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The *International Meteor Conference* in Petnica, Yugoslavia, which took place from August 25 to 28, 1997, was a big success. Here, we see the participants posing for a group photograph on the grounds of the Petnica Science Center.

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Useful Information

The December Issue *(WGN 25:6)*

The *December issue* will be mailed during the first week of December. Contributions are due on *November 21* at the latest. They should be sent to *Marc Gyssens.*

Administrative Correspondence

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From the Editor-in-Chief

Marc Gyssens

Only one month after the actual observations, 26 455 *Perseid meteors have already been reported to our Visual Commission, which allowed us to make a first, preliminary, analysis. A lot more observations were turned in after the analysis was made, at the* International Meteor Conference (IMC) *in Petnica, were promised to us, or are still expected. This apparent enthusiasm of our observers was reflected at the* IMC, *where a lively exchange of information and experiences took place. We can look back to another very successful* IMC, *a result to which of course all participants contributed, but for which special thanks are due to the organizers for a job very well done! One of the highlights at the* IMC *was the official foundation—after a year of preparations—of the Video Commission, which will be run by Sirko Molau. Besides the Perseids, the Leonids were also an important topic of discussion, of course, as some groups are already planning an expedition for observing the 1998 event somewhere in Mongolia or neighboring regions of Siberia or China. Finally, it was decided to have the 1998* IMC *in or near Tatranská Lomnica in Slovakia, in conjunction with a professional conference. So we may expect to have a lot of professional-amateur interaction next year, as was the case during the 1992* IMC *in Smolenice, in what was then still Czechoslovakia. I think all this activity proves that the* IMO *is still on top of the events!*

Of course, all this activity is mirrored in our journal. Special attention is paid to the 1997 Perseids and Leonids, whereas detailed information on the past and upcoming IMCs *are planned for the December issue. As we are approaching the end of the year, we have to ask those of you who did not yet do so at the* IMC *to renew your membership or subscription. The rates remain unchanged. More information is given below. We want to point our readers' attention to the possibility of taking a 2 year-subscription. In this way, you save twice, first on bank charges, and second, because we anticipate that membership and subscription rates will have to be raised for 1999! Meanwhile, enjoy this issue!*

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Ina Rendtel

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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 9 containing the 1996 visual observations, and the Proceedings of the 1996 and 1997 *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 higher rates are expected for 1999!

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Letters to WGN

compiled by Marc Gyssens

1. Automatic meteor detection

Peter Gural's interesting article [1] on automatic meteor detection makes many useful points. We must be careful to avoid confusion, however, in the use of technical terms used in television.

He describes the television system as having a frame rate of 60 Hz. It actually has a rate of (about) 30 frames per second, which is (about) 60 fields per second. The current television systems (HDTV may differ) have a 2:1 interlace. First the odd-numbered lines are scanned; they constitute one field. Then the even-numbered lines are scanned for the second field. These two fields constitute one frame. I am sure that Peter is aware of this, but we might as well keep our terminology in line with television usage.

Additional information might be useful for those considering developing such systems elsewhere. The 60 fields (30 frames) per second 525-line system is used in North America, some of South America, and in Japan. (This is for monochrome: color uses 59.94 fields = 29.97 frames per second.) Most of the rest of the world uses 50 fields (25 frames) per second at 625 lines [2]. Fifty lines are lost from each frame during the vertical blanking periods, so the available resolutions are 475 and 575 lines respectively. There are around ten current TV systems (ignoring HDTV) [3], but the other differences concern color and sound, which are not relevant to us.

Peter also talks about the processing of each frame being triggered by vertical blanking. This synchronization signal is called the *vertical synch*. The vertical blanking period contains the vertical synch, but also two periods called the *front porch* and *back porch* [4] which serve other purposes.

It will be interesting to see where these developments lead. Computer speeds are increasing, as Peter points out, and it cannot be long before a fully-fledged system spends all night watching the sky and disgorging the occasional floppy disk addressed to the nearest astronomer.

[1] P.S. Gural, "An Operational Autonomous Meteor Detector: Development Issues and Early Results", *WGN* 25:3, June 1997, p. 136.
[2] D.G. Fink (ed.), "Television Engineering Handbook", McGraw-Hill, New York, 1957, pp. 2–4.
[3] "World Radio TV Handbook", Billboard, New York, published annually.
[4] D.G. Fink (ed.), "Television Engineering Handbook", McGraw-Hill, New York, 1957, Chapter 1.

Chris Trayner, September 30, 1997

2. Stones from heaven: some meteoric fossil folklore

I was fascinated by Martin Beech's letter concerning North-American Indian meteor folklore and legends in *WGN* 25:4, August 1997, p. 147, and am grateful for his time and trouble to share the information he did. I hope it will encourage others to do so too.

I can perhaps shed some light on his comments about stars in the sky not being star-shaped. The brightest stars, notably Sirius (α Canis Majoris), but more especially the brighter planets Jupiter and Venus can seem "star-shaped" at times, due to diffraction spikes produced in the eye, which appear to surround the object. There are usually more than five such spikes, however, although the number, and their size, varies from person to person. They are also usually linear, sometimes seeming to widen furthest from the light source (which is of course the opposite of the triangular pattern on a stylized star-shape as commonly drawn). The spikes are larger and more obvious when the eye is dark-adapted, with the pupil wide open. The same principle as works in a pinhole camera operates here; a tiny pinhole can generate a sharp projected image, but a larger hole cannot. Minnaert has some useful comments on this subject in his chapter on the eye [1].

The fact that the spikes are most readily observable with a bright source may well have led to the adoption of the asterisk or star shape as a pictogram to represent stars by early societies. In Sumerian cuneiform, for example, the symbol MUL used to indicate a deity, a star, a constellation or any other heavenly body, including a meteor, is an eight-pointed star [2,3]. This was in use from circa 3000 BCE at least. Deities and the planets have long been associated together, so such a link is not surprising, although the symbol (along with numerous others) has caused confusion and dispute among cuneiform scholars in some cases.

This particular symbol on its own also represents the planet Venus in ancient Mesopotamia from very early times, as well as the associated goddess Inana (later Ištar). This Inana-Venus star was one of the three most important celestial symbols in Mesopotamia, along with the Sun-disc (usually containing eight rays, often with four triangular points, and four sets of wavy lines in between) and the Moon crescent, later crescent-disc.

In Babylonian times, circa 1000–500 BCE, we find other stars appearing on Mesopotamian cylinder seal designs, sometimes four attached to the body of a deity by two long "rods" each. Whether these "rods" are supports to attach the stars to the deity, or whether it shows the stars are radiating from the deity (perhaps like comets or meteors) is unknown. The stars often have serrated edges, frequently with 6–8 points visible.

A pattern of seven circles, thought to be stars, is common too during this period, but these are almost never shown as anything other than circles. They may be the Pleiades (M 45) in Taurus, or perhaps the seven leading stars in Ursa Major. A good selection of cylinder seal impressions showing the range of these symbols is [4], but see also its references.

Whether the North American Indian star- and meteor-shapes arrived with quite recent European influence (itself drawing heavily on Mesopotamian origins, via Greece in many cases), or via Asia in much earlier times (and again, the Chinese and other Asian peoples were heavily influenced in their iconography and some of their thinking through contacts with ancient Mesopotamia), may well never be known.

The five-pointed star shape may reflect the importance of the five naked-eye planets, coupled with the five human limbs, including the head, the five digits per hand or foot, or even the Chinese use of important "fives," for instance. An even number of star points was much more popular in early human history, certainly.

[1] M. Minnaert, "The Nature of Light and Color in the Open Air", Dover Publications, New York, USA, 1954, pp. 90–107, esp. pp. 93–96.

[2] C.B.F. Walker, "Cuneiform", in *Reading the Past: Ancient Writing from Cuneiform to the Alphabet*, British Museum Press, London, England, 1990, pp. 14–73.

[3] J.K. Bjorkman, "Meteors and Meteorites in the Ancient Near East", *Meteoritics* 8, 1973, pp. 89–132, esp. p. 94.

[4] D. Collon, "First Impressions: Cylinder Seals in the Ancient Near East", British Museum Press, London, England, 1987.

Alastair McBeath, August 20, 1997

3. About the Leonids in recent history

In many textbooks, it can be read that the Leonids did not produce a storm around Comet 55P/Tempel-Tuttle's perihelion returns in 1899 and 1932. I do not intend to cover all existing treatises on the recent Leonid history in this short correspondence, but concise stories on the 1899 and 1932 Leonid activity and literature references on this topic can, for example, be read in references [1,2]. For example, Yeomans [1] relates that many people, professionals and lay persons, were anxiously awaiting an 1899 storm and the possibility of such a storm received very extensive publicity in the press. He cites Olivier in concluding that in the face of the great public anticipation and substantial press coverage "the failure of the Leonids to return in 1899 was the worst blow ever suffered by astronomy in the eyes of the public." He mentions an influential prediction by the British astronomer Stoney that a storm would occur near "6 am" on November 15 that year. The *IMO*'s Visual Handbook [2] relates that British observers reported a peak rate of 240 from British observations for 1932, adding that this is "however far less than a storm." Generally, many investigators and writers on the topic of Leonid outbursts seem to take the view that there were no storms in 1899 and 1932.

But were there no storms? Perhaps, it would be more correct to say that there were no storms *observed*—or, at least, that no records of such observations have surfaced. The difference between both views requires some explanation.

Several investigators (e.g., [3–5]) have noted that, from historical records and theory, Leonid storms and storms caused by other streams in the years closest to perihelion return of the parent comet tend to occur very close in time to the crossing of the cometary node, the difference being no more than a few hours at most if we look at the list in [3]. If we accept this to be true in general, we can use this to estimate the time in 1899 and 1932 at which a storm may have occurred. In addition, we can also indicate from which geographical regions the storm may have been observable, taking into account that Leonid storms are very short. The largest part of a Leonid storm takes less than 3 hours, based on historic examples [3]. In some years, e.g., 1866, a second, broader, background structure with activity above a ZHR of 100 of 6 hours or less duration was present. For reasons outlined in [5], we can expect this background to have been prominent in 1899 and 1932. Yet, very high rates remain confined to a short period near nodal passage and, therefore, to a small region of the globe. Recently, Yeomans et al. [4] present highly accurate orbital elements for several historic returns of 55P/Tempel-Tuttle. 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! The next year, 1900, nodal passage was on November 16 at 0^h UT. Very high rates were experienced from Canada only a few hours later [2], perhaps part of the descending branch of a storm peak, perhaps part of the more intense part of the background structure close to the storm peak. For accounts of a possible 1899 storm, Oriental sources should be searched. In his update of historical meteor records [6], Hasegawa lists an entry (#218), taken from a Beijing Observatory compilation, for November 14.7, 1899 ($\lambda_\odot = 233\overset{\circ}{.}5$), stating that "at 2 am, stars fell like rain." The mentioned time is *exactly* one day too early, but could this be a chronicer's (or translator's) mistake?!? A full day in advance of a (storm) peak, Leonid activity should not be that obvious.

