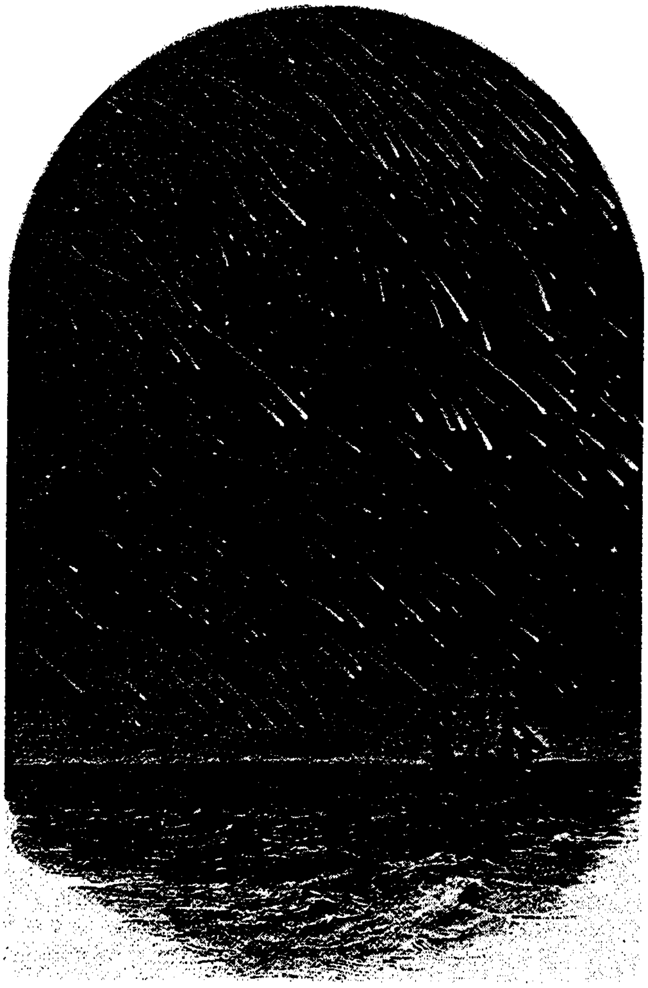

Figure 9 – The Great Leonid Meteor Storm of November 11-12, 1799, as described by Andrew Ellicott from Cape Florida near the edge of the Gulf Stream. Despite the light of a bright Full Moon, tens of thousands of meteors per hour were observed; many even after sunrise! The circumstances that produced this storm were rather unique in that it occurred with the Earth leading 55P/Tempel-Tuttle to the latter's descending node. Over the last six Leonid epochs, only two "pre-nodal" storms have been recorded (1799 and 1832). The 1799 storm took place with Earth leading the comet by 116.9 days and a C–E value of −0.0032 AU. Interestingly, in 1964, the C–E value was also −0.0032 AU, but Earth was leading the comet by a larger value of 169.5 days. As such, no Leonid storm was observed, hourly rates only reaching about 30. In 1997, the pre-nodal distance between Earth and comet was smaller than in 1799 (108.1 against 116.9 days), but the 1997 C–E value was 0.0048 AU greater than in 1799, likely precluding a storm. The author suggests that perhaps there is a very dense, narrow filament of material that is constantly being ejected ahead of the comet which—only under special circumstances—can produce a meteor storm.

Exactly one revolution later, on November 12-13, 1832, another meteor storm took place ahead of the comet's nodal passage: the Earth leading 55P/Tempel-Tuttle by just 50.7 days and with the orbits separated by only 0.0013 AU (194 000 kilometers), Leonids were seen to fall at up to 20 000 per hour from the Ural Mountains in Russia west to the eastern shore of Brazil. Also on this night, ship captains in the north Atlantic made numerous references in their logs to *"...large numbers of brilliant meteors."*[9]

[9] From a Leonid article by T.D. Nicholson in *Natural History* magazine, November 1966.

From these observations, one might speculate that, in 1799 and 1832, the Earth encountered a very dense, narrow filament of fresh particles ejected from the nucleus of 55P/Tempel-Tuttle. Such particles must have been ejected under very particular conditions—very intense and continuous—to achieve some sort of a narrow, compact shape ahead of the comet. This supposed filament is apparently composed of recently released dust, less dispersed but very rich in large (1 gram) particles. Some had even speculated in advance of the recent 1997 Leonid shower that there was a potential of a meteor storm. The explanation behind such reasoning was that, on the comet's inbound approach to the Sun in 1997, it would be positioned 108.1 days from its nodal crossing point as compared to an inbound distance of 116.9 days in 1799. Unfortunately, a quick perusal of the C–E column in Table 2 reveals that the distance separating the orbits of the Earth and comet was $2^1/_2$ *times wider in 1997* than in 1799—a factor that likely played a major role in precluding storm conditions last November.

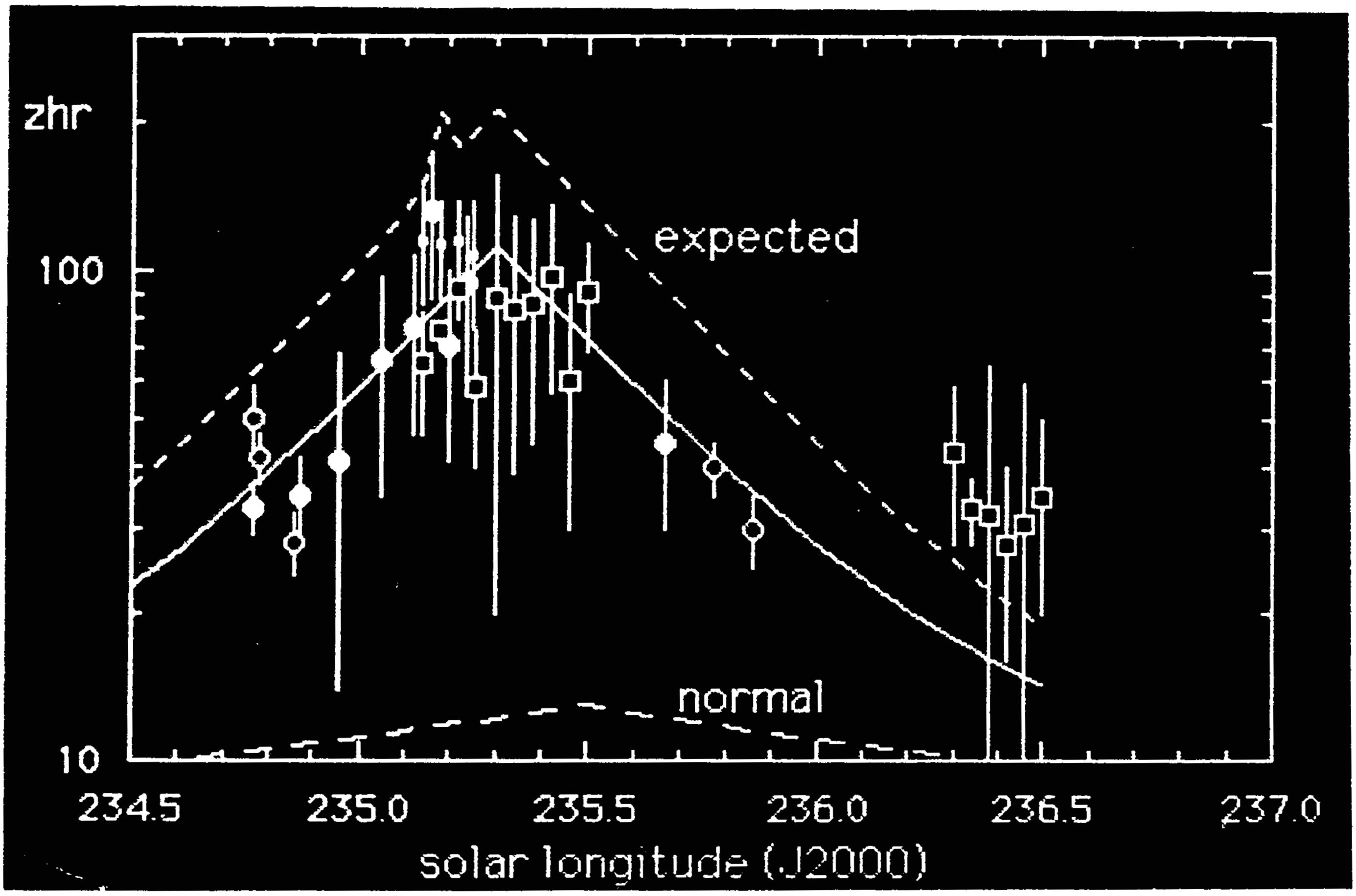

Figure 10 –Zenithal hourly rates for the 1997 Leonids, from data collected by Peter Jenniskens of NASA Ames, California. On the smoothed graph, a peak zenithal hourly rate of just over 100 is indicated, coinciding with solar longitude $\lambda_\odot = 235.^\circ3$. his closely coincides with the time that Earth arrives at the descending node of 55P/Tempel-Tuttle. Note, however, that the highest level of activity actually occurs near $\lambda_\odot = 235.^\circ13$, which is nearly coincident with that part of the Earth's orbit where the epic 1966 meteor storm occurred. However, it should be stressed here that ZHR values that are obtained under bright moonlit sky conditions are rendered meaningless as absolute figures. Indeed, the only real relevance that this rate data might have is to give a clue as to how the shower evolved in the hours before and after maximum.

Nonetheless, a brief, sharp outburst of Leonid activity was noted from the west coast of the United States, as well as Hawaii. All reports confirm that the 1997 shower was rich in bright meteors, apparently even more so than in 1996. The heightened activity was most noticeable in the large numbers of fireballs that were recorded—many in the −6 to −9 magnitude range! In radio observations, the stream was strong especially in overdense (long-duration) reflections from ionized trails left in the wake of the brilliant meteors. An 89% illuminated waning Moon made actual meteor rates difficult to determine, though corrections suggest a peak above 100 per hour (Figure 10). Elsewhere around the globe, a much weaker Leonid display was seen, yet occasionally punctuated by a dazzling fireball or bolide.

Judging the future by the past

A curious fact in studying Table 2 is that, over the past six Leonid cycles, no meteor storm has occurred with the Earth reaching the nodal crossing point any earlier than 299.4 days after the comet itself (this having happened in 1866). In 1965, for example, Earth reached the node just 195.5 days after the comet. Yet, no meteor storm was seen. Instead, with a Last-Quarter Moon positioned very close to the Leonid radiant, a sharp peak of about 120 meteors per hour was briefly noted from Maui, Hawaii—while from Woomera, Australia, 38 Leonids of an average magnitude of −3 were noted in less than three hours. Elsewhere, much weaker activity was reported with rates of 50 or less. In many ways, it seems that the 1965 Leonids performed in a fashion similar to the most-recent 1997 shower.

It has already been noted that, because of the dominance of radiation pressure forces on small dust particles, the region behind and outside 55P/Tempel-Tuttle appears most heavily populated by dust (0.01 to 0.0001 gram particles). However, the modest rates and rich fireball activity observed in 1965 seem to suggest that, in an area within at least 200 days behind the comet, there appears to be less in the way of dust, while the larger (1 to 0.01 gram) particles are in greater abundance. From (roughly) 300 days and beyond, we appear to be in a region where there is more in the way of smaller dust particles, and it is here where—historically—the Leonid storms of the past two centuries have taken place.

Noteworthy too, is that in 1932, Earth arrived at the nodal crossing point 121.4 days behind the comet. More interestingly, in comparing the 1932 Leonids to those of 1866 (Table 3), we find virtually the same orbital separation.

Table 3 – The 1866 versus the 1932 Leonids.

Year	Date (UT)	C–E (AU)	Earth at node	Activity
1866	Nov 14	0.0065	299.4 after	2000–7200
1932	Nov 16–17	0.0062	121.4 days after	240

As one can quickly see, the major difference comes in the number of days that Earth followed the comet to the node. In 1932, the Earth was 178 days closer to the comet, yet the Leonids of that year only peaked at 240 per hour—as compared to 1866, when they fell by the thousands.

So, where would this leave us for Leonid activity in the coming years? In 1998, Earth will follow 55P/Tempel-Tuttle to the node by 257.3 days—nearly the midpoint between the case of the modest 1965 display and the 1866 storm. In 1999, we will be in a position 622.5 days behind the comet and in a general region where, historically, storms have occurred (Figure 11).

Figure 11 –Location of 55P/Tempel-Tuttle relative to Earth's orbit at the nodal crossing point. Positions for the comet are for after it has passed the descending node of its orbit. Along the horizontal line, 1″ (2.54 cm) is equal to 1 AU. Over the past six Leonid cycles, there has never been a Leonid storm with the comet less than 299.4 days/4.48 AU from its descending node. On no fewer than seven occasions beyond this point—even as far as 1029.9 days/9.86 AU from the node—Leonid hourly rates of over 1000 have been observed. In contrast, on two occasions—1932 and 1965—the comet was less than 200 days/3.35 AU from the node, yet only modest Leonid showers were observed, accompanied by copious fireball activity. The author theorizes that when the comet is roughly 300 days from the node and beyond, there is more in the way of smaller dust particles, while within roughly 200 days behind the comet there is less dust but a greater proportion of larger meteoroids. The year 1998 sees the comet falling almost exactly in between the two supposed zones (whose boundaries are delineated by dashed lines), suggesting that, potentially, either a modest display or another storm may be in the offing. Depiction of the aerial coverage of the three particle sizes have been greatly exaggerated for the sake of clarity.

