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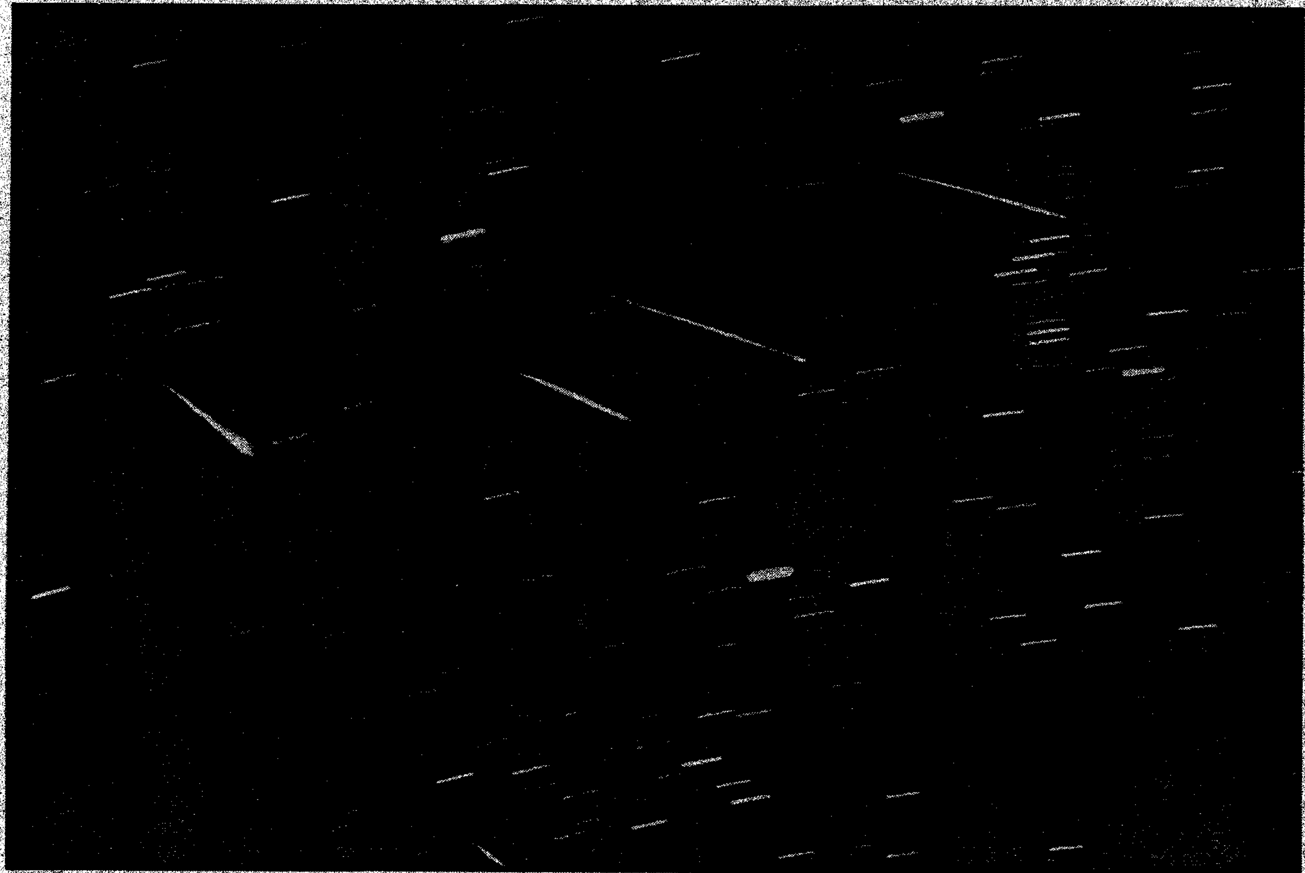

A bunch of Leonids captured by Lorenzo Lovato from Monte Romano, Italy, on November 17, 1998. The photo is one out of a sequence taken between November 16, 1998, 23^h00^m UT and November 17, 1998, 4^h00^m UT on Fuji 800 with a 16 mm, $f/2.8$ lens.

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- More info on the 1999 International Meteor Conference
- IMO financial support for participating at the 1999 IMC
- Leonid dust trails and meteor storms
- Life and work of Igor Stanislavovich Astapovich
- The angular velocity of a meteor
- Observational results

In case of non-delivery, return postage guaranteed. Please return to:
v.u.: Marc Gyssens, Heerbaan 74, B-2530 Boechout, Belgium

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Useful Information

The June issue *(WGN 27:3)*

The *June issue* will be mailed toward the end of June. Contributions are due on *June 4* at the latest. They should be sent to *Marc Gyssens*.

Subscriptions and ordering of publications

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

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

Possibilities for Financial Support to Participants of the 1999 International Meteor Conference

communicated by Marc Gyssens

At the last *IMC* in Stará Lesná, the *IMO* Council decided to create an *IMO Support Fund* from which, each year, up to 1000 EUR could be spent to support various meteor-related projects. Unfortunately, the rules for applying for support to this *IMO Support Fund* have not yet been drafted.

Nevertheless, we already want to activate the *IMO Support Fund* now to support attendance to the 1999 *IMC*, because we realize it is more expensive than usual, and we wish to encourage as many meteor workers as possible to participate in this important event. If you wish to apply for support, proceed as follows:

1. Send a proposal for support by ordinary mail or electronic mail to the President, Jürgen Rendtel (address on inside back cover). The proposal must be submitted by an *IMO* member, but may also request support for other meteor workers of the same local, regional, or national meteor group as the *IMO* member. The proposal must state that all the candidates are committed to attend the *IMC* (except unforeseen circumstances) if the requested support is accorded in full.
2. For each of the candidates, the proposal must contain an *IMC* registration form (unless such a form was already sent earlier) and a brief curriculum vitae, focusing on aspects relevant to meteor work. It is strongly suggested that at least one candidate proposes to give a talk at the *IMC* (to be indicated on the registration form), as this will dramatically increase the chance for success of the proposal.
3. The proposal must contain a motivation for attending the *IMC* and the importance of it to the person or group of persons requesting support.
4. The proposal must contain a budget for travel costs and registration, and the amount requested from the *IMO Support Fund*. Other sources of external support, or their absence, must be mentioned. Finally, the proposal must also indicate to which extent *IMO* support is essential for being able to attend the *IMC*.

All proposals must reach the President *no later than June 30*. The decision of the *IMO* Council will be communicated by July 15. If the requested support is accorded in full, the registration forms become final. If the requested support is not accorded, or only partially accorded, the candidates should inform the President by August 1 if they want to sustain or withdraw their registration. The accorded support will first of all be used to cover the registration fee(s); the remainder (if any) will be paid in cash at the *IMC*.

We strongly encourage all meteor workers who are motivated to attend the 1999 *IMC*, but who are prevented to do so by financial considerations, to make use of this opportunity and to apply for support. Below, the most relevant information concerning the 1999 *IMC* is summarized. On the next page, you find a registration form.

The 1999 International Meteor Conference

Frasso Sabino, Italy, September 23–26, 1999

Massimo Calabresi and Roberto Gorelli

The 1999 *International Meteor Conference* will be held in the historical village of Frasso Sabino in Italy and the local organization is in the hands of the *Associazione Romana Astrofili*. Frasso Sabino is located at 50 km from Rome along the Via Salaria. The Conference will be held near the village (at 1 km), in a locality called Osteria Nuova, on the Via Salaria, in an old 17th-century country palace built on top of a Roman tomb of the 2nd century BC, called "Grotta dei Massacci." This national monument has two lecture rooms and all facilities required for a conference. The participants will be lodged in a new hotel in Osteria Nuova at only 300 m from the lecture rooms. In Frasso Sabino, the *Associazione Romana Astrofili* has its astronomical observatory.

The conference will start on Thursday evening (September 23) and end on Sunday (September 26); the full registration fee amounts to 240 DEM. The payment includes accommodation in double rooms, meals, and a copy of the proceedings. Details about the registration procedure can be found on the Registration Form. There are many ways to reach the conference location, including good connections by bus from Rome and the Leonardo Da Vinci International Airport. By car, Frasso Sabino is located 25 km from the A1 motorway (take the exit *Roma Nord* in the direction of the city of Rieti) on a major road.