In 1932, nodal passage occurred at 16^h UT on November 16. Therefore, a storm most likely materialized above the Western Pacific, and would have been observable from Japan only, or perhaps Hawaii if occurring a few hours before nodal passage. British observers would have had no chance of observing a storm anyway, from Britain at least, the fact that they experienced high rates, almost half a day later [2], might suggest that the time of nodal passage must have seen very high rates indeed. For records of a possible storm, Japanese sources should be investigated. Note that absence of records not necessarily means that a storm was absent given that in this case possible observational locations were really limited. Perhaps weather was bad, or records did not survive the War. Those who do master Oriental languages could do very valuable work in trying to track down reports relevant to the possibility of meteor storms in 1899 and 1932. Captains' logbooks from ships sailing the Western Pacific may also be a worthwhile source to consult.

[1] D.K. Yeomans, "Comets, a Chronological History of Observation, Science, Myth, and Folklore", 1991, pp. 200–201.

[2] J. Rendtel, R. Arlt, and A. McBeath (eds.), "Handbook for Visual Meteor Observers", 1995, pp. 236–243.

[3] P. Jenniskens, "Meteor Stream Activity II. Meteor Outbursts", *Astron. Astroph.* 295, 1995, pp. 206–235.

[4] 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.

[5] P. Jenniskens, "Meteor Stream Activity III. Measurement of the First in a New Series of Leonid Outburst", *Meteoritics and Planetary Science* 31, 1996, pp. 177–184.

[6] I. Hasegawa, "Historical Records of Meteor Showers", in *Meteoroids and their parent bodies*, J. Štohl and I.P. Williams, eds., 1993, pp. 209–223.

Marco Langbroek, September 25, 1997

The International Meteor Conferences of 1997 and 1998

Marc Gyssens

The 1997 *International Meteor Conference* in Petnica, Yugoslavia, which took place from September 25 to 28, was a great success, thereby following the tradition of previous *IMC*s. There were fewer lectures than usual, but this provided more time for informal discussions and exchange of information and experiences, a time that was effectively put to use. As expected, there were many attendees from Eastern and South-Eastern Europe, but many West-European meteor workers also made the effort to travel to the IMC. The enthusiasm and spontaneity of the local meteor workers and the smoothness of the organization greatly contributed to the success of the conference. A more detailed report, together with some photographs, may be expected in the December issue.

The December issue will also contain more details about the 1998 *International Meteor Conference*. In Petnica, it was decided to have next year's *IMC* in or near Tatranská Lomnica, in Slovakia's High Tatra Mountains, from August 20 to 23, in conjunction with the *Meteoroids* 1998 Conference, which will take place from August 16 to 22. An *IAU* Colloquium on comets and asteroids, also in the same region, is planned to be held shortly after the *IMC*. This arrangement allows for plenty of contact between professional and amateur meteor workers, and will certainly result in a very interesting conference, as was proven by the 1992 *IMC* in Smolenice, in what was then still Czechoslovakia. The 1998 *IMC* will be organized by the Slovak meteor workers, in particular Daniel Očenáš and Peter Zimnikoval, another guarantee for a very successful *IMC*, for these people also organized the 1992 event! More information and a registration form, as well as information on the professional conferences, will be provided in the December issue.

The 1997 Perseids

First Analysis of the 1997 Perseids

Rainer Arlt and Jürgen Rendtel

The preliminary analysis of the 1997 Perseid meteor shower delivered a position of the young Perseid peak at $\lambda_\odot = 139\overset{\circ}{.}72$ (eq. 2000.0) and a traditional peak position at $\lambda_\odot = 140\overset{\circ}{.}0$ with ZHR $= 137 \pm 7$ and ZHR $= 105 \pm 6$, respectively. An additional distinct maximum occurs at $\lambda_\odot = 140\overset{\circ}{.}32$ with ZHR $= 102 \pm 8$. The first Perseid peak and this additional enhancement are accompanied by lowered population indices of $r = 1.78$ and $r = 1.87$ compared to the surrounding values of 2.1–2.2.

1. Observational data

The considerable data set of 26 455 Perseids seen by 220 observers from 25 countries has been collected until one month after the maximum of the shower. We would like to thank the following observers for making their data available so quickly:

Sana'a Abdo, Ahmad Alniamat, Rainer Arlt, Joseph D. Assmus, Alja Bajc, Michal Bares, Luc Bastiaens, Petr Becvar, Gert Beeckman, Lance Benner, Felix Bettonvil, Beth Biller, Louis S. Binder, Ragnar Bödefeld, Neil Bone, Frederick Bové, Ines Buljan, Pieter Caillian, Anja Cervek, Koen Clement, Benny Colyn, Matthew Collier, Uros Cotar, Hani Dalee, Goedele Deconink, Johan de Hert, Stijn De Jonge, Marc de Lignie, Didier Dielen, Milos Djordjevic, Ivan Donik, Dave Edwards, Frank Enzlein, Bert Everaert, Raul Fernandez, Tamás Fodor, Andrea Friebel, Robert Gehlhaar, Marcel Geltner, Benny Geys, Maarten Gillis, George W. Gliba, Ivan Goethals, Roberto Gorelli, Lew Gramer, Matthias Growe, Erwin Guetens, Peter S. Gural, Muammar Hadidi, Cathy Hall, Jung Han-Sub, Takema Hashimoto, Roberto Haver, Lars Trygve Heen, Bernd Heinrich, Alaa Hemsy, Bart Hendrickx, Udo Henning, Veerle Herrygers, Mónika Hevesi, Zoltán Hevesi, Wolfgang Hinz, Anti Hirv, Nathalie Hontelé, Dave Hostetter, Stanka Hribar, Jan Hudecek, Richard Huziak, Daiyu Ito, Marko Ivanović, Kiyoshi Izumi, Sinitirou Izuhara, Yumi Izuhara, Helle Jaaniste, Visnja Jankov, Carl Johannink, Javor Kac, Vaclav Kalas, Kenya Kawabata, Ákos Kereszturi, André Knöfel, Jan Kohout, Khalil Konsul, Detlef Koschny, Gabi Koschny, Ralf Koschack, Marija Kotur, Jaroslav Kovarik, Ales Kratochvil, Andreas Krawietz, Lukas Kral, Dita Krcmarova, Alenka Kremzer, Øyvind Kristiansen, Gyöngyvér Kudor, Ralf Kuschnik, Marco Langbroek, Marko Leuštek, Michael Limpens, Richard Löwenherz, Robert Lunsford, Hartwig Luthen, Tom Maets, Szabolcs Majnik, Miroslava Mala, Roman Manak, Tijana Mancic, José Alfonso dos Reis Martins, Alastair McBeath, Norman McLeod, Rostislav Medlín, Hans-Jörg Mettig, Ivo Miček, Teréz Miklos, Iris Miljački, Nikola Milutinovic, Vjera Miovic, Koen Miskotte, Jan Mocek, Sirko Molau, Andres Rafael Paños Moya, Sin Nakayama, Tomas Nasku, Sven Näther, Saša Nedeljković, Kevin Nicasi, Dalibor Nikolic, Mirko Nitschke, Mohammad Odeh, Ibrahim Odwan, Masayuki Oka, Arkadiusz Olech, Artyom E. Oreshonok, Dieter Ortmanns, Elke Ortmans, Tamara Pavlovic, Simon Pelckmans, Lars Petersen, Natasa Petelin, Richard W. Pitaluga, Janja Plazar, Hans-Peter Plott, Ivana Polakova, Mila Popović, Jože Prudič, Thomas Rattei, Andreas Rendtel, Ina Rendtel, Jürgen Rendtel, Petra Rendtel, Janko Richter, Vanja Rodiger, Dirk Rombouts, Marion Rudolph, Victor Ruiz Ruiz, Jaroslav Sajdl, Krisztián Sárneczky, Michael Schmidhuber, Thomas Schreyer, René Scurbecq, Harald Seifert, Miguel Serra Martin, Ivica Skokić, Vesna Slavković, Lukas Smahel, Manuel Solano Ruiz, Umberto Mule Stagno, Lena Steensgaard, Calders Stijn, Enrico Stomeo, Stefano Stomeo, Wesley Stone, Niko Štritof, Masafumi Suzuki, Richard Taibi, Masaaki Takanasi, Mika Takanasi, Syoiti Tanaka, Khaled Tell, Masayuki Toda, Tamás Tóth, Manuela Trenn, Gabrijela Triglav, Mihaela Triglav, Heiko Ulbricht, Erwin van Ballegoy, Kris van Beurden, Mark van den Broeck, Hendrik Vandenbruaene, Jan Vandenbruaene, Geert van de Weyer, Steven van Impe, Frans van Loo, Peter van Loo, Christophe van Olmen, Glenn van Olmen, Brigit van Opstal, Anne van Weerden, Cis Verbeeck, Jan Verbert, Suzana Veren, Wim Vinken, Marija Vucelja, Frank Wächter, Sabine Wächter, Bruno Wagner, Georg Wagner, Thomas Weiland, Thomas Westphal, Barbara Wilson, Roland Winkler, Gudrun Witzler, Oliver Wusk, Yasuo Yabu, Sinitirou Yanagi, Noriko Yosimura, Hans-Georg Zaunick, George Zay, and Martin Zibar.

Brilliant weather over large parts of Europe permitted a huge number of observations in the first half of August. The observations were carried out by amateurs from then following countries:

Austria, Belarus, Belgium, Canada, Croatia, Czech Republic, Denmark, Estonia, Germany, Gibraltar, Hungary, Italy, Japan, Jordan, Korea, Malta, the Netherlands, Norway, Poland, Portugal, Slovenia, Spain, UK, USA, and Yugoslavia.

2. Population index and ZHR-activity

Before the activity of a meteor shower is calculated, the relation between bright and faint meteors has to be checked, the population index r has to be calculated, that is. Figure 1 shows the variation of the r-value with time during the maxima of the Perseids. Two distinct dips in the r-profile are embedded in relatively constant population indices of 2.0–2.2 off the maxima. The first minimum occurs at $\lambda_\odot = 139^\circ\!.72$ with $r = 1.78$, the second minimum is at $\lambda_\odot = 140^\circ\!.4$ with $r = 1.87$. No magnitude data from eastern Asian longitudes were available, leaving a gap of results in the r-profile.

The population index profile was used to calculate the individual ZHRs; the average ZHR-profile is shown in Figure 2 for the period around the maxima of the Perseids. The early activity peak observed in recent years appears distinctly. In order to allow for the short time-scales no observing periods longer than $0^h\!.8$ were used. The peak time is $\lambda_\odot = 139^\circ\!.72$ (August 12, 8^h50^m UT) with ZHR $= 137 \pm 7$ and a half width at half maximum (HWHM) of about $0^\circ\!.15$ ($3^h\!.8$). The peak appears to be skew with a smoother increase and a steep decrease, and the maximal ZHR exceeds the 1996 figure by about 15%.