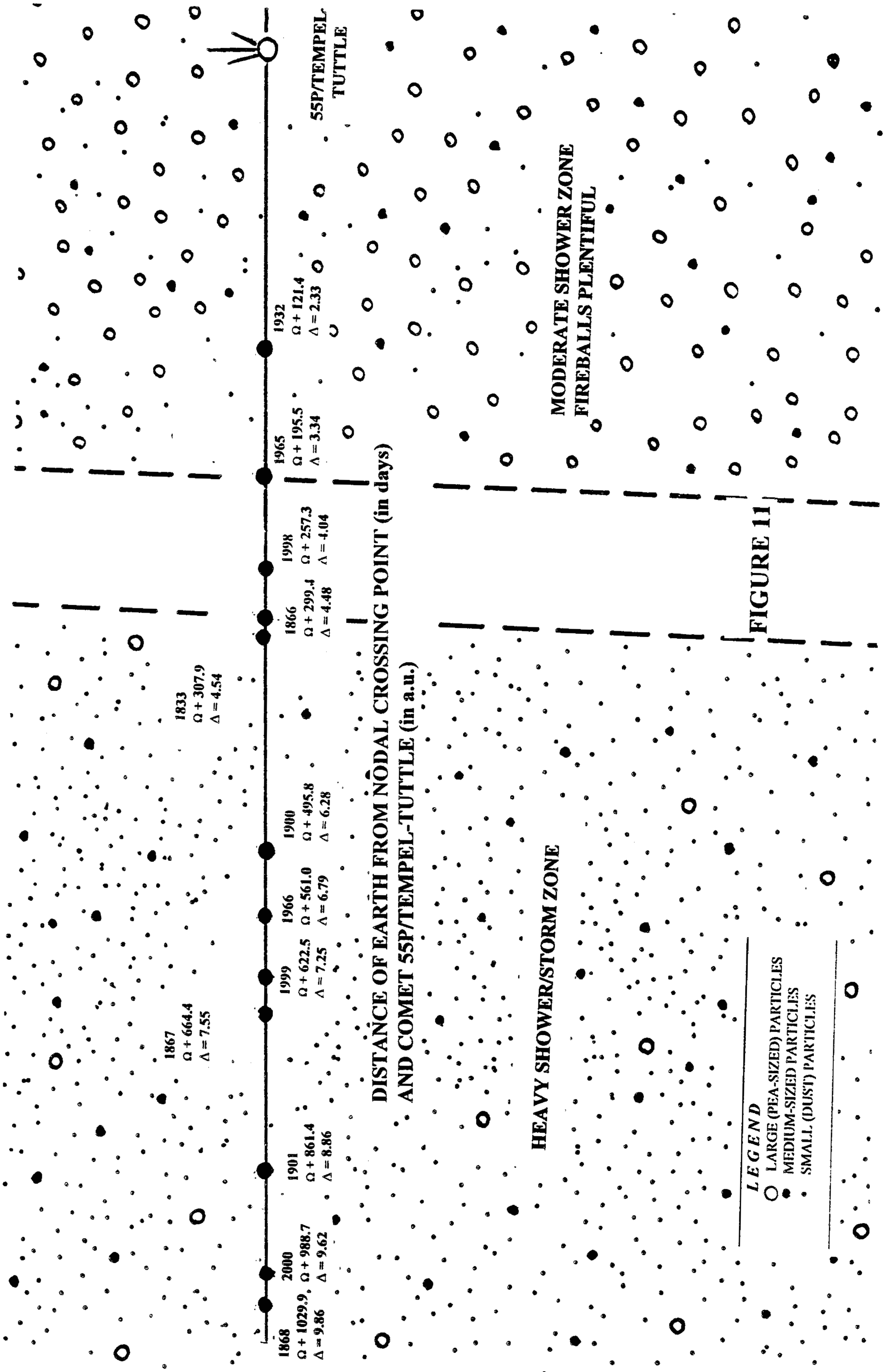
55P/TEMPEL-TUTTLE
1932 Ω + 121.4 Δ = 2.33
1965 Ω + 195.5 Δ = 3.34
1998 Ω + 257.3 Δ = 4.04
1866 Ω + 299.4 Δ = 4.48
1833 Ω + 307.9 Δ = 4.54
1900 Ω + 495.8 Δ = 6.28
1966 Ω + 561.0 Δ = 6.79
1999 Ω + 622.5 Δ = 7.25
1867 Ω + 664.4 Δ = 7.55
1901 Ω + 861.4 Δ = 8.86
2000 Ω + 988.7 Δ = 9.62
1868 Ω + 1029.9 Δ = 9.86
DISTANCE OF EARTH FROM NODAL CROSSING POINT (in days)
AND COMET 55P/TEMPEL-TUTTLE (in a.u.)
MODERATE SHOWER ZONE
FIREBALLS PLENTIFUL
HEAVY SHOWER/STORM ZONE
LEGEND
LARGE (PEA-SIZED) PARTICLES
MEDIUM-SIZED PARTICLES
SMALL (DUST) PARTICLES

FIGURE 11

So, while there certainly is a chance that the Leonids could storm in either (or both) 1998 and 1999, *one should seriously consider the possibility that the 1998 Leonids may merely produce another modest showing with hourly rates being measured only in the hundreds and not thousands, with a large proportion of fireballs.* On the other hand, the comet might have moved just far enough away from its nodal crossing point to place us in a region more heavily populated by dust—"perhaps" leading to a meteor storm. However, there seems to be a better chance of encountering this latter possibility at the greater nodal distances that will be achieved in 1999 and "maybe" even in the year 2000.

The other critical factor for a potential meteor storm to take place is the distance separating the orbits of 55P/Tempel-Tuttle from the Earth's. As has already been noted, the current gap between the respective orbits is noticeably larger at 0.0080 AU compared to the "Great Storm" years of 1833 and 1966. However, meteor storms were also observed in 1900 (from Hudson Bay where the Leonids created *"... a panic"*[10] among the local inhabitants) and 1901 (a sharp maximum over the desert southwest; in Tucson, Arizona, and Tuape, Mexico, the meteors were ambiguously described as *"... too thick to count"*). The separation between the orbits of Earth and comet for these Leonid events was 0.0117 AU (1 750 000 kilometers) or *nearly* $1^1/_2$ *times greater* than in the current situation. Hence, it would appear that a substantial fall of Leonid meteors is still quite possible despite the current orbital geometry.

One point should be made however, concerning those 1900 and 1901 displays: they each seemed to have produced very different degrees of activity from places that were not very far apart on a global scale. Aside from central Canada, for instance, most other locations saw nothing noteworthy about the 1900 Leonids, while in 1901, estimated hourly rates ranged widely from dozens, to hundreds, to even thousands. The highest counts seemed to be over parts of the southwest states and adjacent Mexico. Conventional wisdom is that meteor streams contain no significant structure on scales smaller than Earth (which moves along its orbit by one diameter in just seven minutes). But if the reports of 1900 and 1901 are taken at face value, there may exist very thin, dense bands—overall a complex filamentary structure with gaps and rich spots—that sweep across some parts of the world while other regions are spared. One might also consider perturbations wrought upon 55P/Tempel-Tuttle by Saturn in 1870 and Jupiter in 1898 for the eccentric and erratic performances of the Leonids during the 1899–1903 interval; possibly they even played a role in their poor showing in the early 1930s.

Based on Leonid activity over the past few years, it seems that, in order to try and anticipate the peak of the 1998 and 1999 showers, perhaps the best method is to draw a compromise between the nodal crossing times and the time that nearly corresponds to when Earth is passing across that part of its orbit where the 1966 storm occurred. The Leonid outbursts in 1996 and 1997 have, in fact, been noted very near to the latter location, which occurs roughly $2^1/_2$ hours before the nodal crossing. Any such compromise time would suggest a peak in 1998 near 18^h30^m UT on November 17 and in 1999 near 0^h30^m UT on November 18. Moonlight interference will be completely absent in 1998 with the Moon only a day from new phase. Although it will be a waxing gibbous in 1999, moonlight will be a minimal hindrance since it will set around midnight, leaving the latter part of the night dark for meteor watchers.

The meteors come at us from within the sickle of Leo at $\alpha = 10^h14^m$ and $\delta = +22°$. In mid-November, this famous asterism lies dead ahead of us in our path around the Sun. This means that we have to be on the front of Earth to see them coming—that is, we must be up during the hours from midnight to dawn. One quarter of the Earth is between midnight and dawn at any given moment and it is only that quarter that will be able to see any possible intense meteor display. The expected region of visibility for the 1998 Leonids is depicted in Figure 12, while the expected 1999 Leonid visibility region is depicted in Figure 13.

[10] From *Handbook for Visual Meteor Observations*, 1989, Sky Publishing Corp.

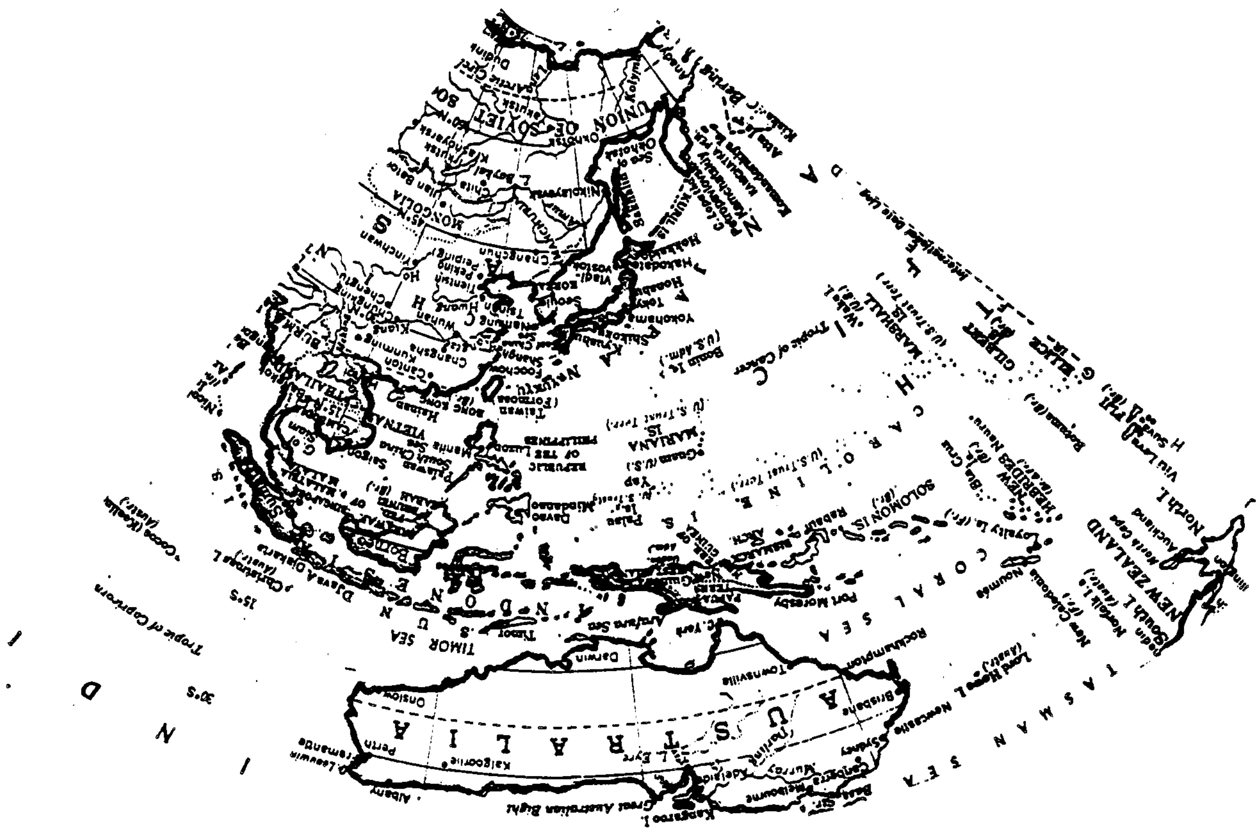

Figure 12 –Predicted regions of visibility for maximum activity of the 1998 Leonids. Based on a compromise between the time derived by D.K. Yeomans of when Earth would be passing closest to the descending node of 55P/Tempel-Tuttle and the time derived by P. Brown and J. Jones of when Earth is passing across that part of its orbit where the Great Storm of 1966 occurred. The compromise time for 1998 is 18^h30^m UT on November 17. Those regions located near and along the easternmost flank of each region will have the Leonid radiant highest in the sky, but coinciding with the onset of daylight; those near and along the western-most flank of each region will have the Leonid radiant very low in the sky or rising, but with the local time near midnight there will be at least several hours or more of darkness before the onset of morning twilight. For this reason alone, it might be better to be positioned farther to the west in these areas than to the east. (Maps were taken from *Hammond World Atlas*, New Perspective Edition, 1967, Maplewood, N.J.)

A word of caution: unknown perturbations in any given year might have shifted Leonid particles somewhat above or below the orbital plane of the comet. In such situations, the maximum could hit us early or late. The 1965 Leonids, for instance, peaked for Hawaii and Australia about 13 hours before the Earth arrived at the comet's orbital plane. The Great Storm of 1966 came about an hour after the Earth crossed the plane, while a surprising 1969 Leonid outburst (which briefly produced a rate of four per minute over the northeastern United States) occurred about 4 hours after. The bottom line is that, even if you are not within the "favored" viewing quadrants in 1998 or 1999, plan an all-night observing session anyway. In this "Leonid lottery," observers anywhere in the world could get lucky.

6. Looking ahead to the next century

The Giacobinids

Based on calculations by Yeomans, our best opportunities for seeing some activity from the Giacobinids early in the next century apparently will come in the years 2005, 2018, and 2031. These will be the years in which the Earth will follow 21P/Giacobini-Zinner to its descending node, with the comet positioned outside of our orbit. Table 4 provides Giacobinid circumstances for these three cases.