For further questions, the *Associazione Romana Astrofili* can be contacted via Mr. Fausto Porcellana (tel. +39(6)40 79 39 94, fax +39(6)40 79 36 30, email `fausto_porcellana@telespazio.it`), Mr. Roberto Gorelli (email `md6648@mclink.it`), and Dr. Massimo Calabresi (email: `mc7851@mclink.it`).

International Meteor Conference

Frasso Sabino, Italy, September 23–26, 1999

Registration Form

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

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

Name: ______________________________ Birth date: ______________

Address: ____

____

____

Phone: ______________ Fax: ______________ E-Mail: ______________

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

I intend to travel by __________, together with ______________________________

Additional requests:

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

For participants wishing to contribute to the program:

Lecture: ____

Duration: __________min. Required equipment: ______________________________

Workshop or discussion: ______________________________

Poster presentation: ______________________________ Space: __________ m^2

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

Date and signature: ______________________________

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

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

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

Ongoing Meteor Work

Leonid Dust Trails and Meteor Storms

Robert H. McNaught and David J. Asher

Leonid storms are caused by the Earth intersecting dense trails of dust ejected from Comet 55P/Tempel-Tuttle. Here, we extend existing studies by examining the higher ejection-velocity regions of young dust trails and the circumstances around the 2031 return of 55P/Tempel-Tuttle. A model of dust trail density is successfully fitted to the observed ZHR of storms. Based on this, predictions are made for encounters in the next few years and around 2031, giving both the times and rates of maxima. The most likely prospects for encounters are from 1999–2002, especially 2001 and 2002. Details of a storm in 1869 are presented and confirm that the time of maximum is predictable to 10 minutes accuracy or better. The consequences of these findings are applied to the satellite threat and to the methods of global analysis of Leonid rates.

1. Introduction

Meteor storms occur when the Earth passes through dense trails of meteoroids and dust such as those observed by the Infra-Red Astronomical Satellite [1]. The motion of Comet 55P/Tempel-Tuttle only has relevance, with regard to Leonid storms, in defining the initial orbits of the meteoroids at ejection. To understand Leonid activity requires a study of the perturbed motion of these meteoroids. It has been known for some time [2–4] that perturbations can be significantly different on Leonid meteoroids that are separated in mean anomaly. Extensive calculations about swarm/trail encounters covering the 19th and 20th centuries were first done by Kondrat'eva et al. [5] and later (without prior knowledge) by Asher [6].

The natural tendency is for the spatial density of meteoroids to decrease, trails becoming dispersed after many orbital revolutions. However, there does exist a dynamical mechanism, namely a mean motion resonance, that can cause meteoroids in the Leonid and other streams to remain very concentrated on longer time scales [7]. Thus, a second source of Leonid storms is meteoroids many revolutions old in the 5/14 resonance with Jupiter. Meteoroids from every return of the comet ultimately add to this, if ejection is within a suitable initial range of semi-major axes. This has been investigated for the 1998 Leonid fireball shower [8], the observed time of maximum for that outburst [9] being demonstrated to be consistent with the prediction from the resonant meteoroids and quite discrepant from the comet node (a difference of 0.8 day). Further study is required on these resonant meteoroids, but this source appears to have been involved in the fireball display of 1965 and maybe also in the storms of 1799 and 1832. These resonant meteoroids cover only around 10° of mean anomaly and so could generally be encountered at high strength only once per comet orbit.

It is not coincidental that the resonant mechanism leads to outbursts that are rich in fireballs. Larger particles, which produce brighter meteors, are expected to have lower ejection speeds from the comet nucleus. This means that they go on to orbits more similar to that of the comet (which is itself in the resonance) and so are more likely to be resonant. However, smaller particles are more numerous, and the highest ZHR storms result from younger trails, which are our subject here.

2. Extended table of dust node

Readers should refer to [6] for a description of why our method is appropriate for calculating dust trail positions. Briefly, the model has meteoroids ejected from 55P/Tempel-Tuttle at each perihelion and integrated until nodal crossing in any specific year. Thus, at the time of ejection, taken to be exactly at perihelion, the perihelion distance and the angular orbital elements are set equal to those of the comet, and the process iterates to find the precise value of the semi-major axis at ejection, a_0, that gives passage through the descending node at the time when the Earth reaches the orbital plane. We used the 15th order Radau integrator [10] in the

MERCURY integration package [11], kindly provided to us by John Chambers, with accuracy parameter 10^{-11} and perturbations from eight planets (Mercury to Neptune). Particles affected by radiation pressure must have smaller a_0 than listed in Table 1 in order to cross the ecliptic at the correct time. For example, $\beta = 0.001$ (ratio of the forces of radiation pressure and solar gravity) means that the correct effective a_0 is 0.2 smaller than that listed (cf. [6,12]). Possible variations in the trail geometry due to ejection away from perihelion or radiation pressure are discussed later (Sections 3 and 5).

Table 1 is an extended version of (some columns of) that given in [6], which included data for trails generated 1, 2, and 3 revolutions earlier, in the two years prior to, and four years after, the perihelion passage of 55P/Tempel-Tuttle. In the present paper, trails 4, 5, and 6 revolutions old are considered in the same years, and a larger range of ejection velocities (allowing nodal crossing to occur in years further from the comet's perihelion) are considered for the 1–3-revolution trails. As more revolutions are considered, the range of Δa_0 over these six years contracts, and encounters with trails of this age outside these years could still produce notable activity, albeit the ZHR will tend to decrease the older the trail. To save extensive further computation, reference was made to [5] for other possible years and trails older than 6 revolutions worthy of consideration; we selected for inclusion the 7-revolution trails in 1832 and 2001 and the 8-revolution trail in 2000 (the values in Table 1 being derived by ourselves).

Table 1 – Data for dust trails generated a reasonably small number of revolutions previously. Below, Δa_0 is the initial difference in semi-major axis from the comet that allows the nodal crossing to occur at exactly the relevant time in November of the year in question; r_D and r_E are the heliocentric distances of the dust trail's descending node and of the Earth at the same longitude; and f_M, the "mean anomaly factor," is inversely proportional to the stretching in mean anomaly that has occurred since ejection, normalized to a fixed, small interval in a_0 centered on the value of Δa_0 in question (refer to Section 5). The spatial density of a trail encountered by the Earth depends on Δa_0 (ejected meteoroids being concentrated towards orbits nearer the comet), $r_E - r_D$ (which gives a measure of the distance between the Earth and the center of the trail), and f_M (since the particle density decreases as the trail lengthens), as investigated quantitatively in Section 5. Finally, Ω is equal to the longitude of the Sun at the time of nodal crossing (calculated for orbit of Earth at relevant date, but expressed in J2000). A dash indicates that the relevant part of the trail had been disrupted to a greater or lesser extent (cf. [6]), a blank space simply that we did not attempt to calculate the data.