The traditional maximum is covered by a few data points from Japan and peaks at about $140^\circ\!.0$ (August 12, $\sim 16^h$) with ZHR $= 105 \pm 6$. A peculiar feature appears after the traditional maximum this year: A distinct peak at $140^\circ\!.32$ with ZHR $= 102 \pm 8$ could be witnessed by European observers centered at 23^h50^m on August 12. The peak was reported by several observers verbally, and in fact it shows up in the profile when using exclusively observing periods no longer than $0^h\!.5$ hours. The peak has a symmetric shape and the HWHM is $0^\circ\!.15$ ($3^h\!.8$). The feature may have appeared in recent years too; it should be an item of future comprehensive analyses to search for short-lived peaks off the maximum besides the two well known maxima.

While the peak's position shifted further as expected from the previous returns [1] to $\lambda_\odot = 139^\circ\!.72$ in 1997, its strength has not decreased. Summaries of the evolution of the Perseid maximum and peak [2] gave no clear picture about the origin of the outburst meteoroids and the future appearance of the peak. Any new simulation of orbital evolution has to consider the continuous shift of the peak position as well as its strength. Despite the moonlight conditions and the large attention towards the Draconids and Leonids in 1998, the coming return of the Perseids deserves an adequate observation of the near maximum period as well.

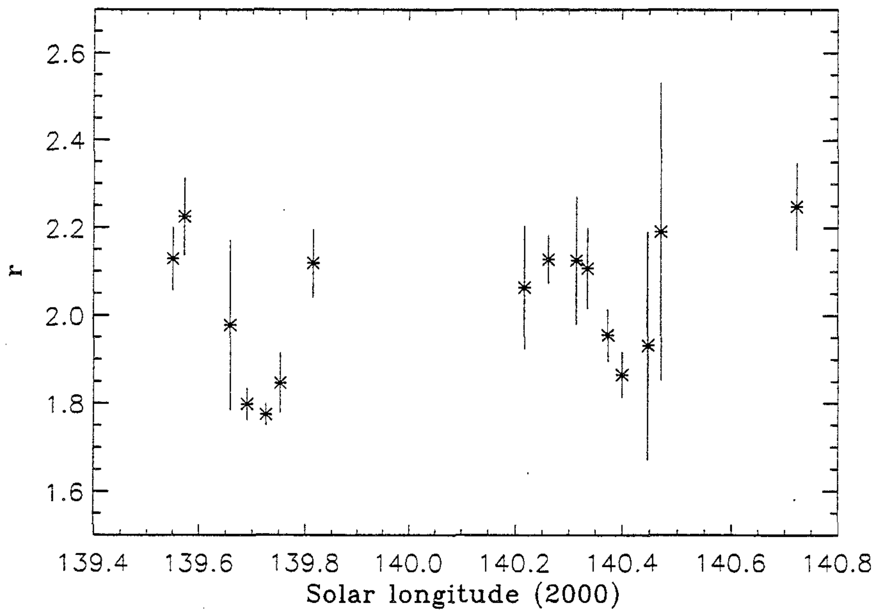

Figure 1 – Profile of the population index of the 1997 Perseid maximum nights.

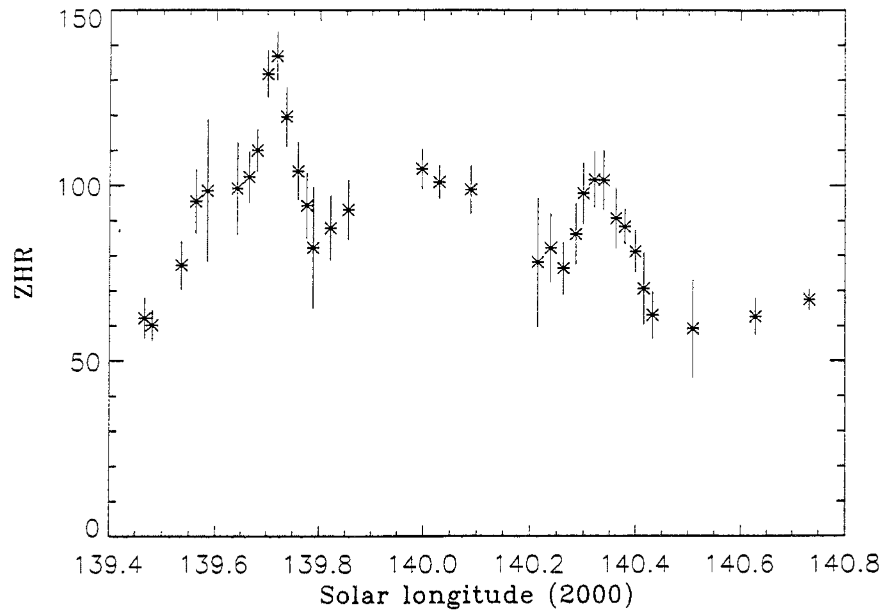

Figure 2 – ZHR-profile of the 1997 Perseid maximum nights.

References

[1] J. Rendtel, R. Arlt, "Perseids 1995 and 1996–An Analysis of Global Data", *WGN* 24:5, October 1996, pp. 141–147.

[2] P. Brown, J. Rendtel, "The Perseid Meteoroid Stream: Characterization of Recent Activity from Visual Observations", *Icarus* 124, 1996, pp. 414–428.

Postscript

A large number of observations has been submitted at the *IMC* in Petnica, from Slovakia in particular, and a comprehensive analysis of the complete set of data is expected for early 1998.

The "New" Peak of the Perseids from Spain in 1997

Josep M. Trigo

An impression of the first, "new" peak of the Perseids is given from the author's observations in Spain

Four years after the magnificent 1993 Perseid return, the interest in observing this radiant at the same solar longitude is to establish the possible vanishing of the short-lived peak at $\lambda_\odot = 139\overset{\circ}{.}48$ (eq. 2000.0). Making the simple assumption of symmetry in the evolution of the new peak activity since 1988, it is reasonable to predict a ZHR of no more than 100 meteors per hour. Despite these considerations, the Spanish press announced very high activity for the Perseid maximum. As a result, the general public was disappointed with normal levels of activity of the shower, which, however, was very rich in bright meteors. I followed the first maximum from Benicassim (Castelló), and my observations show a great quantity of fireballs. The visual results were sent to the *IMO* Visual Commission. Besides Perseids and sporadic meteors, some Northern δ-Aquarids were seen. Finally, the photographic results obtained from my station include 1 sporadic meteor and 2 Perseids.

The Leonids
Bulletin 10 of the International Leonid Watch: Final Results of the 1996 Leonid Maximum

Peter Brown and Rainer Arlt

The activity profile for the 1996 Leonids from 434 observations made by 109 observers and comprising 4449 shower meteors is presented. Two peaks in the ZHR profile are found, one very distinct at $\lambda_\odot = 235.^\circ17 \pm 0.^\circ07$ (eq. 2000.0) and a less well-defined peak at $\lambda_\odot = 235.^\circ4 \pm 0.^\circ1$. The former peak has a ZHR of 86 ± 22 and the latter a maximum of 45 ± 4. There is a statistically significant increase in the population index near the first peak, from a pre-outburst value near $r = 1.7$ to $r = 1.9$ at the early maximum and falling again to $r = 1.6$ in the period $\lambda_\odot = 235.^\circ30$–$235.^\circ40$. The maximum flux at the early peak corresponds to 0.012 ± 0.004 meteoroids per square kilometer and per hour with absolute magnitudes greater than 6.5, and 0.003 ± 0.001 meteoroids per square kilometer and per hour for the later peak. We associate the early peak with material of very recent ejection from Comet 55P/Tempel-Tuttle and the broader, less visible maximum, with the more traditional peak comprising older material.

1. Introduction

For the third year in a row, the Leonid shower has shown significantly enhanced activity over its usual annual performance. The increased activity observed in 1994–1995 and recorded again in 1996 is related to the impending return of the parent comet, 55P/Tempel-Tuttle, which is due to reach perihelion on February 28, 1998.

The parent comet was recovered on March 4, 1997 [1], very close to the predicted location based on the work of Yeomans et al. [2]. Pre-discovery observations of Tempel-Tuttle have also been found from as early as May of 1996 taken with the ESO 2.2 m telescope [3]. Current estimates of the nuclear radius of the comet based on its brightness at discovery suggest a value of 1.9 km, assuming an albedo of 0.04. This estimate is very similar to an earlier estimate by Sekanina [4] of 2 km based on the brightness of the comet at its 1965 passage. The refinement of this estimate along with further confirmation of the size of the comet using observations at other than visual wavelengths should provide some of the needed information for modelers to begin constructing more precise models of the dynamics of the stream in preparation for the strong Leonid returns expected from 1998 to 2000.

The 1996 return marks the first occasion when the narrow outburst component of the shower was unambiguously detected during the current Leonid epoch [5]. Though significant scatter does exist amongst the 10 or so observers reporting rate data during the outburst period, there appears to be enough information from these visual data to conclude that this component was observed in 1996. It would be most interesting to determine if other observational techniques detected this increase or not, but the time of occurrence of the central portion of the outburst (5^h UT on November 18) falls between the European and North American observing windows and makes independent confirmation less likely. Calibrated radio observations from 1996 could be particularly useful in this regard.

In addition to the outburst component, a broad level of activity consisting of larger particles, very similar to the profile seen in 1994 and 1995 was also detected.

2. The ZHR activity profile

Figure 1 shows the ZHR profile for the 1996 shower over a one day interval centered about $\lambda_\odot = 235.^\circ5$. Also shown is the level of sporadic activity recorded over the same interval. A nearly monotonic increase in shower activity from $\lambda_\odot \approx 235.^\circ0$ to $\lambda_\odot = 235.^\circ17$ is apparent, where the peak ZHR of 86 ± 22 is reached. Note that the higher-than-average sporadic rates in the early portion of this interval suggests that some of the early activity in the rising portions of the curve may be overestimated. At the peak, however, the sporadic HR is very near the normal value of 10–15. The scatter in individual ZHR estimates is apparent during the peak period and is manifested by the large error margins. The activity associated with this first peak has a half-width to half-maximum (HWHM) of $0.^\circ07 \pm 0.^\circ02$ (1.7 ± 0.3 hours).

A second, weaker peak is also visible in this profile near $\lambda_\odot = 235.^\circ4 \pm 0.^\circ1$. This peak is ill-defined within the error margins and is likely associated with the normal annual peak which has shown a maximum near $\lambda_\odot = 235.^\circ5$ in past years [6]. The 1995 ZHR profile showed a very similar structure at this location [7]. The peak ZHR associated with this maximum is 45 ± 4, which is more than 4 times the normal annual maximum and is 10 above the 1995 level. This peak is an order of magnitude broader than the early maximum having a HWHM of $0.^\circ6 \pm 0.^\circ2$. This HWHM is for the broad profile, ignoring the sharp early maximum. It is instructive to note from the sporadic and shower ZHR profiles that Leonid activity in 1996 climbed above the sporadic background only over the interval $\lambda_\odot = 234.^\circ0$–$236.^\circ0$.