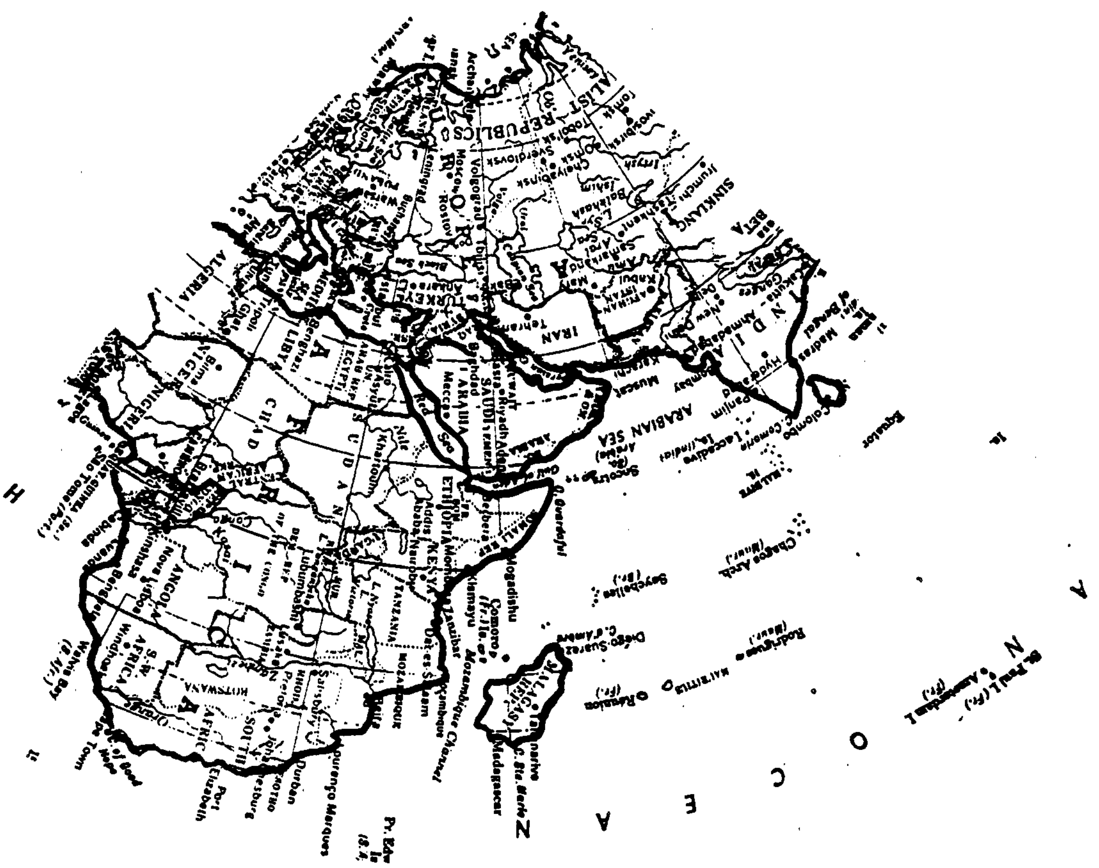

Figure 13 –Predicted regions of visibility for maximum activity of the 1999 Leonids (cfr. Figure 12). The compromise time for 1999 is 0^h30^m UT on November 18.

Table 4 – An analysis of 21st century Giacobinid meteor showers.

Year	Date (UT)	C–E (AU)	Earth at node
2005	Oct 08.70	+0.043	91.8 after
2018	Oct 09.00	+0.017	22.7 after
2031	Oct 08.37	+0.076	29.6 after

By far, the most favorable scenario is that of 2018. Earth will follow the comet to the nodal crossing point by only 22.7 days, and the separation between the orbits of Earth and comet will be 0.017 AU (2 543 000 kilometers). This is roughly midway between the C–E value for the storm observed from Europe in 1933 and for the heavy shower briefly seen from Japan in 1985. Refer also to the 2018 position (quadrant II) in Figure 7. Earth is due to arrive at the nodal crossing point at 0^h hours UT on October 9, which would correspond to 20^h EDT (dark sky conditions) on October 8 along the United States east coast. Add to this the fact that the Moon will be at new phase, and observing conditions seem ideal![11] Unfortunately, an approach to within 0.37 AU of Jupiter by 21P/Giacobini-Zinner in February 2029 will cause a significant widening of C–E to 0.076 AU (11 367 000 kilometers) by 2038.

... and the Leonids

As previously pointed out in the November 1996 *Sky and Telescope* (p. 74), the years 1998 through 2000 may be the last time for several more 33-year cycles when a Leonid storm can be considered possible. Yeomans as well as Marsden and Gareth Williams (Minor Planet Center, Cambridge, Massachusetts) have calculated the path of 55P/Tempel-Tuttle through future perturbations. They all find that, as the comet approaches the Sun toward a May 2031 perihelion, it

[11] *"Still,"* comments Yeomans, *"I would not bet the farm that a meteor storm will occur on this date."*

will pass within 1.5 AU of Jupiter in August 2029. This encounter will push the comet closer to the Sun and increase the distance between Earth's orbit and the comet's to 0.0162 AU (2 423 000 kilometers). This will be the largest separation between our respective orbits since 1733. Such a large gulf between the two orbits may preclude any substantial meteor activity for the years 2031 through 2033. There will be little improvement at the following return in 2065; the separation diminishes only slightly to 0.0146 AU (2 184 000 kilometers). Not until 2098, when the separation shrinks to 0.0062 AU (927 000 kilometers), or perhaps 2131, when, for the first time since 1633, the comet crosses our orbital plane slightly outside the Earth's orbit (at a distance of 0.0089 AU/1 331 000 kilometers), will any hopes for a Leonid storm again be justified.

Acknowledgment

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References

[1] P. Brown, J. Jones, "Evolution of the Leonid Meteor Stream", University of Western Ontario, London, Ontario, N6A3K7, 1992.

[2] P. Jenniskens, "Leonid Meteor Web Page", 1997, `http://www-space.arc.nasa.gov/~leonid`.

[3] G.W. Kronk, "Comets—A Descriptive Catalog", Enslow Publ., Hillside, NJ, 1984.

[4] G.W. Kronk, "Meteor Showers—A Descriptive Catalog", Enslow Publ., Hillside, NJ, 1984.

[5] M. Langbroek, "1998 October Draconid Prospects?", *WGN* 25:1, February 1997, pp. 37–39.

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

[7] T.D. Nicholson, "Sky Reporter", *Natural History* 75:9, 1966, pp. 42–45.

[8] G. Ottewell, "Astronomical Calendar 1998", Department of Physics, Furman University, Greenville, SC, 1998.

[9] J. Rao, "Storm Watch for the Perseids", *Sky and Telescope* 86:2, 1993, pp. 43–46.

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

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

[12] R.S. Richardson, "Getting Acquainted with Comets", McGraw Hill Books, 1967.

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

[14] C. Sagan, A. Druyan, "Comet", Random House, Inc., New York/Toronto, 1985.

[15] G.H. Spalding, "The Giacobinid Meteor Shower—Prospectus for 1985", *Journal of the BAA* 95:5, 1985, pp. 211–212.

[16] E.K.L. Upton, "The Leonids Were Dead, They Said", *Griffith Observer* 41:5, 1997, pp. 5–9.

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

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

[19] D.K. Yeomans, J.C. Brandt, "The Comet Giacobini-Zinner Handbook", NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 1985.

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

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

Taurid Swarm Appearing in 1998?

David Asher and Kiyoshi Izumi

Observations of the Taurids in 1998 will help to confirm or disprove a theoretical model of a resonant meteoroid swarm in the Taurid Complex.

A model of a meteoroid swarm at the heart of the Taurid Complex was described at the 1993 *IMC* in Puimichel [1]. The idea is that the action of a mean motion resonance (in this case, the 7:2 resonance with Jupiter) prevents meteoroids from dispersing all around their orbit, even over thousands of years. Instead, meteoroids concentrate in a restricted range of mean anomaly, spanning about ± 30–$40°$ from the swarm center. As a result, in about 20% of years, the Earth passes through the swarm.

This model was found to explain the appearance of many bright Taurid meteors in 1951, 1978, and 1988, compared to some other years where Taurid activity was less. The position of the model swarm also matched the timing of a cluster of meteoroid impacts on the Moon in June 1975 (the post-perihelion intersection of the Taurid stream with the Earth's orbit).

In [2], we found that the same swarm model was consistent with the appearance of bright Taurids observed in Japan in 1934, 1954, 1964, and 1971. Is there really a resonant swarm in the Taurid Complex as described by the model? The model predicts [1–3] the years when meteor activity resulting from the swarm is expected and so further observations can help to test the hypothesis. One of the years with a predicted swarm encounter is 1998.

Observations [4–9] in previous years of predicted swarm activity can give an idea of what should be expected.

The Taurid swarm does not produce a high and quite sharply peaked ZHR such as with the Quadrantids, Perseids, and Geminids. Instead, the swarm is quite broad, lasting a couple of weeks, during which unusually many bright meteors or fireballs appear, compared to average years for the Taurids. In the years in question, observers have seen several Taurids brighter than magnitude 0 in a single night. The Taurids as a whole last a couple of months, the swarm being at the center of the complex.

The unusual Taurid activity that may relate to the swarm is in the last few days of October or first ten or so days of November [4–9].

References

[1] D. Asher, "Meteoroid Swarms and the Taurid Complex", in *Proceedings of the International Meteor Conference*, Puimichel, 1993, P. Roggemans, ed., International Meteor Organization, 1994, pp. 88–91.

[2] D.J. Asher, K. Izumi, "Meteor Observations in Japan: New Implications for a Taurid Meteoroid Swarm", *Monthly Notices of the Royal Astronomical Society* 297, 1998, pp. 23–27.

[3] D.J. Asher, S.V.M. Clube, "An Extraterrestrial Influence During the Current Glacial-Interglacial", *Quarterly Journal of the Royal Astronomical Society* 34, 1993, pp. 481–511.

[4] N.M. Bone, "1988 Taurids Live Up to Reputation", *Astronomy Now* 3:4, 1989, pp. 6–7.

[5] S.G. Fonk, "Tauriden radiant 1951", *De Meteoor* 7, 1951, pp. 35–36 (in Dutch).

[6] M. Furuhata, "Taurid Fireballs", *Tenmon to Kisho (Astronomy and Weather)*, October, 1980, p. 25 (in Japanese).

[7] C. Henshaw, "Meteor Notes", *The Astronomer* 16, 1979, pp. 163–166.

[8] T. Markham, "Meteor Notes", *The Astronomer* 26, 1990, pp. 200–202.

[9] J. van Diggelen and C. de Jager, "On Some Recently Observed Fireballs", in *Meteors*, T.R. Kaiser, ed., Pergamon, Oxford, 1955, pp. 162–167.

First Impressions of the 1998 Perseids

Rainer Arlt

A short summary of the 1998 Perseid activity is given, based on the reports of 104 observers who saw 4469 Perseids in 723 hours. The ZHR-profile seems to underestimate the true activity. High ZHRs over 130 were reported from Japan at $\lambda_\odot = 139.^\circ7$–$139.^\circ8$ (eq. 2000.0). The traditional maximum occurred around $\lambda_\odot = 140.^\circ0$ with ZHR ≈ 80.

The 1998 Perseid maximum was certainly not an event many amateurs will remember for long. A Full Moon on August 8 caused considerable disturbance during the peak nights, as the summer waning Moon moves higher in declination, which is why the time of moonrise does not shift quickly towards morning hours.

Despite these unfavorable conditions, the interest in this year's Perseid return was high, since the meteor astronomy community was waiting to see what would happen to the fresh peak occurring before the traditional peak since 1988. It will be hard to derive small-scale results for the activity profile of the Perseids in 1998, yet a considerable number of 104 observers already reported their tallies to me.

I would like to thank all the following amateurs for the observational information:

Sana'a Abdo (ABDSA, 14.h55), Zaid Abdullah (ABDZA, 3.h55), Iyad Ahmad (AHMIY, 4.h50), Ziad Al-Khatieb (ALKZI, 14.h16), Ahmad Al-Niamat (ALNAH, 9.h50), Ibrahim Al-Sabban (ALSIB, 6.h25), José Alvarellos (ALVJO, 2.h13), Rainer Arlt (ARLRA, 13.h23), Ivo Babarovič (BABIV, 2.h90), Lars Bakmann (BAKLA, 2.h60), Michal Bares (BARMC, 3.h70), Nikola Biliskov (BILNI, 2.h04), Emil Brezina (BREEM, 0.h55), Jens J. Carlsen (CARJE, 5.h64), Roman Cecil (CECRO, 2.h47), Aleš Cesen (CESAL, 7.h31), Hani Dalee (DALHA, 6.h96), Michael Funke (FUNMI, 5.h70), Ivanka Getsova (GETIV, 5.h27), George W. Gliba (GLIGE, 2.h00), Valentin Grigore (GRIVA, 5.h79), Matthias Growe (GROMA, 4.h05), Michal Haltuf (HALMI, 3.h57), Yahia Hamed (HAMYA, 3.h00), Takema Hashimoto (HASTA, 5.h50), Ala'a Hemsy (HEMAL, 7.h81), Udo Henning (HENUD, 4.h48), Anti Hirv (HIRAN, 3.h78), Amera Hjeaj (HJEAM, 5.h33), Danielle Hoja (HOJDA, 6.h12), Dave Hostetter (HOSDA, 1.h00), Tomaš Hynek (HYNTO, 2.h67), Helle Jaaniste (JAAHE, 4.h85), Miroslav Jedlicka (JEDMI, 0.h57), Carl Johannink (JOHCA, 23.h98), Javor Kac (KACJA, 24.h37), Primož Kajdič (KAJPR, 3.h51), Vaclav Kalas (KALVA, 5.h01), Veiko Kask (KASVE, 0.h52), Tarek Katbeh (KATTA, 10.h02), Kenya Kawabata (KAWKE, 1.h50), Ylo Kestlane (KESYL, 1.h69), Jakub Koukal (KOUJA, 5.h70), Ales Kratochvil (KRAAL, 3.h00), Andreas Krawietz (KRAAN, 5.h94), Lukas Kral (KRALU, 3.h27), Dita Krcmarova (KRCDI, 1.h88), Maris Kuperjanov (KUPMA, 2.h65), Ralf Kuschnik (KUSRA, 0.h68), Sylvio Lachmann (LACSY, 16.h82), Marco Langbroek (LANMA, 23.h34), Endriko Leks (LEKEN, 1.h75), Viktor Lukyanov (LUKVI, 4.h17), Hartwig Lüthen (LUTHA, 1.h04), Kouji Maeda (MAEKO, 1.h58), Miroslava Mala (MALMI, 1.h50), Katuhiko Mameta (MAMKA, 3.h50), Pierre Martin (MARPI, 27.h27), Petr Masek (MASPE, 3.h00), Alastair McBeath (MCBAL, 3.h67), Rossitsa Miteva (MITRO, 6.h92), Sirko Molau (MOLSI, 3.h78), Ivelina Momcheva (MOMIV, 9.h10), Sven Näther (NATSV, 15.h00), John Newton (NEWJO, 4.h00), Mirko Nitschke (NITMI, 7.h03), Mohammad Odeh (ODEMO, 4.h81), Ibrahim Odwan (ODWIB, 9.h95), Arkadiusz Olech (OLEAR, 2.h85), Artyom Oreshonok (OREAR, 7.h40), Kazuhiro Osada (OSAKA, 5.h82), Urška Pajer (PAJUR, 1.h53), Nataša Petelin (PETNA, 1.h75), Pavel Platos (PLAPA, 3.h18), Jürgen Rendtel (RENJU, 23.h14), Jaroslav Sajdl (SAJJA, 2.h03), Mitsue Sakaguchi (SAKMI, 8.h00), Koetu Sato (SATKO, 1.h17), Thomas Schreyer (SCHTH, 9.h91), Harald Seifert (SEIHA, 14.h72), Zybnek Slama (SLAZY, 1.h32), Manuel Solano Ruiz (SOLMA, 1.h42), Jiři Srba (SRBJI, 0.h60), Niko Štritof (STRNI, 1.h10), Pavel Svozil (SVOPA, 0.h60), Idgrid Tago (TAGID, 1.h00), Khaled Tell (TELKH, 8.h00), Manuela Trenn (TREMA, 3.h75), Gabrijela Triglav (TRIGA, 9.h11), Mihaela Triglav (TRIMI, 5.h20), Josep Trigo Rodriguez (TRIJO, 7.h08), Ivaylo Videv (VIDIV, 8.h36), Jaroslav Vošahlík (VOSJA, 0.h28), Marija Vucelja (VUCMA, 5.h76), Anne van Weerden (VANAE, 1.h11), Roland Winkler (WINRO, 1.h87), Oliver Wusk (WUSOL, 34.h65), Ilkka Yrjölä (YRJIL, 3.h86), Jan Zacios (ZACJA, 2.h90), Jure Zakrajsek (ZAKJU, 4.h51), Georg Zaunick (ZAUGE, 8.h65), Jan Zavitski (ZAVJA, 1.h65), George Zay (ZAYGE, 93.h36), and Irena Živković (ZIVIR, 5.h70).