Year	Trails 1 revolution old				Trails 2 revolutions old				Trails 3 revolutions old			
	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω
1798	−0.28	+0.0043	1.08	233°04	−0.15	+0.0058	0.53	233°02	−0.09	+0.0017	0.41	232°15
1799	−0.07	+0.0032	1.00	233°04	−0.04	+0.0035	0.52	233°03	−0.02	+0.0018	0.27	232°84
1800	+0.14	+0.0028	1.00	233°03	+0.07	+0.0020	0.52	233°06	+0.02	+0.0060	0.17	233°32
1801	+0.35	+0.0029	0.95	233°02	+0.19	+0.0006	0.53	233°17	+0.06	+0.0105	0.15	233°58
1802	+0.56	+0.0029	0.95	233°04	+0.31	−0.0011	0.55	233°49	+0.09	+0.0134	0.18	233°95
1803	+0.76	+0.0022	0.95	233°18	+0.42	−0.0008	0.43	234°45	+0.12	+0.0208	0.11	234°84
1831	−0.25	+0.0034	1.00	233°16	−0.13	+0.0051	0.55	233°17	−0.10	+0.0068	0.40	233°16
1832	−0.04	+0.0014	1.00	233°18	−0.02	+0.0017	0.55	233°18	−0.02	+0.0019	0.39	233°17
1833	+0.17	−0.0003	0.95	233°18	+0.09	−0.0015	0.53	233°18	+0.07	−0.0028	0.45	233°21
1834	+0.38	−0.0017	0.95	233°18	+0.20	−0.0044	0.52	233°17	+0.15	−0.0070	0.61	233°27
1835	+0.59	−0.0026	0.95	233°18	+0.31	−0.0065	0.50	233°16	+0.24	−0.0107	0.39	233°42
1836	+0.79	−0.0033	0.95	233°18	+0.42	−0.0083	0.50	233°18	+0.33	−0.0142	0.43	233°80
1864	−0.25	+0.0124	1.06	233°96	−0.13	+0.0138	0.55	233°94	−0.10	+0.0156	0.41	233°95
1865	−0.04	+0.0072	1.00	233°32	−0.02	+0.0074	0.59	233°31	–	–	–	–
1866	+0.17	+0.0036	1.00	233°30	+0.09	+0.0026	0.55	233°31	+0.07	+0.0012	0.40	233°31
1867	+0.37	−0.0002	1.00	233°42	+0.20	−0.0026	0.55	233°43	+0.15	−0.0057	0.45	233°42
1868	+0.58	+0.0012	0.95	234°06	+0.31	−0.0044	0.54	234°03	+0.24	−0.0096	0.40	234°01
1869	+0.78	+0.0103	0.95	233°43	+0.43	+0.0055	0.53	233°49	+0.32	−0.0005	0.44	233°54
1897	−0.35	−0.0020	1.00	234°24	−0.18	+0.0008	0.45	234°93	−0.12	+0.0013	0.25	235°26
1898	−0.14	+0.0155	1.06	234°84	−0.07	+0.0167	0.55	234°96	−0.05	+0.0176	0.41	235°04
1899	+0.07	+0.0138	1.02	235°02	+0.04	+0.0132	0.54	234°98	+0.03	+0.0126	0.41	234°98
1900	+0.28	+0.0199	1.00	234°07	+0.15	+0.0182	0.55	234°02	+0.11	+0.0168	0.41	234°05
1901	+0.48	+0.0146	1.00	233°85	+0.25	+0.0125	0.53	233°82	+0.19	+0.0097	0.46	233°85
1902	+0.68	+0.0114	0.95	233°85	+0.36	+0.0086	0.59	233°85	+0.28	+0.0035	0.45	234°03

Table 1 – Data for dust trails (continued).

Year	Trails 1 revolution old				Trails 2 revolutions old				Trails 3 revolutions old			
	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω
1930	−0.36	+0.0075	1.00	235°09	−0.17	+0.0071	0.40	235°24	−0.12	+0.0018	0.32	235°39
1931	−0.14	+0.0065	1.08	235°09	−0.08	+0.0105	0.53	234°90	−0.06	+0.0125	0.37	235°09
1932	+0.07	+0.0060	0.95	235°09	+0.03	+0.0059	0.46	235°36	+0.02	+0.0059	0.31	235°43
1933	+0.28	+0.0054	1.00	235°15	+0.11	+0.0118	0.27	236°01	+0.07	+0.0135	0.16	235°99
1934	+0.49	+0.0040	0.95	235°50	+0.16	+0.0173	0.28	236°24	+0.10	+0.0182	0.21	235°95
1935	+0.69	+0.0182	1.00	235°96	+0.23	+0.0342	0.39	236°20	+0.16	+0.0327	0.41	235°66
1961	−0.75	+0.0109	1.14	235°03	−0.39	+0.0160	0.57	235°10	−0.25	+0.0078	0.42	234°93
1962	−0.53	+0.0083	1.08	235°06	−0.28	+0.0116	0.55	235°10	−0.18	+0.0114	0.28	235°27
1963	−0.31	+0.0059	1.00	235°09	−0.17	+0.0077	0.55	235°11	−0.13	+0.0136	0.34	235°10
1964	−0.10	+0.0038	1.00	235°12	−0.05	+0.0043	0.53	235°12	−0.04	+0.0063	0.44	234°95
1965	+0.11	+0.0023	1.00	235°13	+0.06	+0.0017	0.59	235°13	+0.04	+0.0015	0.37	235°45
1966	+0.32	+0.0016	0.95	235°13	+0.17	−0.0001	0.52	235°16	+0.09	+0.0033	0.19	235°94
1967	+0.53	+0.0012	0.95	235°13	–	–	–	–	+0.12	+0.0063	0.16	236°21
1968	+0.73	+0.0010	0.95	235°15	+0.39	−0.0036	0.55	235°44	–	–	–	–
1969	+0.93	0.0000	0.95	235°27	+0.51	−0.0058	0.54	236°09	+0.20	+0.0136	0.13	237°37
1992									−0.45	+0.0176	0.43	235°41
1993									−0.36	+0.0109	–	235°54
1994					−0.38	+0.0102	0.57	236°40	−0.28	+0.0155	0.12	236°43
1995					−0.26	+0.0168	0.57	235°48	−0.19	+0.0211	0.42	235°47
1996	−0.28	+0.0099	1.08	235°29	−0.15	+0.0126	0.55	235°27	−0.11	+0.0149	0.41	235°27
1997	−0.06	+0.0085	1.00	235°26	−0.04	+0.0091	0.55	235°26	−0.03	+0.0095	0.40	235°26
1998	+0.14	+0.0068	1.00	235°26	+0.08	+0.0055	0.55	235°27	–	–	–	–
1999	+0.35	+0.0047	0.95	235°28	+0.19	+0.0019	0.53	235°27	+0.14	−0.0007	0.38	235°29
2000	+0.55	+0.0031	0.95	235°29	+0.30	−0.0012	0.55	235°27	+0.22	−0.0051	0.38	235°32
2001	+0.76	+0.0022	0.95	235°29	+0.41	−0.0034	0.52	235°25	+0.30	−0.0086	0.39	235°39
2002	+0.96	+0.0018	0.95	235°27	–	–	–	–	+0.39	−0.0119	0.45	235°56
2003	+1.16	+0.0019	0.90	235°27	+0.63	−0.0061	0.49	235°23	+0.48	−0.0151	0.78	236°03
2004					+0.74	−0.0074	0.78	235°30	+0.56	−0.0167	0.32	237°14
2005					+0.85	−0.0099	0.50	235°63	+0.61	−0.0111	0.13	238°90
2006					+0.96	−0.0001	0.53	236°62	+0.63	+0.0106	0.08	240°21
2007									+0.65	+0.0214	0.08	238°99
2008									+0.67	+0.0254	0.12	238°24
2009									+0.70	+0.0264	0.18	237°46
2025									−0.38	+0.0026	0.10	237°13
2026									−0.34	+0.0122	0.20	237°19
2027					−0.39	+0.0126	0.57	235°82	−0.29	+0.0170	0.31	236°57
2028					−0.28	+0.0104	0.37	235°66	−0.22	+0.0156	0.42	235°90
2029	−0.32	+0.0071	1.00	235°88	−0.17	+0.0083	0.55	235°93	−0.13	+0.0112	0.42	235°97
2030	−0.11	+0.0219	1.00	236°21	−0.06	+0.0224	0.95	236°21	−0.04	+0.0232	0.44	236°21
2031	+0.10	+0.0183	1.00	235°42	+0.05	+0.0179	0.53	235°42	+0.04	+0.0171	0.41	235°42
2032	+0.30	+0.0154	0.95	235°36	+0.16	+0.0140	0.55	235°35	+0.12	+0.0114	0.46	235°36
2033	+0.51	+0.0133	0.95	235°38	+0.27	+0.0107	0.53	235°37	+0.21	+0.0063	0.42	235°36
2034	+0.71	+0.0112	0.90	235°40	+0.38	+0.0072	0.53	235°40	+0.29	+0.0010	0.44	235°37
2035	+0.91	+0.0094	0.95	235°43	+0.49	+0.0040	0.53	235°41	+0.38	−0.0039	0.39	235°35
2036					+0.60	+0.0013	0.52	235°41	+0.46	−0.0079	0.38	235°31
2037					+0.71	−0.0007	0.52	235°38	+0.54	−0.0111	0.40	235°26
2038					+0.82	−0.0021	0.50	235°34	+0.62	−0.0135	0.38	235°24
2039					+0.93	−0.0033	0.50	235°33	+0.70	−0.0158	0.36	235°30
2040									+0.78	−0.0192	0.38	235°56
2041									+0.87	−0.0229	0.41	236°73
2042									–	–	–	–

Year	Trails 4 revolutions old				Trails 5 revolutions old				Trails 6 revolutions old			
	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω
1798	−0.09	+0.0044	0.38	232.15	−0.08	+0.0069	0.29	232.36	−0.03	−0.0039	0.11	232.49
1799	−0.02	+0.0015	0.24	232.80	−0.01	+0.0015	0.25	232.77	−0.01	−0.0001	0.10	232.80
1800	+0.01	+0.0066	0.13	233°32	+0.01	+0.0068	0.10	233°32	0.00	+0.0083	0.04	233°25

Table 1 – Data for dust trails (continued).