3. The population index

From the quiet-time activity compiled between 1988 and 1993, the mean r-value for the Leonid stream was found to be 2.0 [6]. Figure 2 shows the r-profile over the same interval of solar longitude as given in Figure 1. Outside this interval, there was only enough magnitude data reported to accurately measure the r-value once (at $\lambda_\odot = 234.^\circ3$) pre-maximum and three times post-maximum ($\lambda_\odot = 236.^\circ26$, $\lambda_\odot = 236.^\circ31$, and $\lambda_\odot = 237.^\circ0$). The pre-maximum and extreme post-maximum measurements of r all suggest values in the 2.0–2.2 range as being most appropriate.

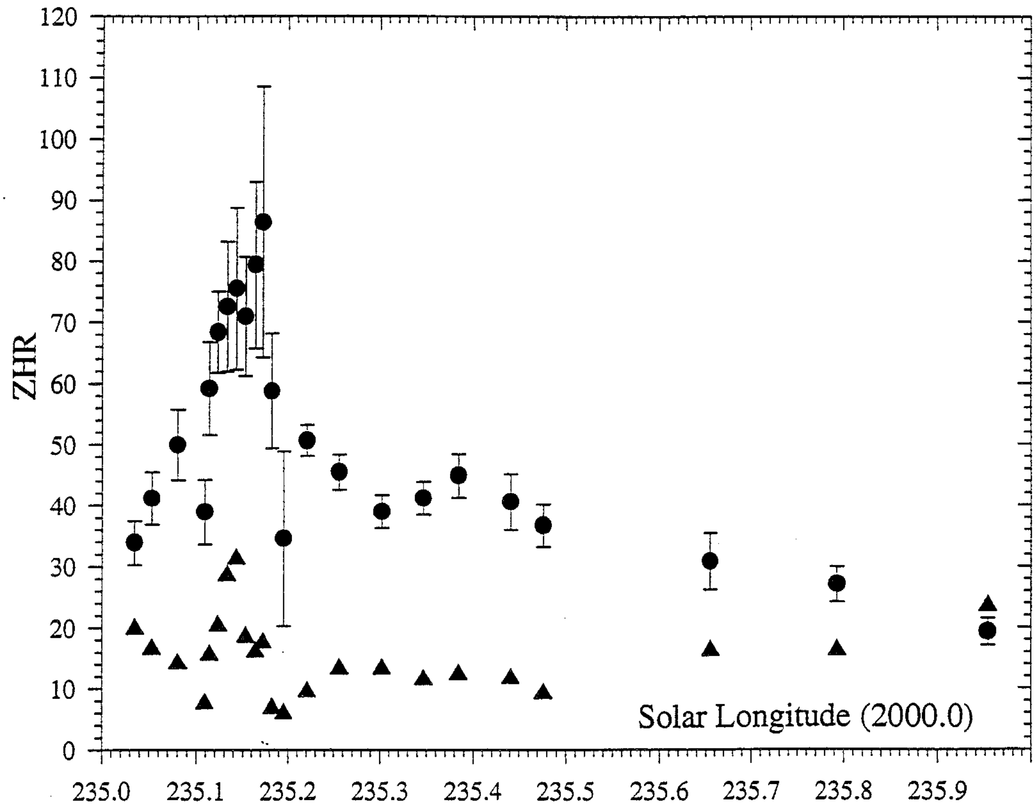

Figure 1 – ZHR versus solar longitude for the 1996 Leonid return. This profile was constructed using $0.^\circ1$ smoothing intervals shifted by $0.^\circ05$ before $\lambda_\odot = 235.^\circ1$ and $0.^\circ02$ intervals shifted by $0.^\circ01$ during the period $\lambda_\odot = 235.^\circ1$–$235.^\circ2$. The remainder of the profile was found using $0.^\circ1$ increments shifted by $0.^\circ05$ during the period $\lambda_\odot = 235.^\circ2$–$235.^\circ5$ and $0.^\circ5$ increments shifted by $0.^\circ25$ thereafter. The solid circles are shower ZHRs while the solid triangles are the sporadic HR in the corresponding intervals.

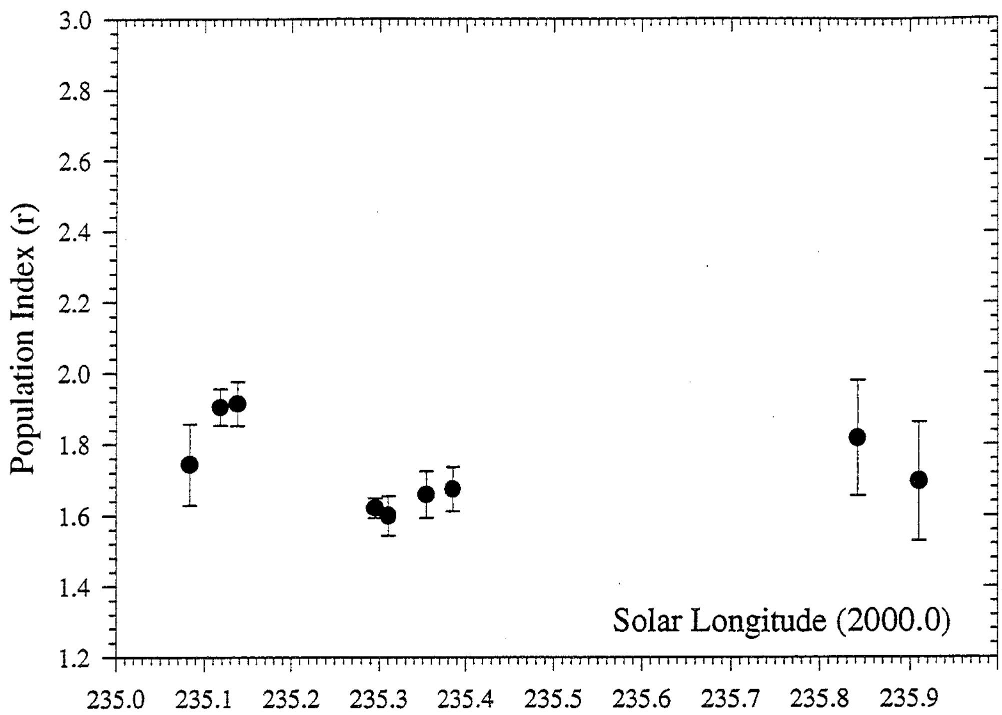

Figure 2 – The r-profile for the 1996 Leonids as derived from magnitude data comprising 3220 Leonid meteors. Each datum was derived from a group of between 25 and 688 Leonid meteors.

From Figure 2, there is an increase in r near the time of the early ZHR peak relative to the intervals immediately before and following. The extreme minimum in r is reached at about $\lambda_\odot = 235\overset{\circ}{.}31$ when it attains a value of 1.6. This low value for r remains until at least $\lambda_\odot = 236\overset{\circ}{.}0$ with values constant near 1.7–1.8. This is very much lower than the $r = 2$ normally associated with the central portion of the stream and if true would indicate an abundance of brighter Leonids over the roughly day-long period centered about the normal peak as compared to quiet-time activity during the 1996 display. However, the abundance of bright meteors in this interval may be due to reduced observer attention to the fainter meteors as fewer experienced observers contributed data at the time of the minimum in the r-profile.

From the r-profile and the ZHR-activity it is possible to derive a flux profile for the 1996 Leonids and this is shown in Figure 3. The peak flux at the early peak corresponds to 0.012 ± 0.004 meteoroids per square kilometer and per hour with absolute magnitudes brighter than 6.5. The later, broad peak is roughly 4 times lower than this value, in large part due to the very low values for r in this interval.

4. Discussion

The high ZHRs associated with the early outburst peak, combined with its short duration and increase in numbers of fainter meteors as compared to adjacent observational periods is consistent with the interpretation that it is composed of very young material (only 2–3 revolutions old) and potentially associated with the storm-producing segment of the stream (the Ortho-Leonids). Very similar characteristics are associated with the 1966 and 1969 showers [8]. The broader activity which peaks later near the time of the normal maximum is composed of larger meteoroids than either the outburst peak or the normal annual shower. The total duration of this section of the stream is roughly 2 days—this is the length of time the shower is above the sporadic background. From the quiet-time analysis of the stream [6] it is known that the normal annual peak is just barely at the level of sporadic activity. This suggests that material in this portion of the stream is significantly older, probably of the order of 10 revolutions, which is enough time to allow for the degree of nodal spread observed as well as allow a noticeable enhancement in the proportion of larger meteoroids (cfr. Arlt et al. [9] for more discussion on these points).

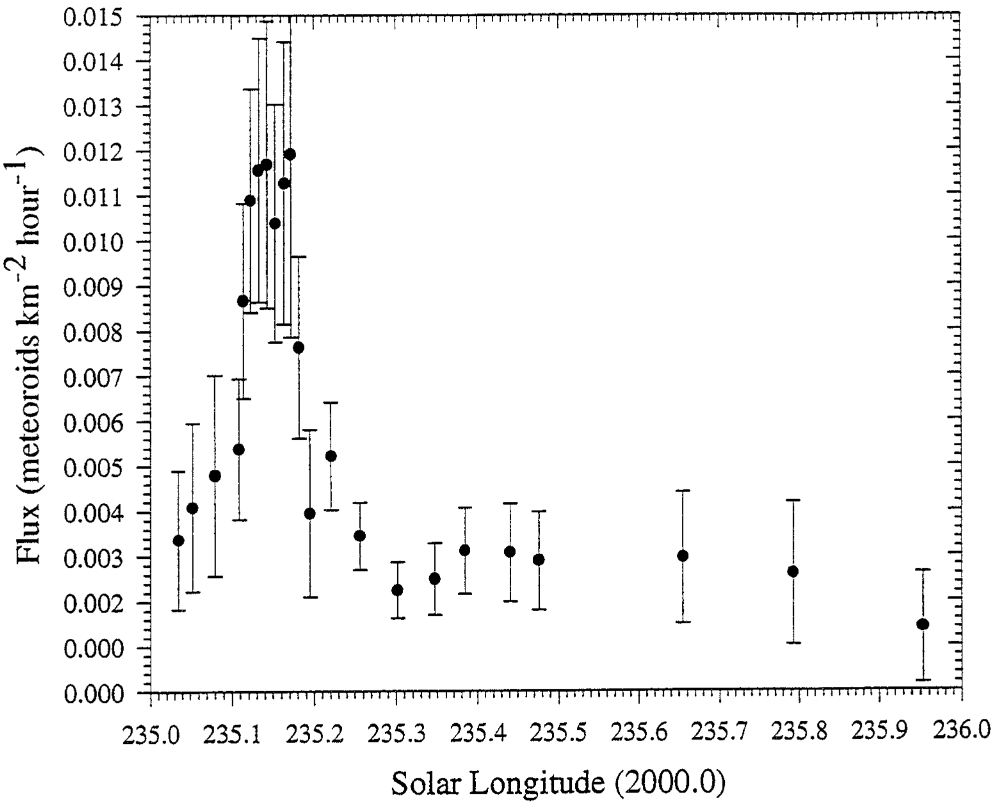

Figure 3 – Flux profile for the 1996 Leonids.