The observers were from

Belarus, Bulgaria, Canada, the Czech Republic, Denmark, Finland, Germany, Japan, Jordan, the Netherlands, Poland, Slovenia, Spain, the United Kingdom, the United States, and Yugoslavia.

At this time of analysis, it is, of course, very difficult to give precise statements about the peak times of either the traditional or the new Perseid peak. The general comments by the observers stated the apparently slow activity, which is naturally due to the disturbance of the Moon. Even after limiting-magnitude correction, however, ZHRs are seemingly too low.

Japanese observers reported highest rates throughout their dark hours (see *AMOTA* home page). Because of the unfavorable conditions in 1998, the scatter in their values is extremely large. Several ZHR values are in the range 150–200, and the averages suggest to adopt a peak value of ZHR $= 180 \pm 50$ in this first report about the Perseid activity. This result indicates that the strength of the new Perseid peak has at least not diminished since 1997. The time of maximum should lie between $\lambda_\odot = 139.^\circ7$ and $\lambda_\odot = 139.^\circ8$.

The traditional maximum occurred around $\lambda_\odot = 140.^\circ0$ with a rounded activity of ZHR $= 80 \pm 10$. The error bar is definitely an optimistic estimate, since the whole profile, except the fresh Perseid peak, seems to underestimate the activity. The Moon certainly had a very bad influence on the perception characteristics of the observers. It will be worthwhile to study whether observers tend to overestimate their stellar limiting magnitude compared with the meteor limiting magnitude. Curiously, the contrary has been noticed on several occasions. We are looking forward to completing this picture with a more comprehensive data set.

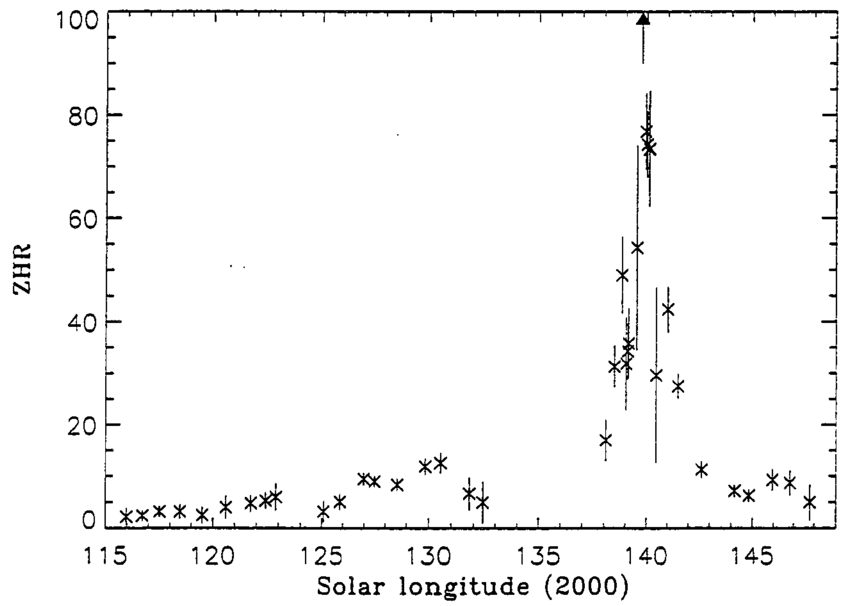

Figure 1 – Profile of the 1998 Perseids over the entire activity period.

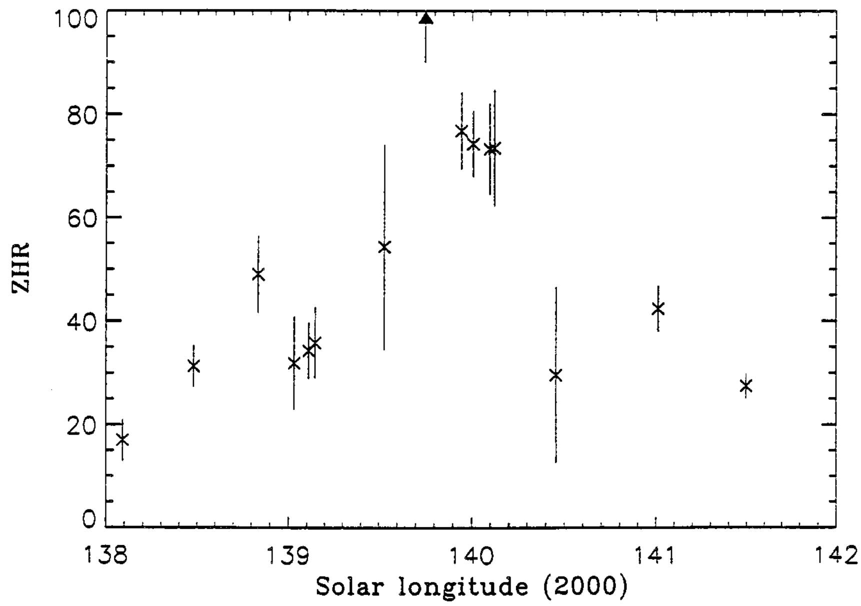

Figure 2 – Magnification of the 1998 Perseid maximum. Note that the peak value of roughly 180 at $\lambda_\odot = 139.^\circ75$ (indicated by an arrow) is omitted because of the extremely large scatter.

A Spiral Meteor Train

Yoshihiko Shigeno, Masayuki Toda, and Masato Kobayashi

A spiral meteor train was successfully observed and photographed at two stations. The spiral was 4.17 ms in period and 461 m in diameter. We calculated the centrifugal acceleration and atmospheric drag of the meteoroid, and found that it is not the meteoroid but only the emitted gas which is making a spiral motion. A non-linear meteor trail may be curved or branched, if not spiral. We attempted a dynamic study. Since a meteoroid has a very large kinetic energy, compared to the force received from the atmosphere, its motion is not changed greatly.

1. Introduction

Meteor trails are usually linear, but some trails were reported to be non-linear. Beech [1–3] collected many reports and analyzed non-linear meteors mainly using naked-eye observations in the 1800s. A non-linear meteor may have a trail of a curved, spiral, branched, or combined shape. The data classification results of non-linear trails are as follows:

1. About 0.5% of the meteors were non-linear.
2. Of the non-linear meteors, 60% were curved and 40% were spiral.
3. These phenomena were observed for meteors of various durations, magnitudes, and colors.

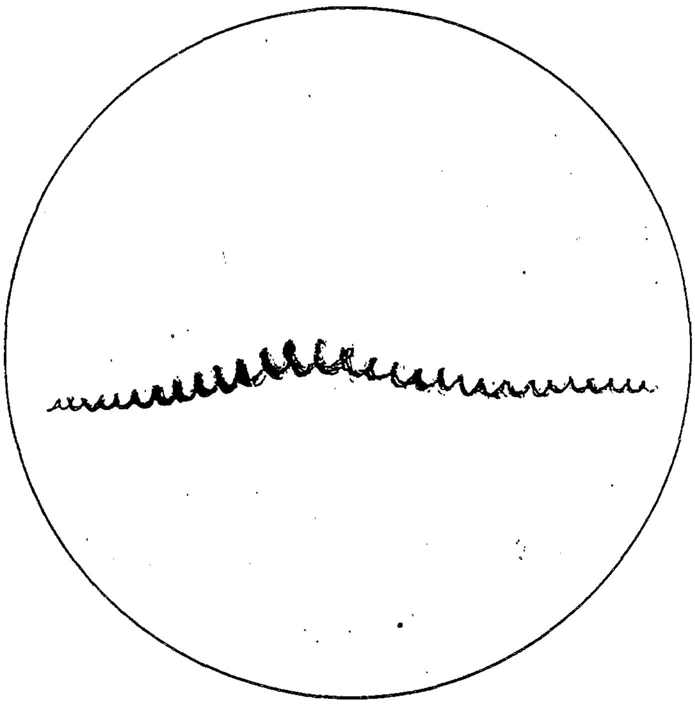

Figure 1 – Kunihiko Suzuki observed this Orionid spiral meteor train through 9×35 binoculars at $18^h 14^m$ UT on December 22, 1982, from Mt. Tsukuba, Japan. The drawing shows the train 10 s to 15 s after the meteor appeared.

Beech explained these phenomena with the magnus effect and torque-free precession in hydrodynamics. A revolving baseball draws a curve, while a revolving football draws a spiral. However, he says he has never seen a non-linear meteor on a photograph. Shigeno [4] never saw a non-linear meteor either, although he made double-station observations and measured more than 1 000 meteors recorded by photography and TV. *Sky and Telescope* [5] published an example of a photographed spiral meteor trail. Suzuki [6] sketched a spiral meteor train which he observed with binoculars. Figure 1 shows this sketch. To check this phenomenon, Toda has continued photographic observations. On November 17, 1997, Toda successfully observed a spiral meteor train in the Leonids. This is a double-station observation, together with Kobayashi. Based on this meteor train observed at two stations, our report analyzes a spiral shape and discusses the mechanism of a non-linear meteor trail.

2. Observation

Figure 2 shows the photograph of a spiral meteor train where the train becomes spiral in the middle and returns to linear again. This meteor train was not observed at both stations, although this one appeared two minutes after the double-station meteor analyzed here. Figure 3 shows the photo of the double-station observation. Since the meteor train was about 250 km away from the stations, we were not able to determine the fine structure, but the spiral shape could be measured.

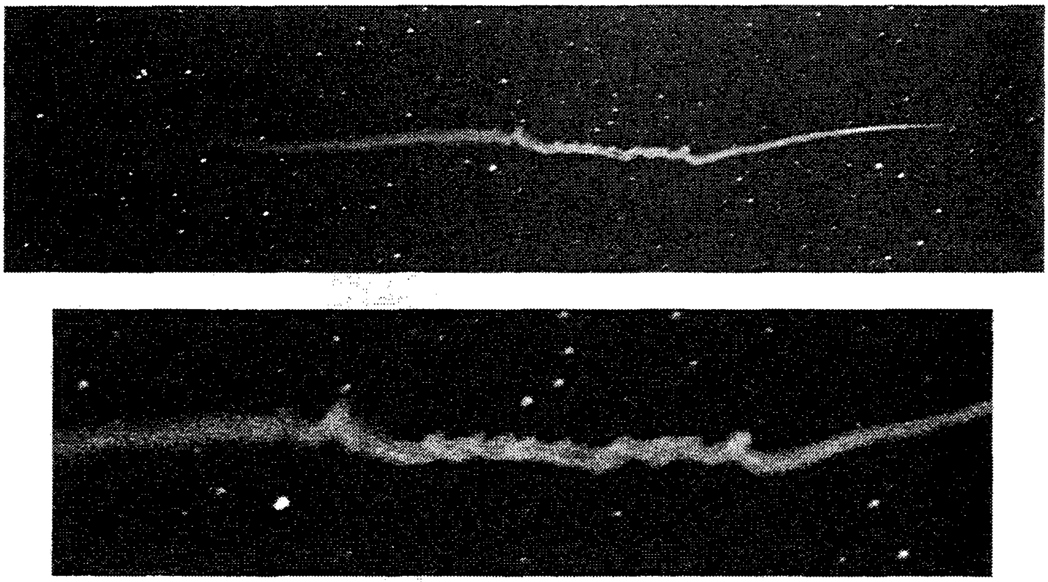

Figure 2 – A magnitude −3 Leonid meteor appeared at $17^h44^m47^s$ UT on November 17, 1997. The photograph taken by M. Toda shows the meteor train from $17^h44^m56^s$ to $17^h45^m00^s$ UT, as well as an enlargement. The photograph was taken with a Nikon F4s, $f = 200$ mm, $f/2.0$, on Fuji HR1600 film.