Year	Trails 4 revolutions old				Trails 5 revolutions old				Trails 6 revolutions old			
	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω
1801	+0.03	+0.0114	0.10	233°.47	+0.03	+0.0114	0.09	233°.42	+0.01	+0.0144	0.04	233°.24
1802	+0.06	+0.0139	0.15	233°.72	+0.05	+0.0134	0.14	233°.60	+0.02	+0.0174	0.10	233°.21
1803	+0.08	+0.0218	0.09	234°.45	+0.08	+0.0213	0.33	234°.25	+0.04	+0.0252	0.08	233°.56
1831	−0.07	+0.0035	0.34	232°.50	−0.07	+0.0056	0.42	232°.34	−0.07	+0.0091	0.08	232°.47
1832	−0.01	+0.0012	0.20	233°.10	−0.01	+0.0011	0.17	233°.09	−0.01	+0.0010	0.16	233°.07
1833	+0.02	+0.0010	–	233°.47	–	–	–	–	–	–	–	–
1834	+0.05	+0.0013	0.12	233°.69	+0.03	+0.0022	0.08	233°.61	+0.02	+0.0023	0.07	233°.56
1835	+0.08	+0.0013	0.13	233°.90	+0.05	+0.0021	0.10	233°.72	+0.04	+0.0018	0.10	233°.63
1836	+0.11	+0.0022	0.12	234°.50	+0.07	+0.0032	0.09	234°.27	+0.06	+0.0029	0.09	234°.17
1864	−0.09	+0.0178	0.37	233°.93	–	–	–	–	−0.08	+0.0188	0.61	233°.07
1865	–	–	–	–	–	–	–	–	–	–	–	–
1866	+0.06	−0.0004	0.37	233°.33	+0.02	+0.0029	–	233°.60	–	–	–	–
1867	+0.14	−0.0093	0.44	233°.51	+0.05	−0.0019	0.12	233°.93	+0.03	−0.0010	0.08	233°.86
1868	+0.21	−0.0147	0.35	234°.22	+0.07	−0.0037	0.12	234°.73	+0.05	−0.0030	0.10	234°.56
1869	+0.29	−0.0078	0.36	234°.05	+0.10	+0.0058	0.13	234°.80	+0.07	+0.0069	0.10	234°.62
1897	−0.10	+0.0023	0.12	235°.45	−0.09	+0.0039	0.17	235°.54	−0.07	+0.0008	0.17	234°.85
1898	−0.05	+0.0187	0.35	235°.12	−0.05	+0.0201	0.36	235°.17	−0.03	+0.0187	–	234°.91
1899	+0.02	+0.0119	0.36	234°.97	+0.02	+0.0110	0.34	234°.98	+0.01	+0.0124	0.15	235°.13
1900	+0.10	+0.0145	0.59	234°.05	+0.10	+0.0112	0.35	234°.11	+0.04	+0.0165	0.05	234°.49
1901	+0.17	+0.0048	0.40	233°.87	+0.18	−0.0017	0.49	234°.11	+0.06	+0.0077	0.14	234°.67
1902	+0.25	+0.0044	0.24	234°.46	+0.24	+0.0062	0.44	234°.69	+0.09	+0.0187	0.11	235°.14
1930	−0.10	+0.0011	0.23	235°.55	−0.08	+0.0018	0.18	235°.70	−0.08	+0.0031	0.16	235°.82
1931	−0.05	+0.0134	0.31	235°.26	−0.05	+0.0143	0.13	235°.40	−0.05	+0.0154	0.24	235°.54
1932	+0.02	+0.0058	0.25	235°.48	+0.02	+0.0054	0.23	235°.52	+0.02	+0.0049	0.23	235°.57
1933	+0.05	+0.0137	0.13	235°.98	+0.05	+0.0132	0.12	235°.96	+0.05	+0.0121	0.15	235°.95
1934	+0.08	+0.0175	0.25	235°.81	+0.08	+0.0158	0.23	235°.69	+0.09	+0.0128	0.28	235°.59
1935	+0.14	+0.0299	0.35	235°.43	–	–	–	–	–	–	–	–
1961	−0.20	+0.0126	0.26	235°.42	−0.14	+0.0124	0.12	235°.90	−0.12	+0.0122	0.08	236°.07
1962	−0.14	+0.0054	0.32	235°.31	−0.12	+0.0064	0.20	235°.59	–	–	–	–
1963	−0.09	+0.0111	0.19	235°.48	−0.08	+0.0087	0.16	235°.66	–	–	–	–
1964	−0.04	+0.0088	0.04	234°.99	–	–	–	–	−0.04	+0.0128	0.27	235°.30
1965	+0.03	+0.0018	0.21	235°.57	+0.02	+0.0019	0.19	235°.66	+0.02	+0.0016	0.04	235°.71
1966	+0.06	+0.0051	0.11	236°.00	+0.05	+0.0056	0.09	236°.02	+0.04	+0.0053	0.08	236°.03
1967	+0.08	+0.0082	0.11	236°.10	+0.06	+0.0084	0.10	236°.04	+0.06	+0.0075	0.14	235°.98
1968	+0.11	+0.0096	0.16	236°.30	–	–	–	–	–	–	–	–
1969	+0.13	+0.0157	0.11	237°.00	+0.12	+0.0157	0.12	236°.81	+0.13	+0.0135	0.17	236°.60
1996	−0.10	+0.0215	0.33	235°.15	−0.08	+0.0217	0.18	235°.55	−0.07	+0.0195	0.14	235°.78
1997	−0.03	+0.0107	0.40	235°.14	−0.03	+0.0130	0.59	235°.11	–	–	–	–
1998	+0.04	+0.0040	0.29	235°.63	+0.03	+0.0044	0.18	235°.79	+0.03	+0.0044	0.04	235°.85
1999	+0.08	+0.0016	0.17	236°.04	+0.06	+0.0034	0.10	236°.13	+0.05	+0.0039	–	236°.16
2000	+0.11	+0.0008	0.13	236°.28	+0.07	+0.0028	0.09	236°.23	+0.06	+0.0030	0.08	236°.19
2001	+0.14	+0.0002	0.13	236°.46	+0.09	+0.0017	0.11	236°.29	+0.08	+0.0014	0.13	236°.20
2002	+0.17	0.0000	0.15	236°.89	+0.12	+0.0015	0.12	236°.72	+0.11	+0.0014	0.13	236°.67
2003	+0.20	+0.0031	0.10	237°.62	+0.14	+0.0059	0.08	237°.29	+0.12	+0.0062	0.08	237°.12
2029	−0.11	+0.0144	0.49	236°.02	−0.12	+0.0228	0.34	236°.05	−0.09	+0.0204	0.19	236°.53
2030	−0.04	+0.0242	0.38	236°.21	–	–	–	–	−0.05	+0.0321	0.50	236°.18
2031	+0.03	+0.0161	0.36	235°.42	–	–	–	–	+0.03	+0.0150	–	235°.84
2032	+0.11	+0.0086	0.36	235°.36	+0.07	+0.0092	0.14	236°.02	+0.05	+0.0107	0.10	236°.15
2033	+0.18	+0.0016	0.35	235°.39	+0.11	+0.0054	–	236°.29	+0.07	+0.0072	0.09	236°.29
2034	+0.25	−0.0054	0.36	235°.43	+0.13	+0.0012	0.13	236°.46	+0.09	+0.0028	0.10	236°.33

Year	Trails 7 revolutions old				Trails 8 revolutions old			
	Δa_0	$r_E - r_D$	f_M	Ω	Δa_0	$r_E - r_D$	f_M	Ω
1832	0.00	+0.0004	0.06	233°.09				
2000					+0.06	+0.0008	0.27	236°.10
2001	+0.08	−0.0004	–	236°.11				

3. Use of comet and dust node to predict peak time

Much of the uncertainty in predicting Leonid storms in the past has been due to the reliance on the comet's nodal longitude and distance, to predict activity. Based on the dust trail data in [6] and the observed times of maxima in [13], it has been shown [14] that the comet's orbit only gives a first approximation to predicting storms, but that the dust trails represent the time of maximum of a storm to within the uncertainty of the observed maximum (±8 minutes in the best observed cases).