A similar peak was observed in 1995, but with far less confidence. It is still not clear if this is a genuine feature of the stream or simply an artifact of the reductions and poor observer coverage in that year. The peak location for the possible outburst in 1995 is 4 hours earlier than in 1996, though the two just barely agree within the (large) errors for the location in 1995.

The location of the outburst peak is almost precisely the same as the location of the 1966 storm and an enhancement recorded by radar in 1965 [10]. This might imply that the material we are currently encountering has suffered virtually no perturbations in the intervening years and thus has not significantly changed its nodal longitude. Kazimircak-Polonskaja et al. [11] were among the first to explicitly point out that the mean secular advance of the nodes of the stream (amounting to some 29′ per revolution) is actually achieved through a number of punctuated advances associated with perturbations from Jupiter, Saturn, and Uranus. Thus the actual rate of change for any one Leonid meteoroid from one revolution to the next may be anywhere from nearly 0 to several times the average rate. According to Kazimircak-Polonskaja et al. [11], the portions of the stream likely to be nearest to the Earth in 1999 shows virtually no change in nodal longitude between 1950 and 2000. In particular this section of the stream maintains essentially identical nodal longitudes from 1966 to 2000. If this is in fact the case, then the activity we have first seen in 1996 presages the probable location of the shower peaks over the years 1997–2001. Similar results were also found by Brown and Jones [12] on the basis of numerical modeling of the stream who suggested shower peaks during the current Leonid epoch would be most probably near $\lambda_\odot = 235\overset{\circ}{.}16$. Further detailed modeling needs to be done in light of the recovery of the parent comet and a key observation during the 1997 Leonid return will be the presence or absence of a strong component of the shower near these solar longitudes.

5. Seventh ILW period: November 5–25, 1997

The seventh *International Leonid Watch* (*ILW*) period is almost certain to reveal further heightened activity from the stream. With the parent comet little more than three months away from perihelion, 1997 is the first year in which the possibility of a very strong Leonid shower/storm can be taken seriously.

Unfortunately, the rather promising shower activity is hindered to a large degree by an 18-day old Moon on the night of maximum. The Moon will rise well before the radiant and will not set until after sunrise thus eliminating any possibility for dark-sky viewing of the shower. Nevertheless, careful observations at the time of maximum and magnitude estimates may help to roughly define the peak ZHR (as in 1994) as well as provide some reference as to any relative changes in the particle make-up across the stream.

If the patterns from the last few years persist, it seems probable that there will be an extended level of activity lasting perhaps 2 days centered around the peak with a peak ZHR of 50–60 in 1997 composed of larger Leonids. The visibility of the outburst maximum will be heavily compromised by the Moon, but some TV observations as well as careful radio/radar measurements of activity of the stream may be able to detect the expected flurry of fainter meteoroids from the Ortho-Leonids. The position of the outburst maximum detected in 1996 will recur at 11^h UT on November 17 in 1997 and will be best seen from the Central and Western United States. The time of nodal crossing in 1997 is $13\overset{h}{.}5$ UT, which places best viewing on the extreme West Coast of North America and Hawaii. The "normal" maximum at $\lambda_\odot = 235\overset{\circ}{.}5$ occurs at 19^h UT, and will be best seen from Eastern Asia.

As activity associated with the first maximum in 1996 had a higher r-value than adjacent periods, particular attention is drawn to the possibility of numerous faint meteors (which will certainly be difficult to see due to the moonlight) in addition to the probable large number of brighter events.

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Successful Leonid Airborne Mission Validation Flight during August 1997 Perseids

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We report on current plans to explore the Leonid meteor storms of 1998 and 1999 from two airborne platforms in a multi-instrument aircraft campaign. With science proposals pending, we received an opportunity to validate some of the optical and astrometric techniques during two flights that coincided with the return of the 1997 Perseid stream. The airborne observations monitored the same region in the atmosphere that was covered by a three-station ground-based campaign in mid-California. This paper gives a brief report just days after the event, in style with campaign reports from active amateur meteor observers worldwide.

1. Introduction

Earlier this year, we proposed to NASA to fund a multi-instrument aircraft campaign to explore the Leonid meteor storms of 1998 and 1999. Our objective is to be above clouds and lower stratosphere dust at the time of the event, to do measurements such as mid-infrared spectroscopy that cannot be done from the ground, and to bring meteor and upper-atmosphere scientists together to observe the same meteors with a multitude of techniques.

The Leonid returns of 1998 and 1999 offer a unique opportunity to use instrumental techniques that are not normally used for meteor observations because of high flux. Also, the Leonid meteors are more interesting than the normal annual meteors, because the storms represent relatively fresh ejecta that still contain information about the ejection process and ejection conditions. The proposed mission is a low-cost mission to Comet 55P/Tempel-Tuttle, whereby the meteoroids are the probes of the comet composition, mass, and ejection process.

This type of observations complements in-situ measurements with satellites. Meteor observations provide unique information on the ejection of large dust grains. Faint meteors are at the peak of the mass flux curve, while such grains have too low number densities to be detected in large numbers by spacecraft. The meteors present to us information about the motion of the particles to high accuracy and their breakup can be studied in detail to reveil information on density and morphology.

The present program contains ten well defined experiments by as many instrument principal investigators. The instruments address astrometry (orbits, ejection velocities, densities of particles), spectroscopy (elemental composition, interaction with the atmosphere, content of organic matter), flux (particle size distributions, absolute flux levels, and rate variations), as well as the mass-to-luminosity relationship of fast Leonid meteors and the scattered sunlight off the Leonid particles in space. Flux measurements cover meteors from -10 to $+14$ magnitude, which is a range of 10 orders of magnitude in mass.

Participants at present are M.J. Betlem (photography, high-resolution spectroscopy), J. Borovicka (low-resolution spectroscopy), P. Brown (ground-based radar), C.S. Gardner (lidar), B.A.S. Gustafson (scattering of sunlight), R.L. Hawkes (video), M.C. de Lignie (video, photography), J. Jones (radar), R.W. Russell (Mid-IR spectroscopy), G.V. Swenson (all-sky sodium airglow imaging), and J. Turk (mid-infrared imaging). We expect this list to grow as further segments of the science community are accommodated.

With proposals for the scientific mission pending, we received the opportunity for proof-of-concept flights during the Perseid return of 1997. As of August 16, the flights have been performed as planned and below is a first informal impression.

2. First impression of the validation flights of August 12 and 13

The USAF management team of the *Advanced Ranging Instrumentation Aircraft* (*ARIA*) at Edwards Air Force Base enabled us to perform two flights during this year's return of the Perseid meteor shower. The ARIA is a modified Boeing 707 (EC18-B), and was proposed as a possible platform for the Leonid missions in 1998 and 1999, having the necessary range and altitude for the proposed multi-instrument aircraft campaign. During the Perseids, it was flown as a single platform.

Our goal was to demonstrate the concept of filming and photographing meteors from an airborne platform. We wanted to (*i*) learn what problems were raised by putting such equipment on an aircraft; (*ii*) demonstrate the concept of triangulation by correlating the result with ground-based observations; (*iii*) assess the practicality of different ballistic streak camera systems available by the ARIA team; and (*iv*) develop aircrew coordination procedures to be employed during the 1998 and 1999 Leonid returns.

We were not able to perform the mid-infrared spectroscopy and imaging that were planned earlier, because the available windows for ARIA at this moment are not mid-IR transparent. However, there is a possibility that such experiment will be possible at a later time.

The flights did commence as planned on August 11-12 and August 12-13 between 23^{h} (pm) and 3^{h} (am) PDST (6^{h}–10^{h} UT). The imaging devices consisted of a pair of $f/1.8$ 50 mm Canon T-70 35 mm cameras and an image intensified camera using regular USAF 4949 night vision goggles and recording on Hi8. This equipment is similar to cameras and video equipment operated from the ground to allow direct comparison. In addition, a 5 inch near-infrared spectrograph and a cinematic camera was flown. Also, various experiments were performed such as direct imaging on betacam and storage of the Hi8 signal on betacam tape.

The video imaging was very successful. The plane's motion proved sufficiently gradual to provide rock steady images during a 1/30 s exposure, which, we believe, will result in as good astrometric results as the ground-based cameras. At the time of writing, the tapes have not been analyzed yet. However, in-flight records taken during the second night show 170 or so meteors recorded.

At the time of writing, only the 35 mm camera films have been developed. We have not yet developed the films of the other cameras. On the 35 mm cameras, 9 meteors were photographed. We established that the gradual motion of the plane does allow the record of the star images at all time during the 5-minute exposure. In this test, the cameras were not mounted on gyro-stabilized platforms, and the star trails show erratic motion. The cameras were closed, and a new exposure started immediately after a bright meteor was seen and end-points or beginning points can be recognized in some of the images. That should enable us to calculate the height-azimuth coordinate system at the time of the meteor and compare the result with those of ground-based observations.

The flights gave valuable insight in various communication procedures, flight techniques, and crew-scientist interactions. There was an exponential learning curve, with the second night benefiting a lot from the experience gained in the first night. Very important for morale proved a monitor that showed the filmed meteors to the flight crew.

3. The ground-based campaign

The ground-based campaign was also very successful. At this time, the films of the stations of Mercey and Holler have been developed, while those of Fremont Peak are still in the mail. A preliminary count resulted in 98 meteors on the Mercey negatives and 51 on the Holler negatives for the night of August 11-12. For the next night, the tally was 16 and 16, respectively. Those numbers have not been corrected for meteors captured on more than one negative and result from a relatively quick survey. Each station operated 13 cameras, which covered the sky from 28° elevation upward.

During the night of August 11-12, a Perseid meteor outburst occurred much as expected. The outburst is clearly seen in the rate of photographed meteors. Between $7^{\mathrm{h}}45^{\mathrm{m}}$ and $9^{\mathrm{h}}15^{\mathrm{m}}$ UT, counts were higher than the annual Perseid background, with peak rates at about $8^{\mathrm{h}}30^{\mathrm{m}} \pm 0^{\mathrm{h}}10^{\mathrm{m}}$ UT. At the peak, the detection rate was about twice that of the annual shower only. Those numbers are preliminary, and based solely on the Mercey station data.

Around the time of the outburst, between 7^h30^m and 9^h00^m UT, 84 meteors were filmed from Mercey. That is the only tape that was viewed in full thusfar. A quick inspection of the Holler tapes show that many meteors were filmed simultaneously. A comparison with the ARIA aircraft tapes has still to be made.

A bright -5 Perseid at $8^h35^m00^s$ UT was recorded on video from Mercey and the ARIA aircraft, and also on photographic film from the stations Mercey and Holler and also from the ARIA aircraft.

Further information

To remain informed about future developments concerning *Leonid Airborne Mission*, please consult the website `http://www-space.arc.nasa.gov/~leonid/`.