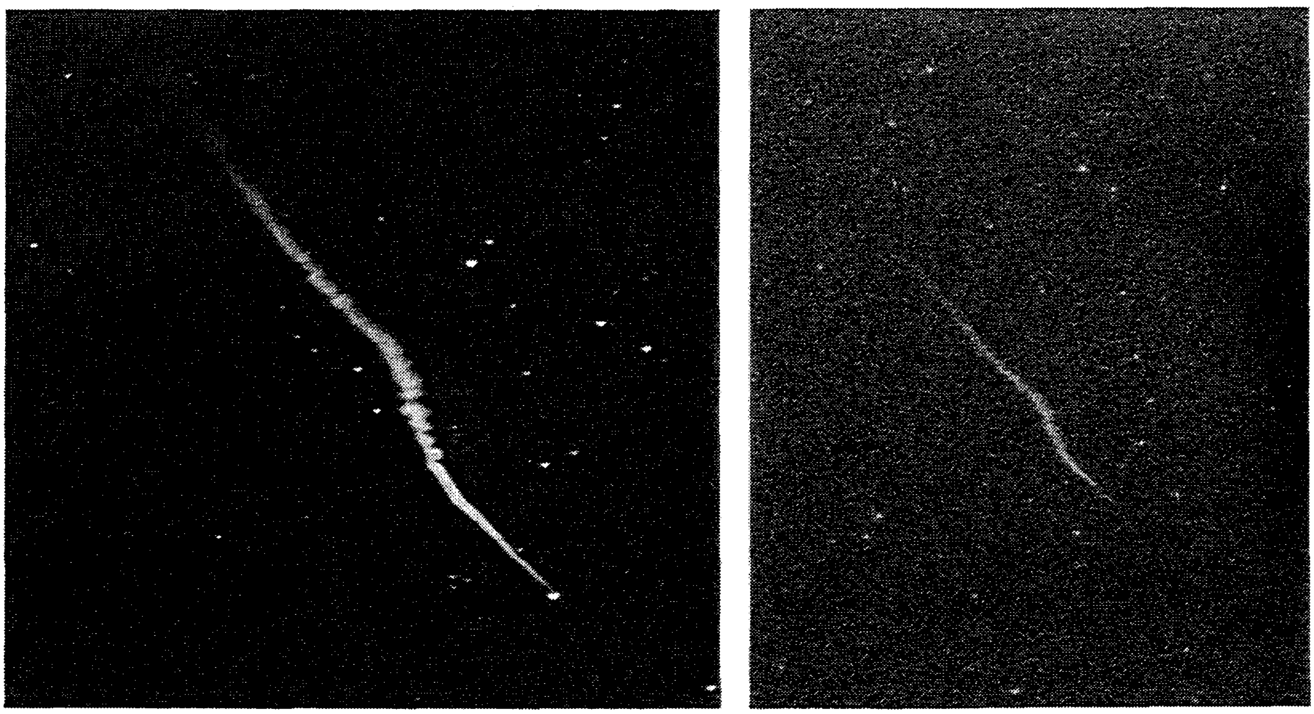

Figure 3 – This magnitude −4 Leonid meteor appeared at $17^h42^m26^s$ UT on November 17, 1997. *Left*: Meteor train photographed by M. Toda from $17^h42^m35^s$ to $17^h42^m39^s$ UT, with a Nikon F4s $f = 200$ mm, $f/2.0$, on Fuji HR1600 film. *Right*: Meteor train photographed by M. Kobayashi from $17^h42^m36^s$ to $17^h42^m40^s$ UT, with a Nikon F3 $f = 85$ mm, $f/1.4$, on Konica GX3200 film.

Table 1 lists the measurement results. The distance between the two stations was 72.0 km. The train began at a height of 102.2 km and the spiral at 97.7 km. The first measured point of the spiral was at a height of 95.0 km. The spiral disappeared at a height of 92.8 km and the train ended at 89.1 km. In Table 1, the distance in the direction of motion between two spiral cycles is L_s, the spiral cycle time is P_s (with an assumed Leonid velocity of 72 km/s, according to Lindblad [7]), and the spiral diameter is D_s. As a result, the spiral was found to draw circles of 461 m in diameter at 4.17-ms cycles.

Table 1 – Positions of the meteor train. Location of observer 1: Mt. Fuji, halfway-point; location of observer 2: Mt. Yatsugatake. For explanation of the symbols, please refer to the text.

	λ (° E)	φ (° N)	h (km)	L_s (m)	P_s (ms)	D_s (m)
Obs. 1 location	138.79861	35.33333	1.420			
Obs. 2 location	138.36694	35.87813	1.049			
Train begin	140.92983	34.23761	102.202			
Spiral begin	140.89171	34.23332	97.701			
Spiral 0	140.86089	34.23217	94.987			
Spiral 1	140.86057	34.23110	94.680	331	4.59	438
Spiral 2	140.86023	34.22999	94.358	345	4.79	439
Spiral 3	140.86001	34.22923	94.140	234	3.26	405
Spiral 4	140.85970	34.22821	93.845	317	4.41	488
Spiral 5	140.85941	34.22722	93.560	306	4.25	561
Spiral 6	140.85911	34.22623	93.275	306	4.25	493
Spiral 7	140.85881	34.22521	92.984	314	4.36	504
Spiral end	140.85857	34.22442	92.755	247	3.43	358
Train end	140.81869	34.22507	89.100			
Spiral mean				300	4.17	461
Spiral SD				39	0.54	64

3. Discussion

If a spiral is assumed to be the result of a rotational movement of a meteoroid around an external axis, the centrifugal acceleration becomes

$$r\omega^2 = 3.1 \times 10^8 \text{ m s}^{-2}, \tag{1}$$

where r is the "orbital" radius and ω is the angular velocity. The radius of the spiral is half the diameter D_s of the spiral minus half the diameter of the train. In our case this amounts to (461 m − 185 m)/2. This calculation ended in an unreasonable large value for the centrifugal acceleration.

Then, the drag that the meteoroid received from the atmosphere was calculated. The absolute magnitude of the meteor was determined from the observed magnitude of −4 to be −5.5. By using the formula of Nagasawa [8], the meteoroid mass was calculated to be 5.8 g. The meteoroid density was 0.6 g/cm^3 [9] and the meteoroid diameter was 26 mm. Recently, Babadzhanov [10] determined the density of the Leonids to be 2.5 g/cm^3, but this result does not change the conclusion of this report.

To calculate the atmospheric drag F, the following formula of Barger and Olsson [11] was used:

$$F = -0.5 \times C_D \times S \times \varrho_a \times V^2 = -2.2 \text{ kg m s}^{-2}. \tag{2}$$

Here, C_D is the drag coefficient (assumed value $C_D = 1.0$), S is the cross-section area of the meteoroid, ϱ_a is the atmospheric density (1.6×10^{-6} kg/m^3), and V is the meteor velocity (72 km/s). The value of C_D is 0.4 when a sphere moves through the atmospheric density at the ground. However, it is assumed $C_D = 1.0$, because the atmospheric density is very low in the height level considered here. As to ϱ_a, the atmospheric density at 94 km high was calculated using Terada's formula [12] derived from the U.S. Standard Atmosphere [13]. Strictly speaking, equation (2) pertains only to a meteoroid moving at a sub-sonic velocity through the atmospheric density at the ground, but is usable for the purpose of this report.

From this drag force, the meteoroid receives an acceleration of $-380\ \mathrm{m\,s^{-2}}$. The meteor velocity decreases by about 38 m/s if this acceleration acts for 0.1 second. This value is plausible as an atmospheric acceleration. Compared to the atmospheric drag in equation (2), the acceleration in (1) is too large. This means that the meteoroid itself was not moving along a spiral trajectory. So we have to assume that only the gas of the meteoroid train was in a spiral. This reminds us of the spiral jet of a comet (Sekanina [14]), although the mechanism may be different. The spiral train forming mechanism is discussed here.

The Knudsen number, Kn (Nanbu [15]) can be calculated as follows:

$$\mathrm{Kn} = \lambda/L = 2.2, \tag{3}$$

where λ is the mean free path (56 mm) in the atmosphere at 94 km height and L is the object size (26 mm). If the Knudsen number is 0.01 or higher, the atmosphere is regarded as a thin gas. This means the spiral train was formed synchronously with the rotation of the meteoroid.

However, since the gas emitted from the meteoroid seems more dense than the atmosphere, a whirl is generated behind the meteoroid. The whirl turns as the meteoroid revolves while emitting gas spirally. In this case, the revolution velocity of the meteoroid is faster than that of the spiral train.

If we assume that the thickness of the gas flow immediately after the meteor is equal to the cross-section of the meteoroid, and take into account the path length of the meteor, which is 16.7 km, we obtain a gas density of $6.6 \times 10^{-4}\ \mathrm{kg/m^3}$, about 400 times the atmospheric density.

We cannot tell which of the above cases the current observation belongs to. The fact that the spiral begins and ends along the trail may give a hint to the solution. In the remainder of this article, we discuss curving and branching meteors.

We first consider the possibility of a meteor trail to be bended by a force orthogonal to the direction of the above meteor. For example, a force of $580\ \mathrm{kg\,m\,s^{-2}}$ gives a velocity of 10 km/s after 0.1 second. Since the atmospheric drag is as in formula (2), however, such a great bending is not possible. As the atmosphere is a thin gas at high altitude, a bending force hardly occurs, even when the meteoroid is revolving.

How about a branching meteor trail? In Figure 4, one rotating meteoroid splits into two parts which moves in different directions. To change the direction of a Leonid meteor (72 km/s) by 15°, for example, the meteor must be moved at a rate of 19.3 km/s perpendicularly to the direction of the meteor. Two mass points immediately before the splitting are 2 cm away and revolve around each other. The number of revolutions needed for a tangential speed of 19.3 km/s is 3.1×10^5 per second. If the mass at each mass point is 1 g, the centrifugal force involved is $3.7 \times 10^7\ \mathrm{kg\,m\,s^{-2}}$. This force is large enough to split the meteoroid well before the aforementioned high number of revolutions is reached. Therefore, we cannot say that splitting by revolutions causes the meteor trail to branch.

Another possible cause for branching is the explosion of the high-temperature meteoroid. However, it is difficult to see how an an explosion yielding accelerations of several tens of kilometers per second does not produce jetting.

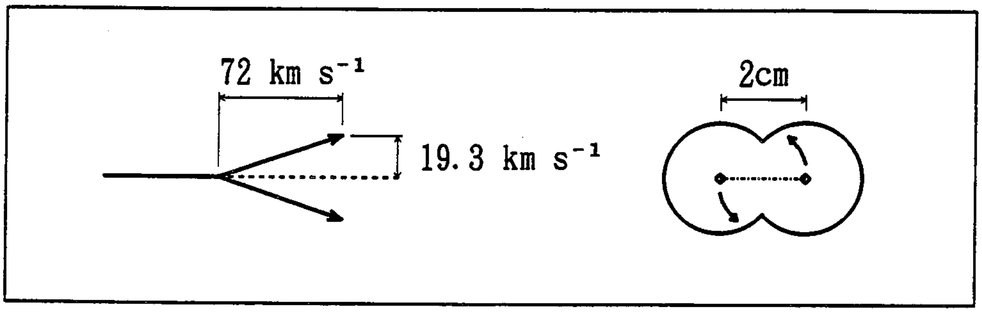

Figure 4 – The branching meteor trail.

Shigeno witnessed a split fireball at $14^h30^m14^s$ UT on August 12, 1975. The fireball was a slow sporadic meteor of magnitude −1. The red meteor lasted for 7 seconds. A single light spot split into a leading light spot and a following light spot on the same trail. Although this meteor was photographed, the photograph does not show splitting, because both light spots continued to follow the same trail.

The phenomenon observed by Shigeno can be explained as follows:

1. the leading light spot is the body of the meteoroid; and
2. the following light spot is a cloud of particles separated from the main body.

The atmospheric drag decelerates a decomposed meteoroid drastically. With equation (2), the diameter of particles decelerating 10% in 0.1 second is calculated. If the meteoroid density is 1 g/cm^3, the atmospheric density (ϱ_a) is $2 \cdot 10^{-5}$ kg/m^3 (altitude: 80 km), and the meteor velocity V is 20 km/s, then the particle diameter is 0.3 mm.

4. Conclusion

Roughly speaking, the atmospheric pressure at 100 km height is about one millionth of that on the ground. The velocity of the meteor is about 1000 times that of a baseball. Since the atmospheric drag is directly proportional to the the square of the velocity, the meteor receives almost the same drag as a baseball does. However, since the kinetic energy per unit of mass is about one million times bigger, the atmospheric drag cannot change the meteoroid motion greatly.

Is a curve or bend of a meteor trail an illusion? When you draw a straight line with a pen, your arm muscles extend and contract continuously. However, since your muscles extend or contract not smoothly but intermittently, the line becomes zigzag. Many of you may have encountered this experience. If you keep tracking a moving meteor with your eyes, the eye muscles extend and contract intermittently and do not move the eyes smoothly. This may end in the zigzag observation of a meteor.

This report clarified the spiral shape of a meteor train and indicated that a meteoroid may be revolving. Rather many meteor trains may be spiral-shaped, although not many spiral meteor trains have been observed. If a spiral train is photographed with a low-resolution camera, the photos may show fine light and shade repeatedly. Because of the long exposure, the spiral train will be photographed in the form of many stripes.

A study on other curved or bended meteor trails ended in a pessimistic conclusion. A meteor further splitting and branching into two trails could not be explained at all. Curving, bending, or branching meteor trails require further studies.

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References

[1] M. Beech, "Non-linear Meteor Trails", *Earth, Moon and Planets* 42, 1988, pp. 185–199.

[2] M. Beech, "Meteors Off The Straight And Narrow", *Astronomy Now*, August 1989, pp. 18–20.

[3] M. Beech, "Non-Linear Meteor Trails", *WGN* 20:1, February 1992, pp. 2–3.

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

[5] "News Notes: Spinning Meteors", *Sky & Telescope* 77, January 1989, pp. 11–12.

[6] K. Suzuki, *Proceedings of the Meteor Science Seminar* 2/2, 1982, p. 80.