It must be stated that the priority in these calculations belongs to Reznikov for the general technique and to Kondrat'eva, Murav'eva, and Reznikov [5] for application to the Leonids. However, the independent work by Asher [6] provided a resolution in nodal longitude of $0\overset{\circ}{.}01$ (about 15 minutes) as opposed to the $\sim 0\overset{\circ}{.}1$ (2.4 hours) of [5]. It is this additional resolution in the nodal longitude that has allowed a critical check on past showers [14] and gives us reason to be confident in predicting the time of maximum of future Leonid storms. The results in [6] and in this paper confirm the times and distances of encounters given in [5] with only some minor differences. Between 100 and 200 years in the past, there appears to be a slight but systematic and unexplained difference in encounter distance ($r_E - r_D$) of between +0.0001 and +0.0002 AU ([5] relative to [6]). One date in [5] appears to be wrong: from [6], we find November 13.8 UT for 1802, whereas Kondrat'eva et al. [5] have November 13.2 UT, possibly duplicated in error from their line immediately above. The encounter distance for the 1866 trail in 2000 is misprinted in [5] and should be +0.00078 AU (Emel'yanenko, *private communication*), confirmed in Table 1.

The validity of a 5th decimal in r_D is questionable as a result of various unconsidered factors like ejection away from perihelion and solar radiation pressure. Preliminary simulations incorporating these suggest that the structure of the dust trail is not uniform. On these grounds, we believe the true center of the dust trail is slightly beyond r_D, but that the peak density is towards the inside of the trail (see Figure 1, later). For these reasons, the 5th decimal in r_D is only partly justifiable. Comparison of our values of $r_E - r_D$ and those in [5] also suggest the differences in this 5th decimal are partly random.

In Table 2, the observed and calculated nodes are given to 3 decimal places for the four showers with well-observed maxima. The simulations just mentioned suggest that the longitude is less sensitive to the unconsidered factors than r_D is, and, even if the accuracy is not quite 1 in the 3rd decimal, the very small residuals against the observed time of maximum given in [13] seem instructive. Even the worst of these well-defined maxima has an O−C of only 7 minutes! The maximum in 1833 is poorly defined and the large residual (45 minutes) may be unimportant.

McNaught [14] showed that, for years with maximum ZHR smaller than around 500, the time of maximum may be poorly defined using predictions based on distant dust trails. This is largely a result of the background dominating the activity curve. However, hidden within the activity, a peak due to the dust trails (the "storm peak") can sometimes be discerned. This was the case in 1965 and 1998 with a peak of faint meteors present close to the correct longitude, but of lower rates than the fireball shower. Several years from the comet's return, when the background rates of Leonids are sufficiently low, a close approach to a dust trail can produce a distinct, short-lived and well-predictable shower. This occurred in 1969 [13], when the observed peak reached a ZHR of 300, and differed in time by only 7 minutes from the calculated dust trail node.

4. Storms since 1833

Over the next four years, the Earth will closely encounter individual dust trails at various distances. To predict the circumstances, it is necessary to examine the past close approaches to such dust trails. Table 2 lists the circumstances of storms using the dust trail data from Table 1 and the observed ZHR from [13]. The ZHRs quoted in [13] are not fully corrected owing to the heterogeneous data and lack of information in many of the primary sources used, but the uniform analysis by Brown makes the data set as uniform as might ever be expected. The data for 1867 have been adjusted to correct for moonlight interference using the value suggested in [13].

Table 2 – Data for storms (excluding 1799 and 1832) and the well-defined 1969 outburst.

Year	Trail	Obs. node (J2000)	Calc. node (J2000)	O − C	Δa_0 (AU)	$r_E - r_D$ (AU)	f_M	ZHR
1966	2 rev	235°160	235°158	+0°002	+0.17	−0.00014	0.52	90 000
1833	1 rev	233°15	233°184	−0°03	+0.17	−0.00029	0.95	60 000
1866	4 rev	233°337	233°333	+0°004	+0.06	−0.00036	0.37	8 000
1867	1 rev	233°423	233°420	+0°003	+0.37	−0.00021	1.00	4 500
1969	1 rev	235°277	235°272	+0°005	+0.93	−0.00005	0.95	300

Since 1833, specific attention has been paid to recording Leonid activity; so, looking for other years that had close approaches to dust trails would be a useful check on the validity of using the dust trails as the main predictor of high activity. The circumstances of encounter with trails up to 6 revolutions old and passing within 0.0010 AU of the Earth are given in Table 3.

Table 3 – All additional approaches to dust trails since 1833 that are within 0.0010 AU and up to 6 revolutions old.

Year	Trail	Obs. node (J2000)	Calc. node (J2000)	O − C	Δa_0 (AU)	$r_E - r_D$ (AU)	f_M	ZHR
1869	3 rev	233°533*	233°536	−0°003*	+0.32	−0.00053	0.44	1 000
1897	6 rev		234°852		−0.07	+0.00079	0.17	
1897	2 rev		234°929		−0.18	+0.00075	0.43	
1968	1 rev	235°65	235°147	+0°50	+0.73	+0.00095	0.95	~ 110

* Time assumed to be local and converted from longitude. See text.

Activity in 1869 could have been expected around November 14.02 UT from western Asia, eastern Europe, and the Middle East. This shower is mentioned by Kronk [15], and the author was contacted regarding the details. We are most indebted to Gary Kronk for his immediate reply giving the full text from his primary reference [16]. Mr. Meldrum and six other observers at Port Louis Observatory and other parts of the island of Mauritius in the Indian Ocean made a specific watch for Leonids on the nights of November 12-13, 13-14, and 14-15. It was on the morning of the November 13-14 night, just at the start of twilight that the peak was observed. Meldrum wrote the following:

> *"I have not had time to analyze the observations carefully, but the time of maximum intensity was about* $4^{h}09^{m}$ *a.m. The only source of doubt in this subject arises from the circumstance that after* $4^{h}15^{m}$ *daylight was setting in."*

Observations continued until $4^{h}40^{m}$ a.m. On the assumption that the time system used was local, as was the function of such observatories for the setting of ship's chronometers, we have corrected these times to UT using a longitude of $\lambda = 57°30'$ for Port Louis as given in the *Times Atlas of the World*. This is $3^{h}50^{m}$ ahead of UT, and the observed time of maximum converts to November 14, $0^{h}19^{m}$ UT. The calculated longitude for the responsible dust trail was $\lambda_{\odot} = 233°536$ (J2000), which converts to November 14, $0^{h}24^{m}$ UT. As Meldrum notes that twilight could have affected the time of maximum, the influence through loss of meteors in the morning twilight would act to make the true maximum later than observed, if it had any influence at all. This could bring the observed and predicted times into even closer agreement. Nautical twilight is calculated to have started at $4^{h}20^{m}$ a.m., in accord with Meldrum's statement.

Meldrum quotes a number of watch durations and meteor counts from which an effective ZHR at maximum of close to 1000 seems to be a reasonable conclusion after making appropriate corrections for factors they mention. It is probable that the rates at maximum were double those half an hour earlier. A fuller account of this shower will be presented as a separate paper.