Acknowledgments

A large number of US Air Force personnel made the ARIA flights possible. We thank especially Greg Hamilton, the ARIA program manager, and Steve Wenke, the optical imaging specialist. From NASA/Ames, Co-PI Steve Butow participated in the flights as well as Paul Langston and assistant Patty from the Ames/Imaging Branch.

The ground expedition was made possible by Mike Koop and Peter Zerubin at the Mercy Hot Springs site, Chris Angelos, Rick Morales, and Dave Holman at Fremont Peak State Park, and Tom Rice and Mike Wilson at the Holler Obervatory site behind Lick Observatory. A large number of visual observers recorded the times and location of bright meteors, many of which responded to newspaper calls for volunteers in the San Jose Mercury News and Sacramento Bee. Some 80 people reported willing to spend the night for this project. We accommodated about 30 people in the end. In addition, several observers operated cameras or did visual observations from other observing sites.

This project is performed in collaboration with Hans Betlem and Marc de Lignie of the *Dutch Meteor Society*, who are participants in the *Leonid Airborne Mission* and who will take a role in the data reduction. The *Dutch Meteor Society* performed a similar campaign from the Netherlands, also with large numbers of meteors recorded. That will provide a baseline to compare with the observations of the outburst Perseids from California.

We thank management at Ames Research Center for making funds available for participation of Paul and Patty, and the ARIA management team at Edwards Air Force Base for providing the flight opportunity.

The η-Aquarids

Double-Station Observations of the η-Aquarids

Yoshihiko Shigeno, Masayuki Toda, and Hiroyuki Shioi

Since 1986, when Comet Halley reappeared, we have continuously conducted double-station meteor observations of the η-Aquarids. This paper reports orbits of 14 photographic meteors and three TV meteors.

1. Introduction

It is known that Comet 1P/Halley is the parent comet of the η-Aquarids. The maximum activity is reached in the beginning of May. The radiant of the shower begins to rise only in the early morning. At our mid-northern latitudes, twilight starts when the height of the radiant reaches just 30°, and we usually observe about 5–10 shower meteors during the last observing hour. On the other hand, observations from the southern hemisphere can be done until the radiant reaches an elevation of 45°. Hence, about 30 shower meteors per hour can be observed.

Table 1 – Orbital elements of the η-Aquarids.

ID	Date (YMD)	Time (UT)	α (2000.0)	δ (2000.0)	SD	V_G (km/s)	SD (km/s)
11862	19540503	$10^h49^m32^s$	336.°21	−01.°63		65.5	
KPM821	19820504	$18^h32^m08^s$	336.°69	−01.°43		66.0	
MSSP03	19870504	$19^h08^m01^s$	335.°27	−01.°75	0.°23	67.3	0.9
MSSP04	19870504	$19^h26^m12^s$	336.°29	−01.°48	0.°05	65.0	3.9
MSSP06	19890504	$18^h35^m18^s$	336.°42	−01.°19	0.°08	65.9	0.4
MSSP07	19890504	$18^{\circ}46^m14^s$	337.°26	−01.°34	0.°21	66.0	0.7
MSSP08	19890504	$18^h49^m35^s$	337.°08	−01.°67	0.°15	65.8	0.7
MSSP0A	19890504	$19^h26^m37^s$	338.°02	−01.°72	0.°45	63.9	1.0
MSSP0B	19890504	$19^h34^m00^s$	337.°17	−01.°46	0.°33	64.8	1.2
MSSP0C	19890504	$19^h45^m09^s$	337.°24	−01.°47	0.°09	65.2	0.3
MSSP0D	19890504	$20^h05^m04^s$	336.°64	−01.°42	0.°35	64.4	0.9
Mean	19890504.804		336.°97	−01.°41	0.°24	65.3	0.7
	SD $\pm$ 0.024		0.°48	0.°19	0.°14	0.7	0.3
MSSP0E	19890505	$18^h23^m51^s$	337.°63	−01.°28	0.°07	66.1	0.5
MSSP0F	19890505	$18^h26^m48^s$	338.°27	−01.°49	0.°10	65.1	0.6
MSSP0G	19890505	$18^h31^m12^s$	337.°65	−00.°91	0.°05	65.0	0.5
MSSP0H	19890505	$18^h36^m29^s$	337.°63	−01.°57	0.°36	65.0	0.5
MSSP0I	19890505	$19^h24^m21^s$	337.°68	−01.°52	0.°02	65.8	0.5
Mean	19890505.778		337.°72	−01.°36	0.°12	65.4	0.5
	SD $\pm$ 0.017		0.°22	0.°27	0.°14	0.5	0.0
MSSIE9	19950506	$16^h46^m03^s$	337.°80	−00.°93	0.°44	66.5	2.4
MSSIEH	19950506	$17^h39^m09^s$	337.°47	−00.°65	0.°36	66.8	0.5
MSSIU9	19970504	$17^h41^m47^s$	338.°28	−01.°56	0.°35	66.1	0.8
Halley							

As for double-station meteor observation of the η-Aquarids, only one meteor was photographed by a Super-Schmidt camera at Harvard University in 1954 [1] (ID is 11862). Then in 1982, a triple-station photographic meteor observation was made at the Damine observation station and the Electric Communication University and by Noriyuki Koshiyama [2] (ID is KPM821).

We conducted double-station photographic meteor observations in Australia three times, in 1986, 1987, and 1989, and then conducted double-station TV observations in Japan.

2. Observing equipment

For the double-station meteor observations in Australia, the equipment shown in Figure 1 was used. Four 35-mm film cameras were mounted and the meteor trail was interrupted at 1/50-second intervals by a rotating shutter. This instrument is called the 4-range camera. Four 4-range cameras were used during our observations in Australia. Although 16 cameras were needed, 12 cameras (Canon T-70) were used actually; $f/1.4$, $f = 50$ mm (Canon) lenses were employed.

The mean measurement accuracy (standard deviation) for the position of the η-Aquarids was $21''$.

Table 1 – continued.

ID	a (AU)	e	q (AU)	ω	Ω	i	Obs Mag	H_b (km)	H_e (km)
11862	13.2	0.958	0.560	95°2	43°1	163°5			
KPM821	18.2	0.968	0.582	98°1	44°2	163°7	−2	108.4	92.0
MSSP03	− 33.5	1.019	0.633	105°3	44°0	163°8	+0.5	110.8	101.2
MSSP04	6.96	0.918	0.568	95°0	44°0	163°3	+0.5	108.3	93.4
MSSP06	14.2	0.958	0.590	98°7	44°4	163°1	−1.0	105+	90.6
MSSP07	26.3	0.978	0.575	97°5	44°4	163°9	+1.0	109.9	102.3
MSSP08	14.8	0.961	0.576	97°2	44°4	164°4	+1.0	111.4	106.1
MSSP0A	4.79	0.892	0.518	88°2	44°5	164°6	+1.0	111.8	104.8
MSSP0B	6.50	0.915	0.553	93°2	44°5	163°8	+2.0	112.2	102.8
MSSP0C	8.50	0.934	0.560	94°6	44°5	164°0	−1.5	114.8	91.3
MSSP0D	5.10	0.891	0.559	93°1	44°5	163°4	+2.0	107.6	100.0
Mean	10.4	0.945	0.571	96°2	44°4	163°7	+0.6	111.3	99.7
		0.023	0.017	2°6	0°0	0°5	1.4	2.4	6.3
MSSP0E	20.3	0.971	0.589	98°9	45°4	164°2	−0.5	115.9	92.4
MSSP0F	7.88	0.929	0.556	93°9	45°4	164°8	+1.5	112.7	101.1
MSSP0G	6.98	0.919	0.565	94°7	45°4	163°2	+0.5	107.0	96.6
MSSP0H	6.48	0.912	0.568	94°9	45°4	164°5	+1.0	104.7	95.1
MSSP0I	11.8	0.951	0.583	97°7	45°4	164°7	+0.5	112.2	93.0
Mean	10.3	0.944	0.578	96°9	45°4	164°3	+0.6	110.5	95.6
		0.020	0.012	1°9	0°0	0°7	0.7	4.5	3.5
MSSIE9	71.2	0.992	0.600	100°8	45°8	163°8	+5.5	106+	102−
MSSIEH	− 85.6	1.007	0.613	102°7	45°8	163°1	+1.0	116+	103−
MSSIU9	109	0.995	0.551	95°2	44°3	164°9	+1.8	117+	106−
Halley	18.2	0.967	0.582	111°8	58°8	162°2			

In Japan, many people wished to purchase this 4-range camera, and all 30 cameras manufactured were quickly sold out. Another 100 units manufactured were also sold out in a few years.

For the double-station TV meteor observations in Japan, an image intensifier is used [3]. Objective lenses of $f/1.2$, $f = 50$ mm (Nikon) were used, and the photographic field of view was $13° \times 17°$. The mean measurement accuracy (standard deviation) for the position of the η-Aquarids was $175''$.

3. Observational results

During the double-station photographic meteor observations in Australia, we observed 14 meteors of the η-Aquarids (IDs are MSSP03–0I). The calculated orbits are listed in Table 1.

The results include the date of observation, the corrected radiant (eq. 2000.0), standard deviation of the corrected radiant, the geocentric velocity, the standard deviation of the geocentric velocity, the orbital elements (eq. 2000.0), the observed magnitude, as well as the beginning and ending heights. The results of the observations have already been reported by Lindblad et al. [4]. The present measurement was conducted by Shigeno, and there were some different results obtained, because he used a different calculation method for the orbit.

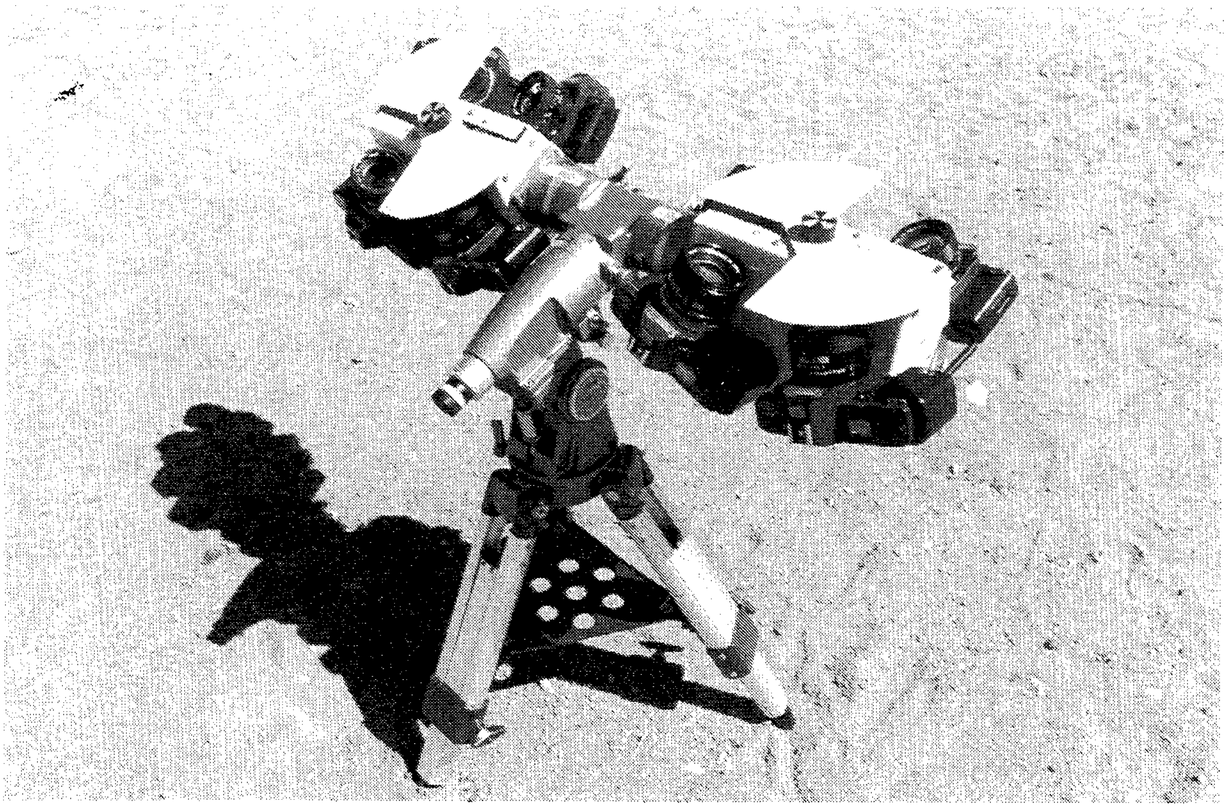

Figure 1 – Photographic equipment.