[7] B.A. Lindblad, "Physics and Orbits of Meteoroids", in *The Evolution of Small Bodies of the Solar System*, Soc. Italiana di Fisica Bologna, 1987, pp. 229–251.
[8] K. Nagasawa, "Approach the meteor", *Chijin-Shokan*, 1972, p. 50.
[9] F. Verniani, "Meteor Masses and Luminosity", *Smiths. Contr. Astrophys.* 10, 1967, pp. 181–195.
[10] P.B. Babadzhanov, "Quasicontinuous Fragmentation and Meteoroid Density", *Astronomicheskij Vestnik* 26-5, 1992, pp. 80–84.
[11] V. Barger, M. Olsson, "Classical Mechanics", McGraw Hill, 1973.
[12] M. Terada, in *Meteor-II, Kousei-sha Kousei-kaku*, K. Saito, K. Nagasawa, eds., 1984, p. 63.
[13] "U.S. Standard Atmosphere", Prepared under NASA, USAF, and USWB, U.S. Government Printing Office, Washington, D.C., 1962, p. 278.
[14] Z. Sekanina, "Anisotropic Emission from Comets: Fans versus Jets", in *Proc. Symposium on the Diversity and Similarity of Comets*, ESA SP-278, 1987, pp. 315–336.
[15] K. Nanbu, "Numerical Fluid Dynamics", M. Yasuhara, H. Daiguji, eds., Tokyo Univ. Publ., 1992, p. 288.

Observational Results

SPA Meteor Section Results: March–April 1998

Alastair McBeath

News and results submitted to the *SPA Meteor Section* from March and April 1998, are discussed. March 15 produced a notably brilliant meteor for south-west England. Relatively few observers recorded any Lyrids because of poor weather, but radio and some visual data support a broad maximum on April 22, without an obvious sharp peak. Some confirmation of two Virginid radiant areas previously found was possible during March and April, and another weak radiant was suspected during early March. Some low early η-Aquarid rates were detected in late April.

1. Introduction

Weather conditions seem to have been generally unfavorable during these two months, and many observers struggled to see anything at all, at least in the northern hemisphere. In South Africa, conditions seem to have been much better, permitting Tim Cooper to carry out some very useful monitoring of several minor showers, most notably the Virginids. Table 1 shows the overall observing tallies possible.

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

Month	Visual	VIR	LYR	ETA	SAG	Meteors	Photo	Radio
March	$76^{h}.7$	48				409	112^{h}	2633^{h}
April	$92^{h}.8$	22	200	17	31	721	7^{h}	3054^{h}

Photographic observations came from *Arbeitskreis Meteore* (*AKM*) members Ina Rendtel, Jürgen Rendtel, Roland Winkler, and Jörg Strunk, all in Germany, with one trail so far discovered on their all-sky fireball patrol negatives, a fireball on April 19-20. Along with all the *AKM* details here, these were extracted from the *AKM*'s journal Meteoros, issues 4 and 5 (1998), thoughtfully submitted by Ina Rendtel.

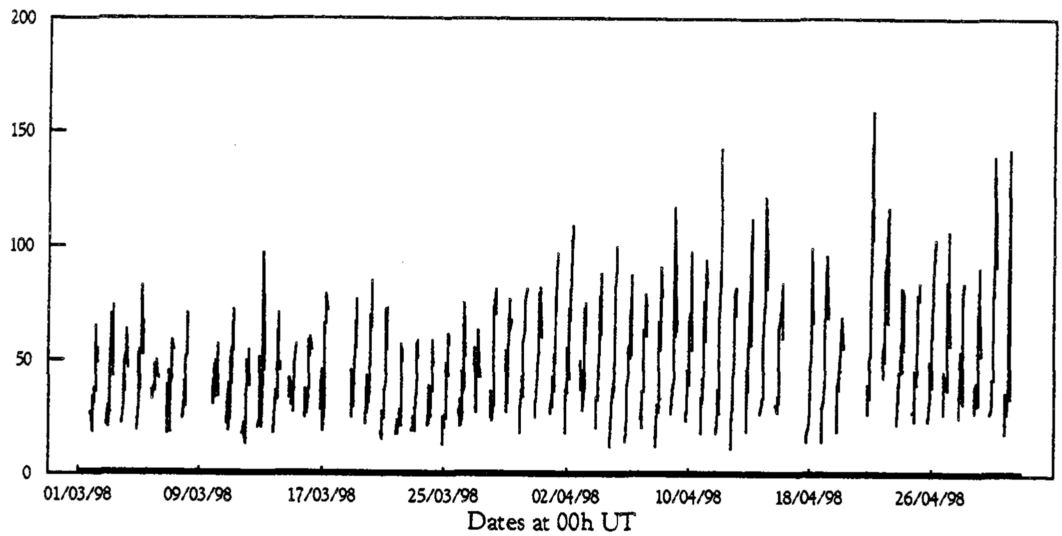

Figure 1 – Raw hourly radio meteor echo counts during March and April 1998, from data collected by Maurice de Meyere. Maurice's set-up was generally operated for 11h daily between 21^h and 8^h UT for most of March, then between 20^h and 7^h UT in late March and during all of April. Rates noted as possibly affected by Sporadic-E have been removed from the data presented here, and the equipment was not operated at all on March 8-9 and 17-18, April 16-17, and 20-21.

All of this time's radio data were extracted from *Radio Meteor Observation Bulletins* 56 (April 1998) and 57 (May 1998), kindly provided by Christian Steyaert. The radio observers included

> Enric Fraile Algeciras (Spain), Michael Boschat (Canada), Maurice de Meyere (Belgium), Ghent University (Belgium), Will Kelsey (California, USA), Werfried Kuneth (Austria), Sadao Okamoto (Japan), Chikara Shimoda (Japan), and Ilkka Yrjölä (Finland).

Our by now standard practices for analyzing raw radio results were utilized, as previously discussed, and a graph showing the overall trends in March-April radio meteor activity from Maurice de Meyere's data was chosen as generally representative; see Figure 1.

Last, but by no means least, our visual observers were

> *AKM* members Matthias Growe, Ralf Kuschnik, Sylvio Lachmann, Hartwig Lüthen, Sirko Molau, Sven Näther (also in Malta), Jürgen Rendtel, Petra Rendtel, Janko Richter, Thomas Schreyer, Harald Seifert, Roland Winkler, all in Germany except where noted, Jay Brausch (North Dakota, USA), Tim Cooper (South Africa), Shelagh Godwin (England), Bob Lunsford (California, USA), and Tony Markham (England).

2. March

March is usually considered a quiet month, meteorically, and so it proved this year, in general terms. Most of the visual observations were confined to the latter half of the month, and recorded generally weak Virginid rates along with the sporadics. Tim Cooper in particular submitted most of the 161 meteor plots received as part of the Section's early year Virginid plotting project during March and April. Tim's data suggests a possible very weak radiant around $\alpha = 181°$ and $\delta = +03°$ (both parameters $\pm 2°$) in the opening days of March, and provides a rather stronger confirmation of Area 6 found in the Section's 1988–1992 Virginid analysis [1], active from late March into early April (radiant center approximately at $\alpha = 195°$ and $\delta = -10°$, but elongated in right ascension).

On March 15 at around 19^h00^m UT (still during evening twilight), a very bright fireball was reported from sites along the southern coast of the south-west peninsula of England. Unfortunately, the evening seems to have been generally cloudy, and the few eye-witness reports received are of a brilliant object in clouds. Very few sightings of the meteor itself appeared even in media reports submitted by several Section correspondents. Just to confuse matters, a small boat was in difficulties off the Devon coast, and some of the reports were clearly of the distress flares shot up by the stranded crew. Too few usable sightings are on-hand to permit an approximate ground track to be established, but a flight path roughly parallel to the coast, probably out over the English Channel, and moving south-west to north-east can be implied. A second fireball was reported by one observer at around 19^h45^m UT in southern England, and several other possible fireballs were suspected, as often seems to happen when a bolide occurs.

Concerning radio activity in comparison with recent years [2], the latter stages of the (eq. 2000.0) $\lambda_\odot = 333°$–$342°$ period were confirmed, but did not seem to extend to $\lambda_\odot = 342°$ this year. Other confirmed peaks were at $\lambda_\odot = 344°$ (and, weakly, $\lambda_\odot = 343°$, too), $\lambda_\odot = 346°$ (again extending to $\lambda_\odot = 347°$), $\lambda_\odot = 350°$ (also $\lambda_\odot = 349°$ and weakly extending to $\lambda_\odot = 351°$–$352°$ in several data sets), $\lambda_\odot = 352°$–$355°$ ($\lambda_\odot = 354°$ only weakly), $\lambda_\odot = 357°$–$358°$ (including $\lambda_\odot = 356°$ in some reports), $\lambda_\odot = 0°$–$4°$ (especially $\lambda_\odot = 359°$ from the extended period; $\lambda_\odot = 1°$ was relatively marked in the Japanese data, but rates were poor over Europe then), and $\lambda_\odot = 6°$–$11°$ (the extended $\lambda_\odot = 7°$–$8°$ spell; most observers confirmed a peak around $\lambda_\odot = 5°$–$8°$ or $\lambda_\odot = 9°$, but extensions beyond $\lambda_\odot = 10°$ were uniformly weak, with the sole exception of one at $\lambda_\odot = 12°$ not previously found, which was detected by almost all operators).

3. April

Although visual observations were generally concentrated in the third week of the month, Lyrid coverage was very patchy, due to some poor weather at the wrong time. Preliminary visual data [3] suggest there was no sharp maximum in Lyrid rates on April 22 this year, which is loosely supported by the few *SPAMS* visual watches then. Stronger support comes from the radio data, where activity was enhanced from $\lambda_\odot = 30°$–$33°$, as has been found previously [2], with virtually all observers in Europe, North America, and Japan registering a distinct peak at $\lambda_\odot \approx 32°$, roughly coincident with the shower's best observability for their respective sites. As Figure 1 illustrates, activity the following day was only a little diminished, and several observers detected comparable echo counts to this post-maximum phase the day before the Lyrid maximum as well. Too few visual Lyrids were reported to allow a full magnitude and train analysis, but their corrected mean magnitude was +1.7 (49 meteors; mean limiting magnitude of +6.4) compared to the April sporadics' value of +3.3 (80 meteors; mean limiting magnitude of +5.9), with 6.1% of Lyrids leaving a train. No trained sporadics were noted.

Some further Virginids were seen during the month, and Tim Cooper's meteor plotting was able to weakly confirm Area 9 found in earlier *SPAMS* data [1] during mid-April, with a radiant centered on $\alpha = 188°$, $\delta = +03°$. Tim also detected rising η-Aquarid activity towards the end of April, with ZHRs of 5–15 ± 3–5 by April's close. This increasing activity was also seen in the radio results. Some weak early Sagittarid rates were noted by several observers too.

Further correlation of the April radio data with [2] confirmed the following peaks: $\lambda_\odot = 14°$–$19°$ (with $\lambda_\odot = 16°$–$19°$ seen in almost all data sets, and $\lambda_\odot = 15°$ confirmed by half the active observers), $\lambda_\odot = 22°$–$24°$ (mostly $\lambda_\odot = 22°$–$23°$, but one data set also showed $\lambda_\odot = 21°$), $\lambda_\odot = 25°$–$27°$ ($\lambda_\odot = 26°$ in Japanese data only, and $\lambda_\odot = 27°$ in just one dataset), $\lambda_\odot = 34°$–$41°$ (the extended $\lambda_\odot = 34°$ and $\lambda_\odot = 40°$ periods, most especially $\lambda_\odot = 39°$–$40°$). The minor peak at $\lambda_\odot = 20°$ was not found this year.

Acknowledgments

As always, I take this opportunity to send many thanks to all the observers and correspondents who have continued to provide such welcome and encouraging support to the Section. Clear skies for your observing!

References

[1] A. McBeath, "UK Visual Results for the Virginids, 1988–1992", *WGN* 20:6, December 1992, pp. 226–237.

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

[3] R. Arlt, "Lyriden 1998", *Meteoros* 1:5, 1998, p. 100.

Outburst of June Bootids over Italy

Roberto Haver and Roberto Gorelli

An overview is given of Italian observations of the 1998 June Bootid outburst.

During the month of June, the weather in Italy was fine and, in spite of summer solstice, there are more than 4 hours of darkness between the end of twilight and the beginning of dawn. Due to the New Moon of June 24, we scheduled observations in the weekend of June 26–29 in order to monitor meteor activity during a period of the year that is usually poorly covered in the Northern Hemisphere. We chose for our observing site Frasso Sabino, 50 km northwest of Rome, site of the *Associazione Romana Astrofili* astronomical observatory.

On Friday evening, June 26, the sky was fairly good, and, in about 4 hours, we observed several meteors, most of them quite slow, and took many pictures. Once at home, on Saturday June 27, the observers realized they observed an anomalous number of slow meteors whose radiant was located between Bootes and Draco. We guessed that the phenomenon was due to unexpected June Bootid activity; the ZHR was around 7. After consulting the available bibliography, we found out that this radiant has not been active at this ZHR level since many tens of years. On June 27, at about 18^{h} UT, we sent a message to the *IMO* in order to inform that a small outburst was probably still in course; the same advice was sent to the observers of the *Union of Italian Amateur Astronomers'* Meteor Section.

On Saturday evening, June 27, at the end of twilight, we saw a high number of bright and slow meteors coming from the same radiant, and this accelerated the preparations for our observations: in 20 minutes, we were ready to take pictures and observe the whole sky. The number of meteors was high, and many of them were fairly slow, slower than Capricornids or κ-Cygnids; a couple of Italian amateur astronomers, who witnessed an analog phenomenon in the same night, even though under different weather conditions, confirmed our evaluations.

The next morning, June 28, we advised the *IMO* via Internet as soon as we arrived in Rome, even though it was too late to alert the observers in Europe or on the East Coast of the United States, so we at least also sent a message to observers in California.

On Sunday evening, June 28 only one amateur astronomer of our group could continue the observations from Frasso Sabino; another one joined the observation program from Sardinia. The result was quite discouraging: the activity was reduced and the meteors from Bootes had all but disappeared.