The two trails in 1897 represent meteoroids on orbits with smaller semi-major axis than 55P/Tempel-Tuttle, something that is known to be less common following ejection. Hasegawa [17] mentions strong activity as seen from Beijing Observatory on November 14–15, 1897, but the maxima predicted from the dust trails are November 15.50 and November 15.57. These would have been visible from western North America, but it would appear that nothing substantial was observed.

The trail in 1968 is of meteoroids with high ejection velocity, although of lower velocity than in the 1969 outburst. This trail and the two trails of 1897 are not approached closely. With values of Δa_0 somewhat outside the range of known storms no substantial activity would be expected. The 1-revolution trail in 1968 is evidently not what was observed at longitude $\lambda_\odot = 235^\circ\!.65$.

5. A model of the relative spatial density

As noted in the Introduction, Leonid storms can result from two causes: close approaches to a single recent dust trail or an encounter with the dense resonant zone. As the storms of 1799 and 1832 were rich in fireballs and probably contain a component of such resonant meteoroids, they are excluded from this analysis. It is also clear from [5] that both these storms comprised encounters with multiple dust trails.

Here, making the assumption that all recent dust trails are created equal, an attempt is made to fit the dust trail parameters, Δa_0, $r_{\rm E} - r_{\rm D}$, and f_M, of the storms listed in Tables 2 and 3, to the observed ZHR. If this can be done, then storm ZHRs can be predicted.

All the observed storms had small negative values of $r_{\rm E} - r_{\rm D}$. This need have no special significance as there simply happen to be no values of $r_{\rm E} - r_{\rm D}$ between -0.0001 and $+0.0008$ since 1833. The values for 1799 and 1832 were -0.0005 and $+0.0005$, respectively, for the several dust trails given in [5] that are older than the ones we considered here. An attempt to fit the observed ZHRs for storms was made initially on the assumption that the density profile in $r_{\rm E} - r_{\rm D}$ is a Gaussian distribution centered on zero. The simulations mentioned earlier (Section 3) produce an elliptical cross section on intersection with the ecliptic, but with a concentration towards the inside of the ellipse (Figure 1). Thus, calculations were also made with the center of the dust trail at distances $r_{\rm D} + 0.0001$ AU and $r_{\rm D} + 0.0002$ AU, values that seem appropriate for the possible outward shift of the trail center.

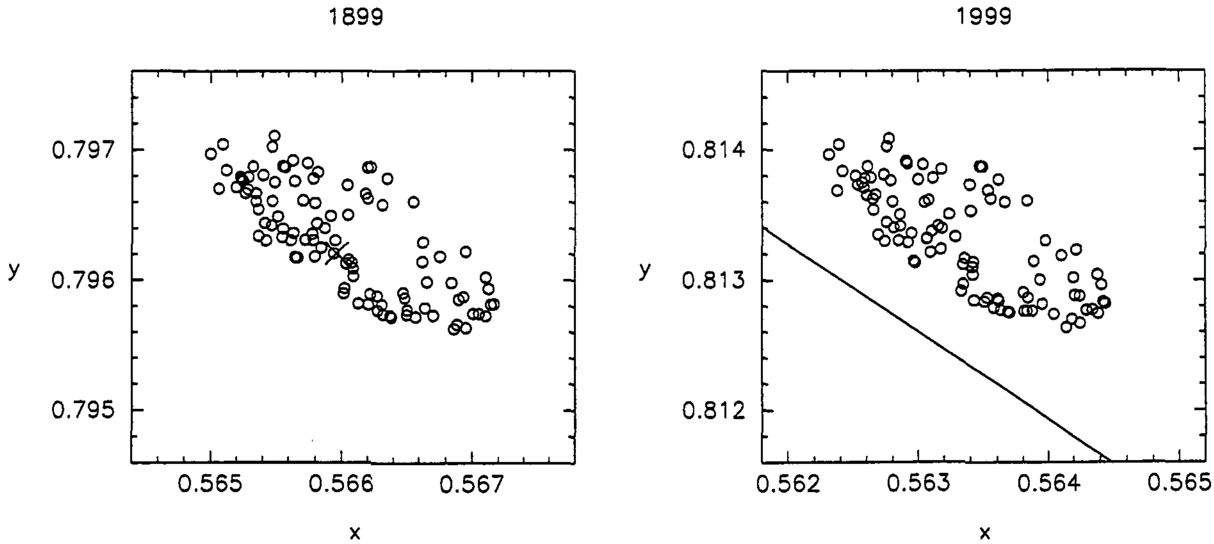

Figure 1 – Cross section in (x, y) ecliptic coordinates of trail generated in 1899, at epoch of ejection and at nodal crossing in 1999. Initial elements of particles were generated by assuming ejection uniform in true anomaly, isotropic, and at $25/r$ m/s (cf. Figure 2), but only particles with appropriate a_0 were integrated and plotted. In the 1899 plot, the cross is the comet's node (which is in a different part of the ecliptic and so not on the 1999 plot). The line on the 1999 plot is the Earth's orbit; slightly higher ejection speeds would bring orbits to Earth intersection.

To fit the observed ZHR to the dust trails, it is necessary to have a relationship defining the relative spatial density of the trails. In a given trail encounter, particles have a tightly constrained value of Δa_0 (Section 2). Therefore, trails' relative densities depend on the relative amount of material ejected on to orbits with different values of Δa_0 (Figure 2), with an effective value of Δa_0 of about +0.2, believed to be a good representation for the bulk of the meteoroids in the stream that are of a size that produce visual meteors. Lower and higher values of Δa_0 will be represented by lower spatial densities and also by a variation in mass. Higher mass meteoroids will tend to be at values of Δa_0 closer to zero.

The initial density is diluted by the stretching of the trail as it evolves. The contribution of this stretching factor to the density can be derived from integrations. Unlike the $r_{\rm E} - r_{\rm D}$ and Δa_0 factors, it is not dependent on the ejection model, and no parameters need fitting. To calculate the stretch of a particular trail, a few particles were ejected at perihelion with orbits identical except for increments in e of 0.000 001, all of which crossed the ecliptic very close to the correct time in November in the relevant year (Earth encounter occurring if $|r_{\rm E} - r_{\rm D}|$ is small). The average difference in mean anomaly M between these particles at the time of encounter gives an indication of the linear stretching, and we introduce a "mean anomaly factor" f_M (Table 1) which decreases as the stretch increases.

Examination of Figure 1 indicates that, to a high degree of accuracy, the dispersion in the other elements does not increase from that at formation during the early evolution of dust trails. It would appear, therefore, that the spatial density decreases linearly with the stretch in M. Thus the variable that is fitted is ZHR/f_M, where f_M normalizes the data to the median stretch value of a 1-revolution trail. No account of dispersion of particles with size due to radiation pressure is considered although it undoubtedly occurs and has the effect of a small outward shift of the center. This would indicate that the mass index will be higher for encounters at positive $r_{\rm E} - r_{\rm D}$.