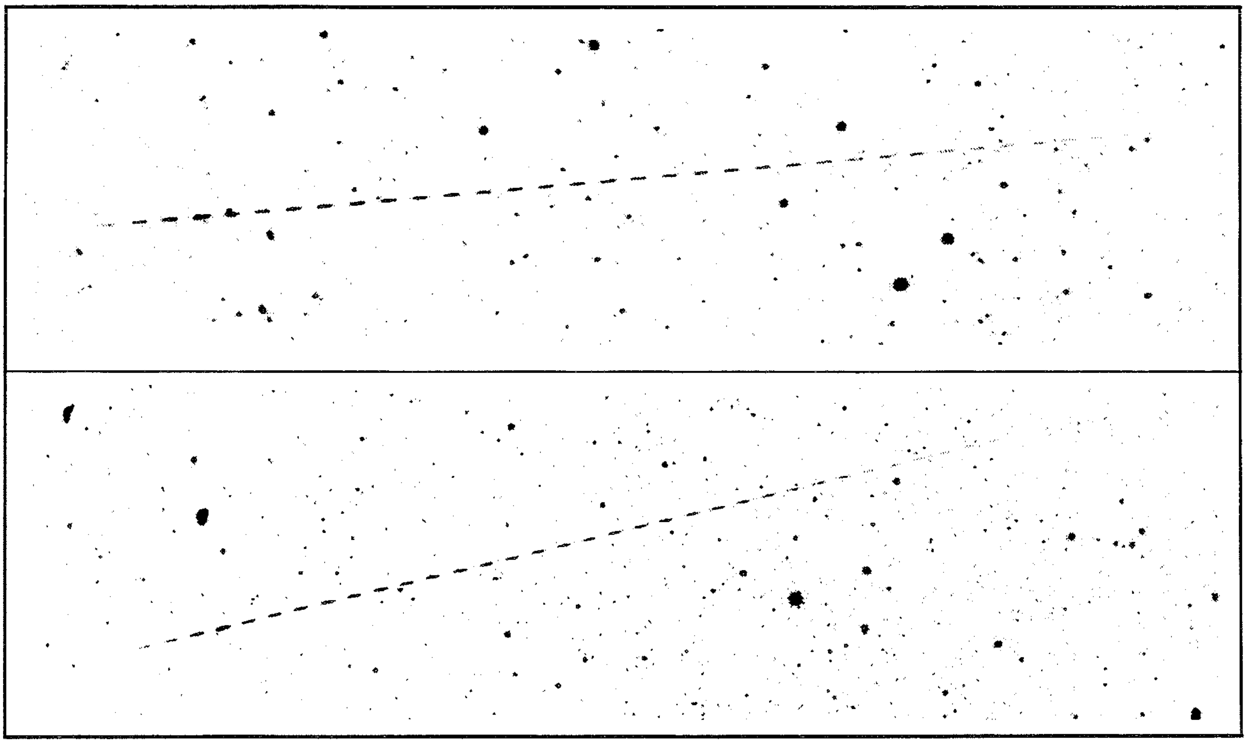

Figure 2 – Double-station photographic meteors (MSSPOE, May 5, 1989, $18^h23^m51^s$ UT).

Table 1 shows each mean and standard deviation for the seven meteors observed on May 4, 1989, and the five meteors observed on May 5, 1989. The comparison between the means on May 4 and May 5 shows very close agreement, indicating that the measurement accuracy was good. Figure 2 shows typical double-station meteor photographs.

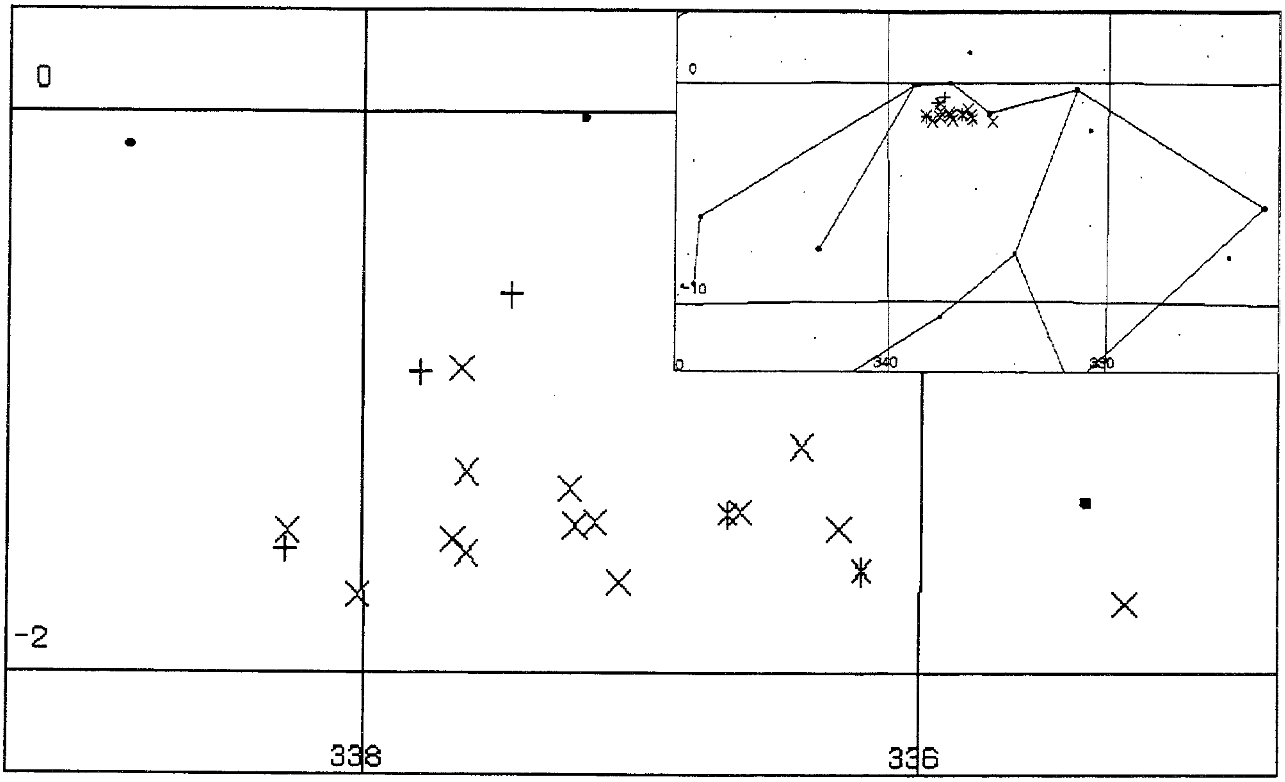

Figure 3 – Corrected radiant map with old photographic meteors ("$\star$," IDs 11862 and KPM821), our photographic meteors ("×," IDs MSSP03–0I), and our TV meteors ("+," IDs MSSIE9–U9).

Table 1 also shows the results from double-station TV meteor observations in Japan (IDs are MSSIE9–U9). Only three meteors remained as the result of selecting meteors having a standard deviation for the radiant of 0°5 or less. Although only meteors with good accuracy were selected, the accuracy of each orbit was inferior to that of the photographed meteors.

Figure 3 shows the corrected radiants of all meteors listed in Table 1, plotted on a star map.

4. Conclusions

There were only very few orbits of the η-Aquarids available, so that additional data are valuable. However, with the Advanced Meteor Orbit Radar (AMOR) in New Zealand, it was possible to determine 334 orbits within 21 days during the period from April 26 to May 16 in 1995 [5].

On the other hand, in Japan, which is in the northern hemisphere, observers can conduct double-station TV observations of the η-Aquarids, although continuous observation is difficult because of the poor weather conditions. TV observations from the southern hemisphere may yield about 20 orbits per day. We will continue TV observations of the η-Aquarids from Australia when the opportunity arises.

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Fireballs and Meteorites

Human Casualties in Impact Events

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It is a widespread error to believe that people were never killed by meteorites. It was concluded that there were no human casualties due to meteorite falls because there were no reports about such incidents, but there are reports of these rare events. The statement of no one ever being killed by a meteorite may intend that the danger even of asteroid and comet impacts onto the Earth is only fiction, but the danger is real. It is a low-probability-high-consequence event for large impactors (more than 1 km). Even from meteorites, however, people were reported struck to death. This article gives a survey over reports of human casualties from 616 A.D. well to our century.

1. Introduction

Collisions of near-Earth asteroids and comets (NEOs) with our planet are rare events, but coupled with high consequences depending on their size. Even small impactors (smaller than 100 m) cause severe local damage, and if they are larger than some 1 km to 3 km there will be a global climate change with dramatic consequences for life on Earth. The number of casualties for such global events is assumed to be on the order of millions to billions. This large number is derived mainly from indirect causes such as tsunamis, fires, and the lack of food after crop failures due to changes in climate.

However, even the relatively frequent impacts of small sized NEOs (less than 100 m) may cause considerable damage and should have been noticed and reported by our ancestors. It is very often believed that humans have never been killed by meteorites falling from the sky, but this statement seems to be wrong if we look into the details of historical reports.