Table 1 shows our observations and those of three amateur astronomers who watched the phenomenon from different places in Italy and under different meteorological conditions during those days.

Making an analysis of June Bootid meteors, both observed and photographed, we noticed that one quarter of them was yellow, and some were bright blue. About 7% of the June Bootid meteors left a short-duration train. Some had flares, as our pictures show: on 14 photographs of meteors taken (using 24 mm and 28 mm lenses at $f/4.0$ on Kodak T-Max 3200 film, developed at 1600 ASA) 4 of them have small flares. The brightest of them (magnitude -1.5) had even three flares.

In analyzing our photographical work, we have estimated the average position of the radiant: $\alpha = 230\overset{\circ}{.}5$ and $\delta = +49\overset{\circ}{.}5$ (eq. 2000.0), in which the meteors are all gathered in 4°. We adopted this position to calculate ZHRs rather than calculating the radiant positions from the visual plottings.

From Table 2, showing the magnitude distribution, we can infer a lack of bright meteors and a good number of weak objects.

Table 1 – Italian observations of the June Bootids (Stefano Crivello (CRIST), Massimo Dionisi (DIOMA), Roberto Gorelli (GORRO), Roberto Haver (HAVRO), and Enrico Stomeo (STOEN)).

Date	Period (UT)	Obs	T_{eff}	Lm	F	JBO	SPO	DIV
June 26-27	21^h20^m–22^h20^m	HAVRO	$0\overset{h}{.}87$	5.90	1.00	3	8	1
June 26-27	21^h20^m–22^h20^m	GORRO	$0\overset{h}{.}89$	5.50	1.00	3	4	3
June 26-27	22^h20^m–23^h20^m	HAVRO	$0\overset{h}{.}88$	6.00	1.00	2	7	2
June 26-27	22^h20^m–23^h20^m	GORRO	$0\overset{h}{.}89$	5.50	1.00	4	3	3
June 26-27	23^h30^m–00^h30^m	HAVRO	$0\overset{h}{.}92$	6.00	1.00	0	6	1
June 26-27	23^h30^m–00^h30^m	GORRO	$0\overset{h}{.}93$	5.50	1.00	0	6	0
June 26-27	00^h30^m–01^h30^m	HAVRO	$0\overset{h}{.}84$	6.00	1.00	3	9	2
June 26-27	00^h30^m–01^h30^m	GORRO	$0\overset{h}{.}92$	5.50	1.00	2	4	1
June 27-28	20^h58^m–22^h00^m	CRIST	$0\overset{h}{.}87$	5.80	1.17	20	3	0
June 27-28	21^h10^m–22^h00^m	STOEN	$0\overset{h}{.}78$	5.20	1.10	6	2	1
June 27-28	21^h20^m–22^h20^m	HAVRO	$0\overset{h}{.}60$	6.00	1.00	31	4	1
June 27-28	21^h20^m–22^h20^m	GORRO	$0\overset{h}{.}77$	5.50	1.00	31	2	0
June 27-28	22^h00^m–22^h38^m	CRIST	$0\overset{h}{.}58$	5.80	1.17	6	2	0
June 27-28	22^h20^m–23^h20^m	HAVRO	$0\overset{h}{.}63$	6.00	1.00	28	3	2
June 27-28	22^h20^m–23^h20^m	GORRO	$0\overset{h}{.}79$	5.50	1.00	21	3	1
June 27-28	23^h20^m–00^h20^m	HAVRO	$0\overset{h}{.}70$	6.00	1.00	18	7	2
June 27-28	23^h20^m–00^h20^m	GORRO	$0\overset{h}{.}74$	5.50	1.00	16	10	1
June 27-28	00^h30^m–01^h30^m	HAVRO	$0\overset{h}{.}71$	6.00	1.00	11	14	1
June 27-28	00^h30^m–01^h30^m	GORRO	$0\overset{h}{.}84$	5.50	1.00	11	10	2
June 28-29	21^h00^m–22^h00^m	HAVRO	$0\overset{h}{.}91$	5.65	1.00	3	4	1
June 28-29	21^h30^m–22^h30^m	DIOMA	$0\overset{h}{.}98$	5.40	1.00	1	0	3
June 28-29	22^h00^m–23^h00^m	HAVRO	$0\overset{h}{.}91$	5.85	1.09	2	2	2
June 28-29	23^h00^m–23^h35^m	HAVRO	$0\overset{h}{.}90$	5.90	1.00	1	8	0
June 28-29	23^h00^m–00^h00^m	DIOMA	$0\overset{h}{.}97$	6.00	1.00	0	3	3
June 28-29	00^h00^m–00^h50^m	DIOMA	$0\overset{h}{.}81$	6.16	1.00	0	4	0
June 28-29	01^h10^m–02^h00^m	DIOMA	$0\overset{h}{.}79$	5.90	1.00	0	8	0
June 30-31	20^h55^m–21^h35^m	STOEN	$0\overset{h}{.}64$	5.32	1.00	2	5	1

Table 2 – Magnitude distributions pertaining to the Italian 1998 June Bootid observations.

Magnitude	−3	−2	−1	0	+1	+2	+3	+4	+5	Tot	$\overline{m}$
June Bootids	1	2.5	7	23	25.5	37.5	58	46.5	24	225	2.51
Sporadics		1	4.5	12	14.5	24	26	36.5	20.5	139	2.75

From the magnitude data, we obtained a first, approximate population index, $r = 2.9$. We adopted this value to calculate the ZHRs in Table 4. Some observations have not been considered for the final computation, because the corrections would have been too big.

From our data, we derive an activity profile that resembles the Perseids during their classical maximum; by the way, the maximum has been reached during our daylight, and has been seen in Japan.

The observations show a steep decrease in activity during the night of June 28-29. About 4 hours after the beginning of the observations that night, the ZHR had dropped to about half its original value, and during the first hours of June 28, activity had fallen further to the level of the night of June 26-27.

From our data, we derive that 22 hours passed between the beginning and the end of activity, with a maximum on June 28, around 15^h UT ($\lambda_\odot = 95\overset{\circ}{.}8$, eq. 2000.0).

Table 3 – Average ZHRs calculated for the Italian observations of the 1998 June Bootids. Solar longitudes refer to eq. 2000.0.

Date (UT)	$\lambda_\odot$	ZHR	Date (UT)	$\lambda_\odot$	ZHR
June 26.910	95°910	8.6 ± 3.5	June 28.042	96°186	50 ± 11
June 26.951	95°145	9.6 ± 3.9	June 28.906	97°010	6.0 ± 3.0
June 27.000	95°192	0	June 28.938	97°040	5.3 ± 3.7
June 27.042	95°232	9.4 ± 4.2	June 29.970	97°071	4.7 ± 4.7
June 27.910	96°059	109 ± 14	June 28.979	97°079	0
June 27.951	96°099	87 ± 12	June 29.017	97°116	0
June 27.993	96°139	69 ± 12	June 29.066	97°162	0

The *IAU Circular* 6966 reports that the orbital elements of the meteors, checked with the Skiymet meteor radar (35.24 MHz) at Saskatoon, Saskatchewan, Canada, are similar to those of Comet 7/P Pons-Winnecke. This is quite strange, considering the minimum distance between the orbit of the comet and that of the Earth (about 0.24 AU); besides, since 77 years, the comet's orbit is outside that of the Earth. Perhaps (this could be an explanation), a part of the dust coming from the comet has been perturbed, possibly at the beginning of the century, when the minimum distance Comet-Earth was only 0.03–0.04 AU, allowing the rendez-vous with the Earth. All this, of course, has to be demonstrated. Therefore, it is important that the activity of this shower is extensively monitored during the years to come, with all possible means (visual, photographic, video, and radar), even if activity turns out to be significantly reduced. Besides, the orbital parameters of the comet Pons-Winnecke show that the 1909 and 1916 passages were similar, so a big "rain of June Bootids" is conceivable; considering an annual displacement of 6 hours, the phenomenon should be visible from Western Europe and North America in 1999. Therefore, we invite all our colleagues to verify this possibility.

1997 and 1998 Perseids and Leonids

Eisse Pieter Bus

Summaries of radio observations by forward-scattering are given for the Perseids 1997 and 1998 (only reflections of more than 1 s) and the Leonids 1997. The reduction of the observations is the same as described in *WGN* 25:6 (1997), p. 248. All solar longitudes refer to equinox 2000.0. Also, summaries are given for prospects on the Leonids 1998 from results of recent recalculations of the Leonid activity in 1833, 1866, and 1966.

1. 1997 and 1998 Perseids

Radio observations at 72.11 MHz of the Perseids on August 12, 1997, show clearly the "new" and the "traditional" peak. Because of the unfavorable antenna geometry in 1998 for the "traditional" peak, only the "new" peak was observed. Since my observations started in 1994, only the peak of long-duration reflections (more than 1 second, which indicates a visually observable Perseid) shifted to later longitudes. That peak shifted gradually from about $\lambda_\odot = 139.^\circ50$ in 1994, to $\lambda_\odot = 139.^\circ65$ in 1995, $\lambda_\odot = 139.^\circ67$ in 1996, $\lambda_\odot = 139.^\circ69$ in 1997, and $\lambda_\odot = 139.^\circ72$ in 1998. It is very interesting to note that the solar longitude of the 1996, 1997, and 1998 long-duration reflections coincides with the position found by Lindblad and Porubčan [1] based on bright Perseids in the period 1937–1985.

The "traditional" peak in 1997 was observed at solar longitude $\lambda_\odot = 140.^\circ09$, at the same position as in 1996.

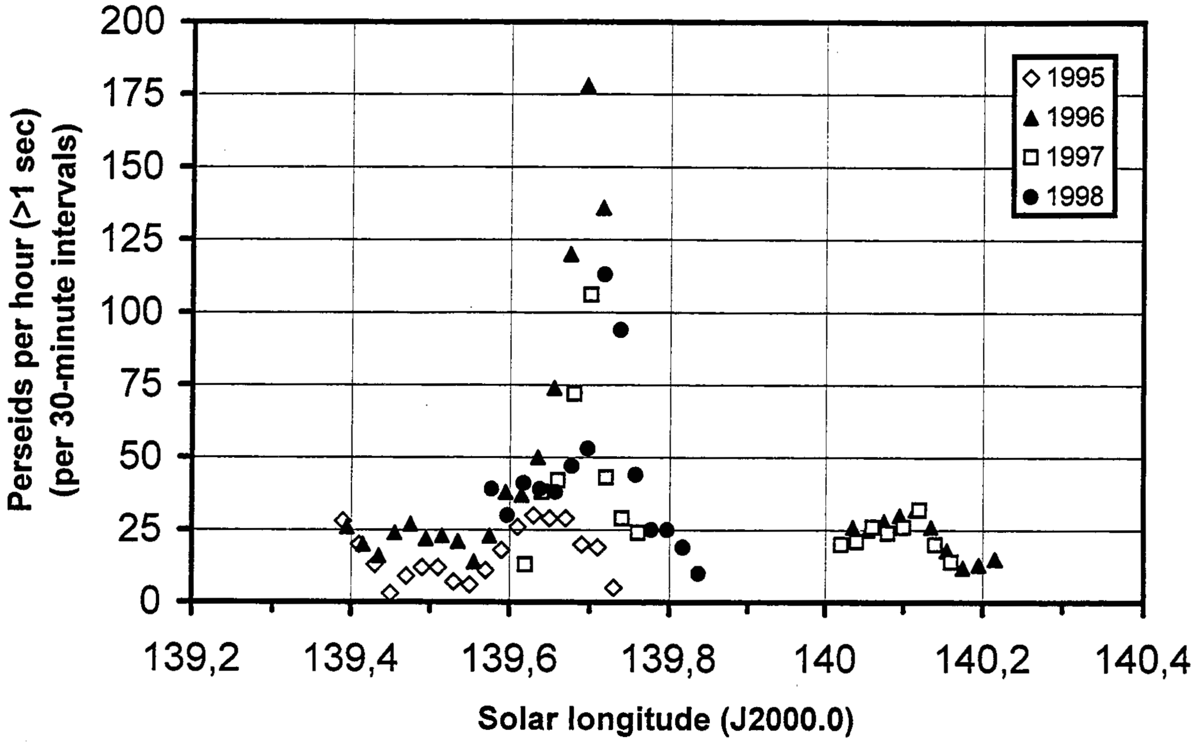

Figure 1 – Hourly Perseid radio rates of only long-duration reflections of more than 1 second. The "new" and the "traditional" peak on August 12, 1997 (open squares) only corrected for dead-time and sporadics. The "new" peak on August 12, 1998 (dots), corrected for dead-time, sporadics, and observability function after Hines [2]. Also, the results of 1995 (open diamonds) and 1996 (triangles) are given.

2. 1997 Leonids

The Leonids showed strong activity for the fourth year in a row. The radio observation period of the 1997 Leonids was from November 15 until November 18. On November 15, between 6^h and 11^h UT, the Leonids showed already clear signs of activity (more than 1 per hour). In the same observation period on November 16, there was some enhanced Leonid activity (more than 3 per hour). On November 17, the observation period was between 5^h and 14^h UT. During this period, 128 long-duration reflections of more than 7 seconds were monitored and 68 long-duration reflections of more than 20 seconds.

In 1997, only one peak was monitored around 10^h50^m UT on November 17 at solar longitude $\lambda_\odot = 235\overset{\circ}{.}16$. This is exactly at the same position as the first peak I observed in 1996. Activity around solar longitude $\lambda_\odot = 235\overset{\circ}{.}27$, observed as a narrow peak of high activity in 1996, was not observed in 1997 because of the very unfavorable antenna-geometry after 12^h UT (radiant is setting at about 13^h40^m UT). On November 18, between 6^h and 11^h UT, the activity of the shower was somewhat over 6 Leonids per hour.

Notes: In 1994, only long-duration reflections of more than 10 seconds were counted. Experience showed there are about 1.2 times more reflections of 7 seconds compared to 10-second reflections. The 1994 counts are not corrected for this factor. In 1994, 1995, and 1997 the observation frequency was 72.11 MHz. In 1996, I observed in Spain using the transmitter at Lousa in Portugal at a frequency of 87.9 MHz. Literature [3] gives an inverse quadratic relation between duration-time and frequency: a 7-second reflection at 72 MHz is equivalent to a 5-second reflection at 88 MHz.