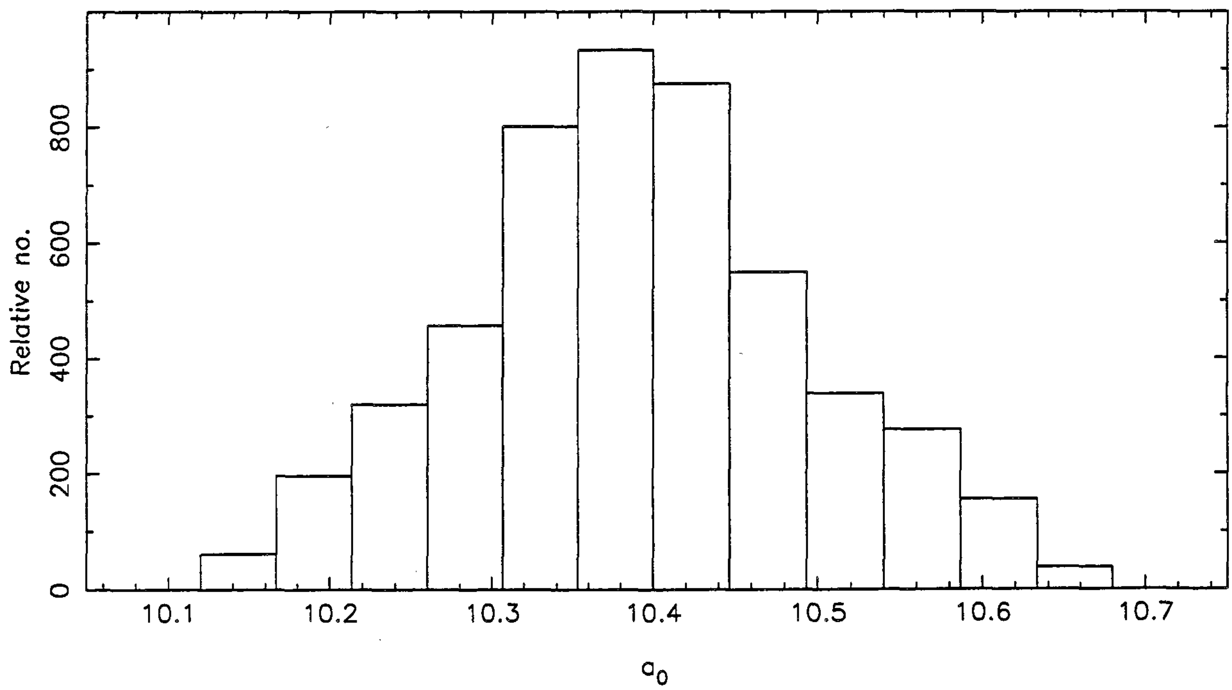

Figure 2 – Initial distribution in semi-major axis of particles ejected uniformly in true anomaly within heliocentric distance $r < 3.4$ AU, ejection velocities being isotropic at $25/r$ m/s. This is probably a reasonable ejection model (see [18]) but there are still free parameters. For example, lower ejection velocities would narrow the distribution. The distribution is centered on the comet's a_0. Particles affected by radiation pressure having the same a_0 as the comet will fall behind the comet, i.e., their *effective* value of a_0 will be greater. This shifts the distribution to the right, but the shift depends on the radiation pressure parameter, which varies among meteoroids. However, to keep our model manageable, it appears acceptable to use a Gaussian distribution, with mean and dispersion to be fitted.

The fit to the data was by a two dimensional Gaussian profile to Δa_0 and $r_E - r_D$. With the observed ZHR being only proportionately correct, a least-squares fit to the fractional residuals was made. This put the maximum in Δa_0 at +0.16 to +0.17 for radial profiles with the center assumed to be in the range r_D to $r_D + 0.0002$ AU. These fits are good for most of the storm data (mean fractional error 10–15%). These data and the observed ZHRs (normalized to 1 revolution) are plotted in Figure 3. It is clear that there is both a paucity of data and a paucity of potential data from past encounters to help refine the fit. The center of the Gaussian can be fitted to a center as small as $r_D - 0.0002$ AU, but with errors of around 25%. Larger values of $r_E - r_D$ are fitted with decreasing errors, but then an anomaly arises that a major storm should have occurred over western Europe in 1801, when at present no activity is known. This is discussed later (Section 7).

The parameters of the fit are given in Table 4. The peak ZHR is the rate that would be encountered by passage through the center of a 1-revolution old dust trail. This potential peak value has to be reduced by the f_M for a specific dust trail.

Table 4 also displays the drop off in rates over the radius of the Earth (0.000043 AU) on the flanks of the profile of a 1-revolution trail. This has significance in the global analysis of meteor rates. The effect is modified by f_M for older trails, and would have to be calculated individually for every storm. With the indication that parts at least of dust trails retain their shape over many revolutions (at least in the case of the Leonid trail cross section simulation mentioned here), this effect will have to be considered for a short outburst from any shower. The center and shape of the profile would have to be known for the specific correction factor to be calculated.

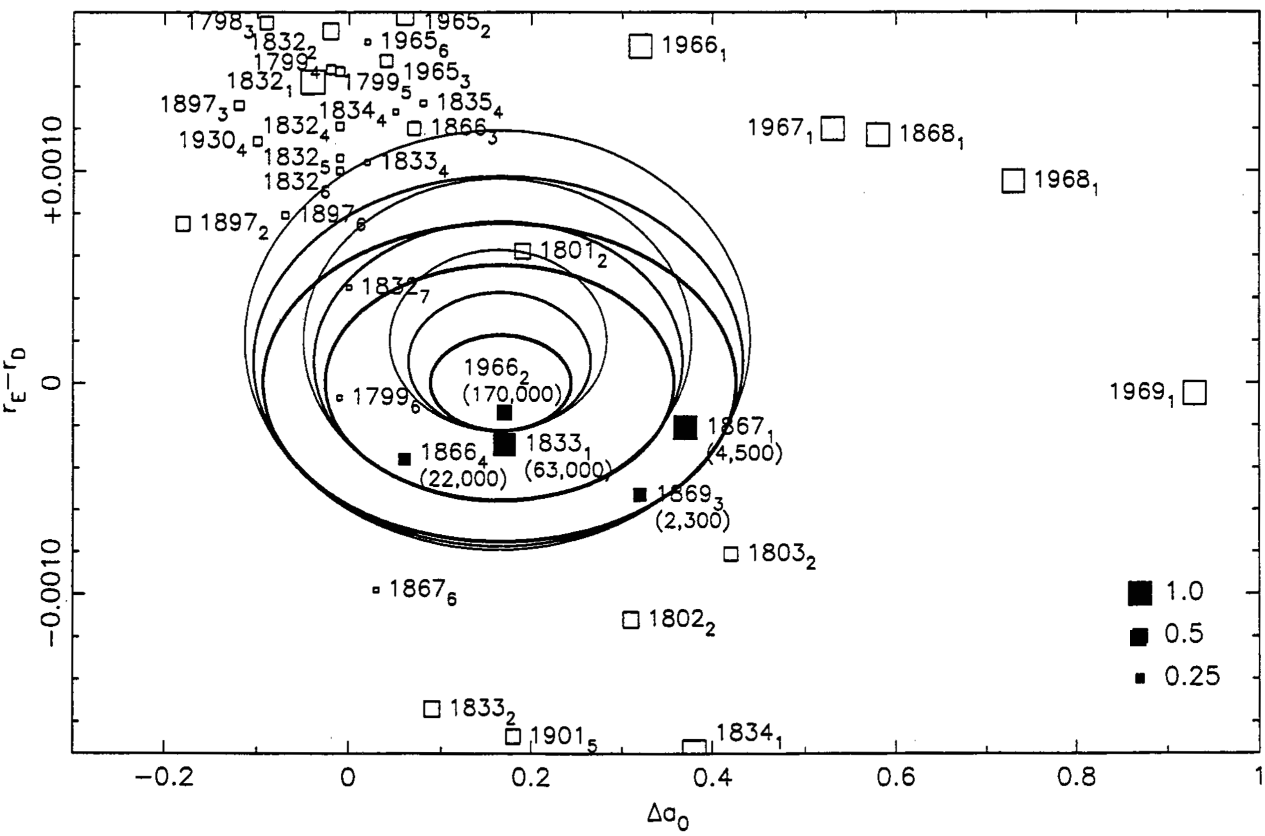

Figure 3 – Variation of ZHR with the three parameters, $r_E - r_D$, Δa_0, and f_M, given in Table 1. As the effect of f_M on the ZHR is calculable from integrations, ZHR/f_M is fitted to $r_E - r_D$ and Δa_0. The five solid squares are the points (Tables 2 and 3) used to derive the fit (observed ZHR/f_M in parentheses), and the elliptical contours represent the fit itself. Three fits have been done, successively assumed to be centered on r_D, $r_D + 0.0001$ AU, and $r_D + 0.0002$ AU, shown as lines of decreasing thickness. In each case the inner, middle, and outer contours correspond respectively to values of ZHR/f_M of 10^5, 10^4, and 10^3. Larger squares are drawn for larger values of f_M, the size of square being illustrated for values of f_M of 1.0, 0.5, and 0.25. Multiplying the fitted ZHR/f_M by f_M gives the estimated ZHR.