2. Historical reports

In 1994, Yau et al. [1] presented their results of the search for meteorite falls in old Chinese history reports. Yau et al. found over 300 records of recovered witnessed meteorite falls in the period from 645 B.C. to 1920 A.D., and they found 7 events where people were reported to be killed by meteorites, the first one in the year 616 A.D. These reports seem to be reliable due to the fact that they are official reports of a Chinese dynasty, even though the large number of casualties in the 1490 event (more than 10 000 people killed) is doubtful. Other reports as presented by Lewis [2] were also included in the following listing:

- *January 14, 616 A.D.*: More than 10 people were crushed to death when a large shooting star fell onto the rebel Lu Ming-yueh's camp destroying a wall-attacking tower, China [1].
- *July/August 1020*: Some people killed by many stones in an unknown place in North-Africa [3].
- *around 1341*: It rained iron in the Province of Yunnan, China. Most of the people and animals struck by them were killed [1].
- *February/March 1490*: Stones fell like rain. They struck dead more than 10 000 people in the Ch'ing-yang district of Shansi Province, China. The stones had a weight from about 1.0 kg to 1.5 kg [1].
- *September 14, 1511*: Monk and several animals were killed at Cremona in Lombardy, Italy [2]. Many stones of at least 50 kg fell near the river Adda [4].
- *1633–1664*: Monk died after being struck on the thigh by a meteorite in Milan, Italy [2].
- *1639*: A large stone fell onto a market place killing several tens of people and destroying houses in the Ch'ang-shou county, China [1].
- *1648*: Two sailors killed by an eight-pound meteorite which fell on the ship Malacca going from Holland to Batavia [2].

- *July 24, 1790*: A meteorite crushed a cottage and killed a farmer and some cattle in Gascony, France [2].
- *January 16, 1825*: One man reported killed and one woman injured by a meteorite fall in Oriang, Malwate, India [2,4].
- *June 30, 1874*: During a thunderstorm, a huge stone fell from the sky in Chin-kuei Shan, China. It crushed a cottage and killed a child [1].
- *January 31, 1879*: Farmer reported killed by meteorite in Dun-le-Poelier, Indre, France [2].
- *September 5, 1907*: A stone fell and crushed a whole family to death in Hsin-p'ai Wei, China [1].
- *June 30, 1908*: Two men died of their injuries and several hundreds of reindeers were reported killed due to the Tunguska event in Siberia, Russia [5].
- *December 8, 1929*: A meteorite hit a bridal party and killed one person in Zvezvan, Yugoslavia [2].

The dates of the 1341 event in Yunnan, China, and the 1633–1664 event in Milan, Italy, are not certain, because there are several reports referring to the same event, but giving different dates. This may originate from errors when copying the reports in former times or from mistakes in the original reports.

Boschke [3] and Graham et al. [4] quote Chladni, who reported a meteorite fall in "Cassandria" or "Cassandra in Mazedonia" that burned a city and killed enemies by "stones of burnt soil." Graham et al. [4] and Aumann [6] mention that some stones were preserved as holy objects, but a date or more details of the fall are not available. Boschke [3] and Graham et al. [4] also report of a meteorite fall in the city of Elbogen (Zapadocesky) in Bohemia, Czech Republic, around 1400. There exists a legend that the tyrannical viscount was struck to death by this iron mass when calling his subjects to do compulsory work. Another version of this legend says that the viscount turned into this iron mass, which was therefore called "the Bewitched Viscount." The 107 kg iron mass was preserved in the town hall until 1811 and is of meteoritic origin, but the killing of the viscount is only delivered as a legend and is not officially confirmed.

Yau et al. [1], Lewis [2], Boschke [3], and Graham et al. [4] present as well reports where people were reported to be hit by meteorites but not killed and where also a lot of structural damage due to meteorite falls was reported. But these reports seem to be much more incomplete than reports of people being killed, especially in former times.

3. Interpretation

It can be seen from the listing in the previous section that individuals were hit directly by a single meteorite fall or during a meteorite shower whereas more people were killed by secondary effects such as collapsing walls and houses or by subsequent fires. It is not yet clear if meteorites can start fires due to their higher temperatures after passing the atmosphere [2,7], but they can start fires as well by secondary effects, e.g., when a collapsing house is ignited by its own fireplace. The high number of people being reported killed in the 616 event in China, in the 1639 event in the Ch'ang-shou county, China, in the 1907 event in Hsin-p'ai Wei, China, and especially in the 1490 event in the Ch'ing-yang district of Shansi Province, China, may result from such secondary causes. The description that "stones fell like rain" from reports of the 1490 event in China rises parallels to the meteorite showers at Pultusk, Poland (1868), Sikhote-Alin, Russia (1947), and Jilin, China (1976), where several thousands of meteorites fell to the ground. There were no reports of human casualties because these falls happened to occur in unpopulated areas.

Assuming an average surface of $AI = 0.3$ m^2 for everyone of the 6×10^9 humans on our planet as seen from a falling meteorite at some 70° above the horizon the individual risk (RI) being hit by a meteorite is given by equation (1). It is assumed that the Earth is homogeneously populated.

The land surface of the Earth AL is 1.325×10^{14} m^2, LT is the average human life time assumed to be 65 years, and $Nmet/y$ is the number of meteorite falls per year. As stated by Hughes [7], the influx of meteorites that were recovered is about 150 to 500 single meteorites over the globe each year or 40 to 130 single meteorites on land. The estimated influx is total 10 000 to 50 000 meteorites worldwide each year or 2800 to 39 000 on land. All further calculations are based on the numbers on land, because the number of people living on the sea is negligible:

$$RI = (AI/AL) \times Nmet/y \times LT. \tag{1}$$

The individual risk RI of being hit by a meteorite once in a lifetime is shown in Table 1. The worldwide average hit interval MHI is shown in equation (2). The factor RI/LT is the individual risk RI per year. In equation (2), WP is the world population:

$$MHI = \frac{1}{(RI/LT) \times Nmet/y \times WP}. \tag{2}$$

The average hit interval for the year 1997 corresponds to a world population WP of 6×10^9 people. The results represent people hit but not necessarily killed by meteorites. Because most meteorites are small (some 10–1000 g), people were often slightly injured but not killed. For establishing a rate of people being killed, an additional factor has to be considered. This factor could be 0.25 assuming that one out of four persons being hit by a meteorite would die due to their injuries, but this value is highly speculative and therefore not further considered.

It is obvious that the individual risk RI is always the same over the centuries when assuming a constant meteorite influx rate, whereas the average hit interval depends on the number of people living on our planet. While there are about 6×10^9 people living on our planet today, there were only 3×10^9 in 1960, 1.6×10^9 in 1900, and about 5×10^8 in 1500 [9]. For the 1892 to 1992 period, a mean Earth population of 2.9×10^9 people was assumed.

Table 1 – Individual meteorite hit risks and hit intervals for several influx rates.

Meteorite influx rate on land ($Nmet/y$)	Comments	Individual risk per lifetime (RI)	Meteorite hit interval (MHI) as of 1997 [yrs]	MHI average for 1892–1992 [yrs]
40	recovered, lower bound	5.88×10^{-12}	1840	3810
130	upper bound	1.91×10^{-11}	570	1180
2 800	predicted, lower bound	4.24×10^{-10}	27	55
39 000	upper bound	5.74×10^{-9}	2	4

Lewis [2] describes 8 events where people were hit by meteorites over the last 100 years (1892–1992). In this period, we have the largest number of such events and the most detailed reports. In these 8 events, more than 40 people were hit, injured, or killed. The resulting hit interval MHI of one event every 12.5 years fits well to the expected average hit interval MHI for the period from 1892 to 1992 (see Table 1), which was corrected for the changing world population in that time (2.9×10^9 persons in average). This result indicates that the predicted meteorite influx rates of 2800 to 39 000 individual falls per year over the land surface of the Earth as presented by Hughes [7] may apply, even when assuming uncertainty factors of 3 to 4. Therefore, a mean annual influx rate of about 8000 to 10 000 meteorites may apply for the 100 year interval from 1892 to 1992.

Nevertheless, there are some uncertainties due to possible variations in the influx rate, a growing number of people being protected by solid houses, missing reports, and other factors.

The expected number of human casualties due to larger events when explosions occur during the impact is much higher. According to Adushkin and Nemchinov [10], the average number N of people killed by an impact depending on the explosion energy E (in MT—megatons of TNT) is given by equation (3):

$$N = 2 \times 10^3 \times E^{2/3}. \tag{3}$$

The known number of people killed in the 10–15 MT Tunguska event is 2, the expected number from equation (3) is 9200–12 200 for a homogeneously inhabited Earth, and could have been as high as millions if a large city as Moscow, Berlin, or New York would have been hit. The real number of casualties is that low, because the impact area was in the sparsely populated Siberian taiga. From crater statistics [11] on Earth and Moon Tunguska-like events are assumed to occur once every 300 years or in even shorter intervals [12], but their effects may much more often be negligible (as in 1908 at Tunguska) than a catastrophe (when hitting a major city), because large parts of the Earth as the seas, deserts, and polar regions are nearly unpopulated.

For NEOs ranging from some 15 m to 200 m in diameter, depending on their density, the radius of destruction is larger in case of an airburst than it would be if the energy would have been released on ground [13]. Whether an incoming NEO will reach the ground or whether it will explode in the atmosphere depends on many factors such as its density, diameter, velocity, entry angle, and strength.

The record of human casualties due to impacts of asteroids and comets would be higher if tsunamis would be taken into account. Tsunamis (Japanese for "harbor waves") are large sea waves generated by earthquakes or impacts. Tsunamis are of low altitude at the sea (some centimeters to meters) but their height multiplies by factors of 15 to 25 or more when reaching the coast. Yabushita and Hatta [14] have shown that there is a 1% chance that a 200 m NEO will drop into the Pacific Ocean in the next century. Such an impact would produce a tsunami with a height range of 15 m to 60 m which will destroy nearly all buildings and cities located at the coastline. Tsunamis are reported having killed many thousands of people, even in our century, but it is mostly impossible to prove an impact origin.

It is not clear what fraction of all impact events was reported in human history. The lack of these reports may be due to the following reasons:

- impact records are not yet discovered in the archives;
- they were recorded only as myths, and are therefore not yet discovered or not reliable;
- they were lost (wars, fires, ...);
- they were not recorded (potential recorders may have been casualties);
- the impacts were not directly observed due to a sparsely populated world in ancient times; or
- meteorite falls were not recognized as what they are.

4. Conclusions

There are reports of human casualties due to meteorite falls from all over the world (but mostly from Europe and China) and from different ages. Those reports are often highly reliable especially when they are part of official historical documents or when they originate from several independent sources.

It was shown that the number of human casualties due to meteorite falls reported worldwide over the last 100 years (1892 to 1992) fits pretty well to the expected events derived from meteor observations.

There are discussions [15–17] about ancient impacts of small NEOs (more than 100 m) which may have caused severe destruction or even regional climate changes in former times, but these theories are not yet proved. Therefore, further studies have to be done to show that impacts have occurred in human history. But the danger from NEO impacts is real. Large impact events happen with statistically large impact intervals, but this has to be combined with high consequences for the inhabitants of our planet [18], and even more ordinary meteorite falls are causing human casualties.

Protection against NEOs is already technically feasible [18,19] and preserving our planet from NEO impacts will become the great task of mankind one day. The question is not if this will happen—the question is when.

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