3. Prospects on the 1998 Leonids

It appears there is a relation between the distance in the orbits of the Earth and Comet 55P/Tempel-Tuttle and the time of outbursts after the comet's node within a year after the comet's perihelion passage.

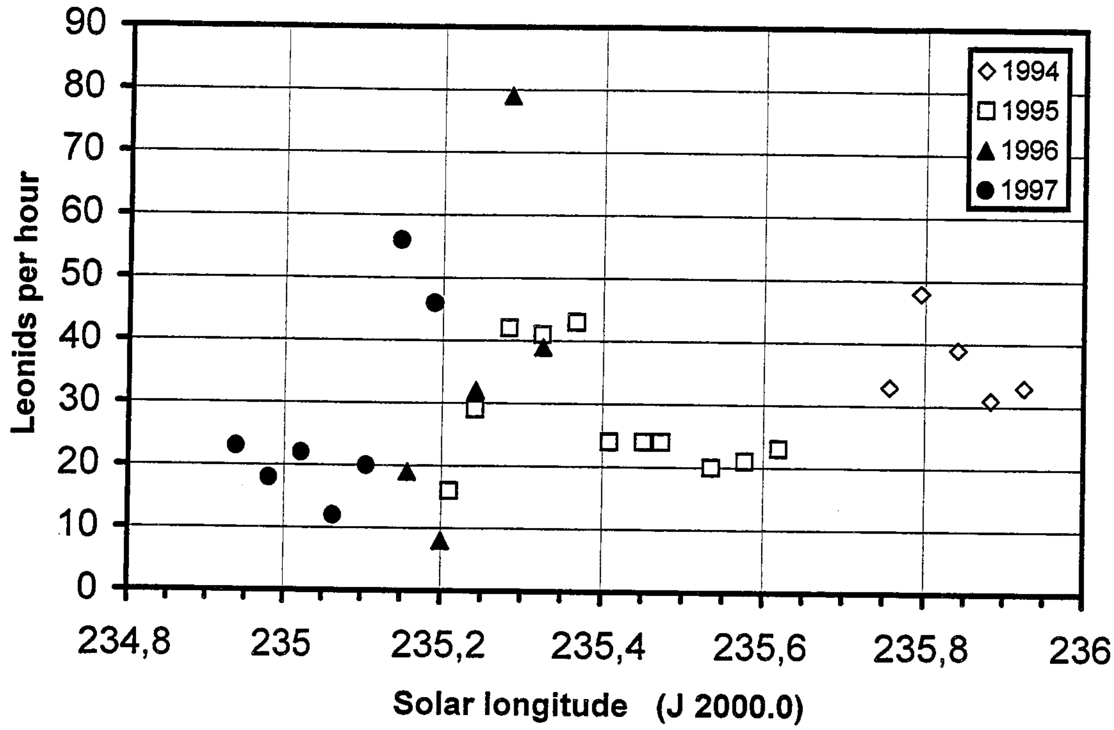

Figure 2 – Corrected counts for 60-minutes periods of the 1994 Leonids (open diamonds), the 1995 Leonids (filled squares), the 1996 Leonids (filled triangles), and the 1997 Leonids (open circles). Observations are corrected for dead-time, sporadics and observability function [2].

An extrapolation departing from the 1833, 1866, and 1966 peak positions, yields a predicted time for the outburst in 1998 on November 17 of about $21^h38^m \pm 12^m$ UT, around solar longitude $\lambda_\odot = 235\overset{\circ}{.}356 \pm 0\overset{\circ}{.}008$. However, a shift to a later time is not excluded. In principle, the window of opportunity stretches from about 21^h00^m until 22^h15^m UT. A first peak shortly before the comet's node is also very likely. Because the lack of well-documented observations of Leonid activity in 1833 and 1966, and the somewhat better documented observations of 1866, only an indication of the peak rates is given. An extrapolation departing from the 1833, 1866, and 1966 peak rates, yields an expected 1998 outburst rate most likely between 1 and 10 Leonids per second and probably around 4 ± 2 Leonids per second. However, a calculation by a model [4] gives a result of 6 Leonids per second. Because of the extrapolations, there is considerable room for deviations from the values given as a "best estimate" above.

Acknowledgment

The author would like to thank Ton Schoenmaker for his helpful comments.

References

[1] B.A. Lindblad, V. Porubčan, *Planet. Space Sci.* 42:2, 1994, pp. 117–122.

[2] C.O. Hines, *Can. Journ. Phys.* 22, 1955, pp. 493–503.

[3] D.W.R. McKinley, "Meteor Science and Engineering", New York, Toronto, London, 1961.

[4] D.K. Yeomans, K.K. Yau, P.R. Weissman, *Icarus* 124, 1996, pp. 407–413.

[5] I. Hasegawa, in *Meteoroids and their parent bodies*, J. Stohl and I.P. Williams (eds.), 1993, pp. 177–180.

[6] L. Kresák, *Astron. Astrophys.* 279, 1993, pp. 646–660.

[7] J.W. Mason, *J. Br. Astron. Assoc.* 105:5, 1995, pp. 219–235.

[8] D.K. Yeomans, *Icarus* 47, 1981, pp. 492–499.

[9] P. Jenniskens, *Astron. Astrophys.* 295, 1995, pp. 206–235.

[10] P. Jenniskens, *Meteoritics and Planetary Science* 31, 1996, pp. 177–184.

[11] P. Jenniskens, in *1996–98 Leonid Outburst Event Summary*, 1998, `http://web99.arc.nasa.gov/ leonid/1998.html`, 1998.

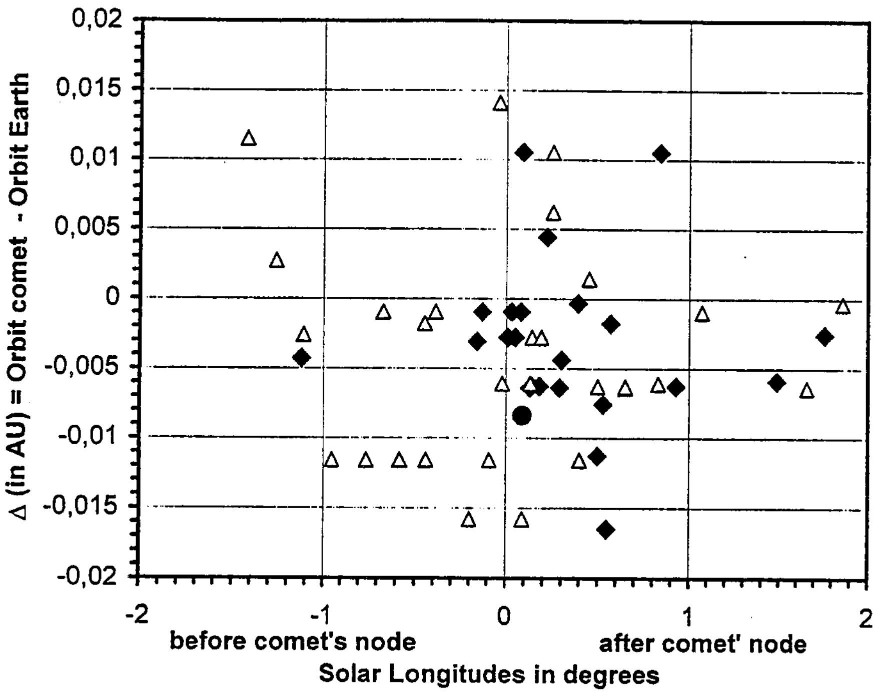

Figure 3 – The activity of the Leonids as given in the literature [5–8] around two days before and after the Earth crosses the comet's orbital plane. Most of the given times are, according to the authors, estimates, and is probably the cause of the high scatter and the very low correlation. "Storms" are marked by diamonds and "showers" or "high activity" by triangles. The dot represents the expected position of 1998. The trend of higher activity after the comet's node than before is clearly noticeable in the figure. The data of 1097, 1399, and 1800 are missing, because the day of maximum is very uncertain, and the date of 1582 is missing because the given day is 11.5 days after the node. This day is probably wrong because of the Gregorian calendar reform in that year, wereby October 4, 1582, is followed by October 15, 1582.

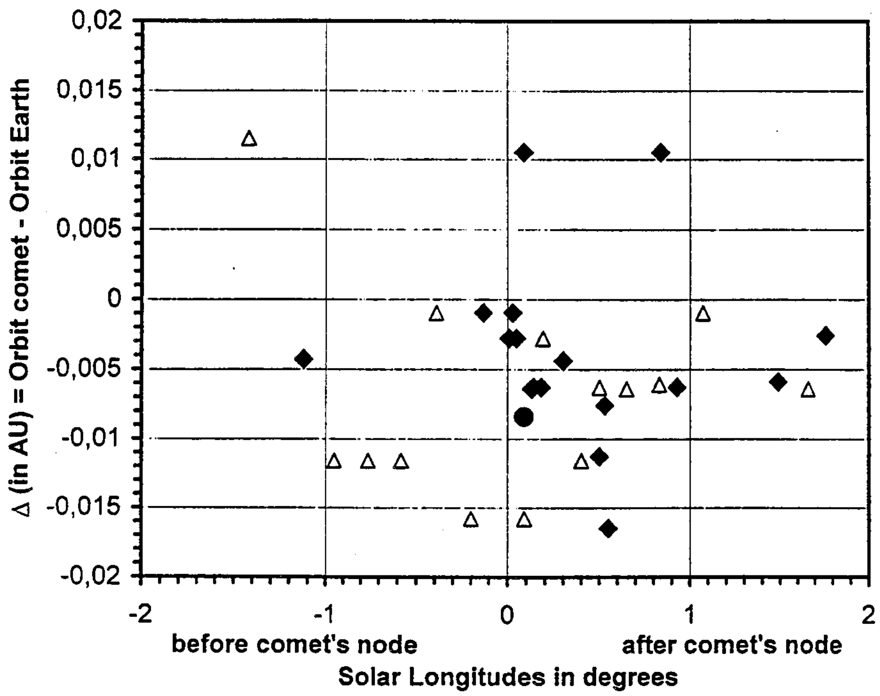

Figure 4 – Same as Figure 3, except that only data after the comet's perihelion passage are taken into account.

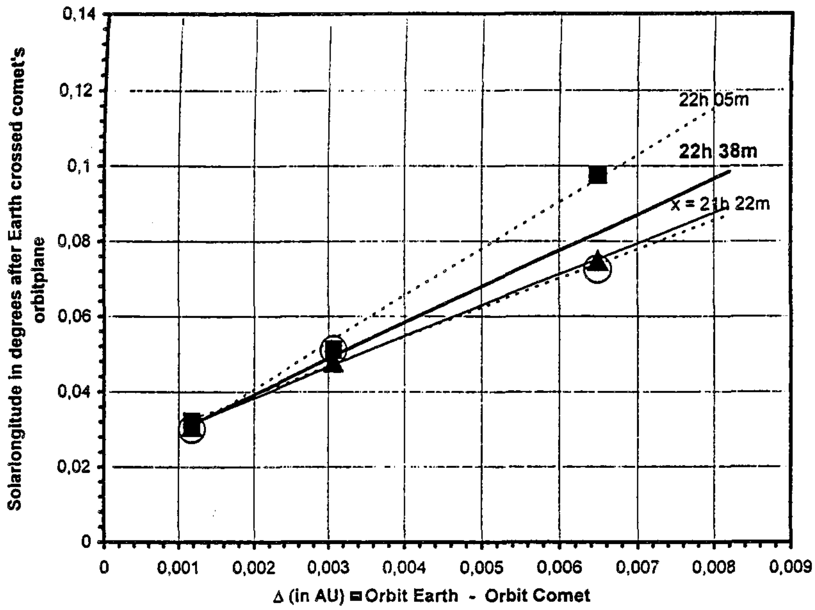

Figure 5 – Correlation between comet and Earth orbital distance and the time of maximum activity of the Leonids after the comet's node within a year after perihelion passage of the comet. The bold line represents the mean result between the different analyses: squares represent the analysis of Kresák [6], open circles the analysis of Jenniskens [9–11], and triangles the analysis in this paper.

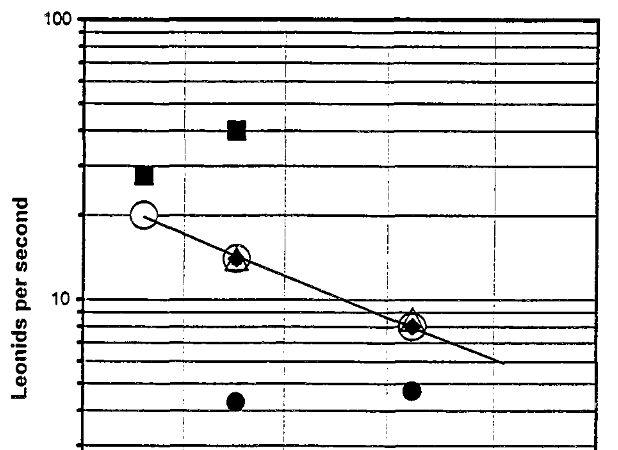

Figure 6 – Relation between the number of Leonids per second at peak activity and the orbital distance between the Earth and the comet. The line represents the results of the model [4] (open circles). The squares represent the analysis of Kresák [6], dots represent the analysis of Jenniskens [9–11], diamonds represent the analysis of Langbroek [12–13], and triangles represent the analysis in this paper.

[12] M. Langbroek, *Leonid outburst activity 1996*, IMC poster, 1998.

[13] M. Langbroek, *personal communications*, June 1998.

[14] P.A. Curry, *Mon. Not. R. Astron. Soc.* 93:3, 1933, pp. 190-192.

[15] E.J. Maanders, *Hemel en Dampkring* 65:6, 1967, pp. 149–160 (in Dutch).

[16] D. Milon, *J. Br. Astron. Assoc.* 77:2, 1967, pp. 89–93.

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