Table 4 – Characteristics and consequences of the fit. Fit 0 is centered radially on r_D, Fit 1 on r_D + 0.0001 AU, and Fit 2 on r_D + 0.0002 AU.

Fit no.	Mean fractional error, %	Peak ZHR	Δa_0	FWHM Δa_0	FWHM r	Percentage drop over 1 Earth radius at distance from trail center, AU			
						0.0002	0.0004	0.0006	0.0008
0	14	160 000	+0.17	0.19	0.00056	13%	25%	35%	45%
1	11	210 000	+0.16	0.19	0.00062	10%	21%	30%	37%
2	10	290 000	+0.16	0.19	0.00064	8%	17%	25%	32%

Extrapolation of the double Gaussian storm profile predicts a ZHR of zero for the 1-revolution trail encountered in 1969, when, as mentioned, the observed peak ZHR was 300. This is hardly surprising, with the sparse and unreliable data used in the fit, and the likelihood that a Gaussian is not a good representation of the spread in Δa_0 this far from the dense storm region. The wings of the Gaussian profiles represented in [13] in every case show activity enhanced above the profile. Whilst the storm peak seems well presented, it appears necessary to use another profile for the overall structure of the dust trail. One such attempt has been made by Jenniskens [19].

6. Predicting time and ZHR of maximum

Encounters at the current epoch

Figure 4 shows that some of the dust trails encountered in the next few years, 1999, 2001 (7-revolution), and 2002, can be interpolated or reasonably extrapolated from the existing data (cf. Figure 3).

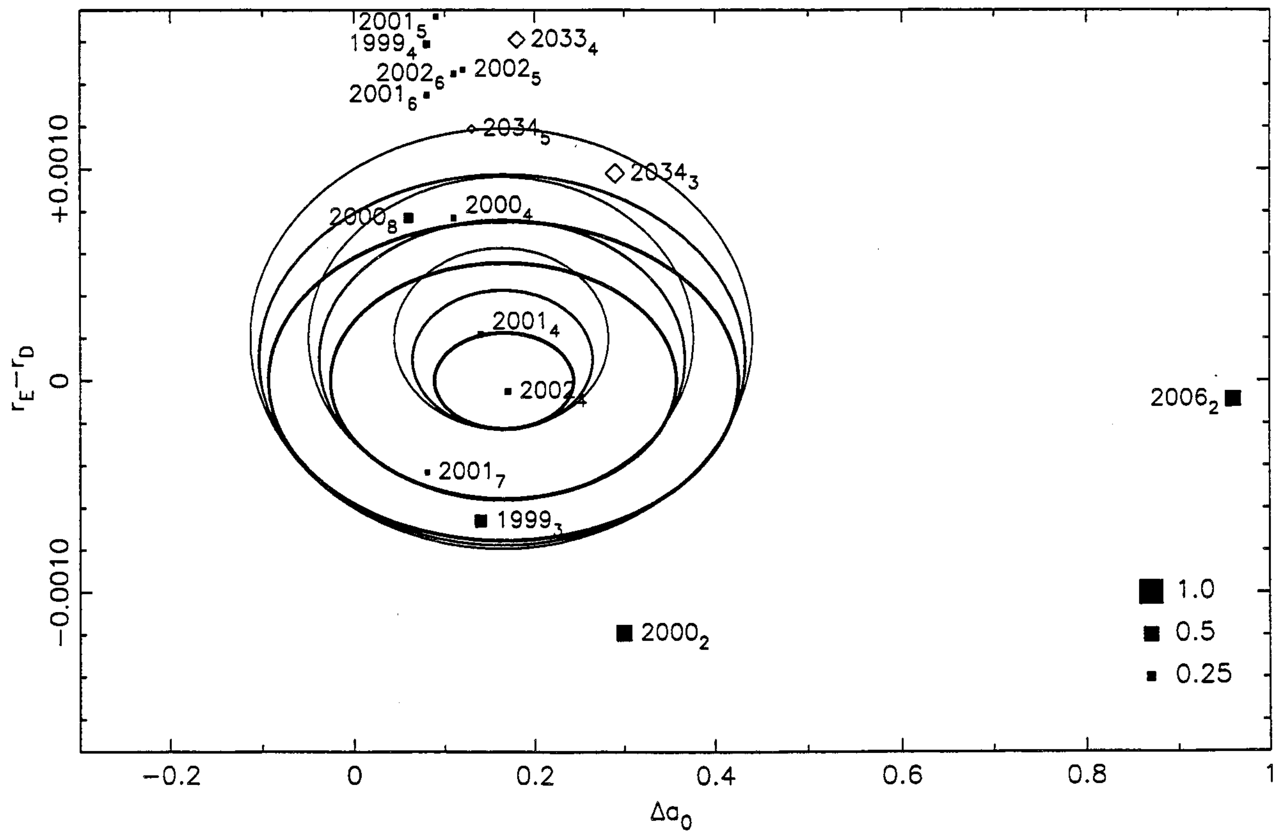

Figure 4 – Values of $r_E - r_D$, Δa_0, and f_M (Table 1) for future trails plotted against the fitted contours of Figure 3. The estimated value of ZHR/f_M is shown by a point's position relative to the contours (see caption to Figure 3), and this should be multiplied by f_M (shown by size of square as in Figure 3) to yield the ZHR.

It is also clear that several trails will be encountered in the previously unobserved zone, 2000 and 2001 (4-revolution). The trails in 2000 probably lie beyond the uncertain peak and on the steep descending profile, making any rate prediction for these years rather uncertain. As previously mentioned, the effect of radiation pressure may increase the number of smaller meteoroids encountered in these years.

The data from each year will allow the fit to be recalculated, or a better model developed. It is possible that before the potential storms of 2001 and 2002 the predictions could be very well defined.

Based on the dust trail parameters in Table 5, predictions for the next few years are given in Table 6. As the trails encountered in 1999 and 2000 (8-revolution) were responsible for the 1966 and 1866 storms, respectively, we should be confident that the cores of these streams are dense. Trails that have never previously been encountered are assumed to be similar to other trails and for our simple analysis all are necessarily assumed equal. Encounters with the same trails at different values of Δa_0 will allow the structure and evolution of specific dust trails to be investigated.

Table 5 – Circumstances of dust trail encounters for the current epoch. The last column indicates previous encounters with the same dust trail.

Year	Trail	Δa_0	$r_E - r_D$	f_M	Previous encounters
1999	3 rev	+0.14	−0.00066	0.38	1966 storm
2000	8 rev	+0.06	+0.00077	~ 0.27	1866 storm
2000	4 rev	+0.11	+0.00077	0.13	none
2001	7 rev	+0.08	−0.00043	~ 0.14	1869 storm, 1893*
2001	4 rev	+0.14	+0.00022	0.13	none
2002	4 rev	+0.17	−0.00005	0.15	none
2006	2 rev	+0.96	−0.00009	0.53	1969

* Mentioned in [5] ($\Delta a_0 = -0.10$, $r_E - r_D = -0.00019$). Outside range of years considered as potentially storm-producing.

Table 6 – Predictions for the current return of 55P/Tempel-Tuttle.

Time (UT)	Estimated ZHR	Trail	Moon age	Visible from
1999, Nov 18.089 (02^h08^m)	1500	3 rev	10	Europe, Middle East, Africa
2000, Nov 18.156 (03^h44^m)	100–5000?	8 rev	22	Europe, Africa
2000, Nov 18.327 (07^h51^m)	100–5000	4 rev	22	E. USA, E. Canada, Atlantic
2001, Nov 18.417 (10^h01^m)	2500?	7 rev	3	Americas
2001, Nov 18.763 (18^h19^m)	10000–35000	4 rev	3	E. Asia, W. Pacific, Australia
2002, Nov 19.442 (10^h36^m)	25000	4 rev	15	Americas
2006, Nov 19.198 (04^h45^m)	150	2 rev	28	W. Europe, W. Africa

The 8-revolution trail in 2000 has nearby sections both in front and behind that have been disrupted owing to close approaches to Earth between 1733 and the present, albeit the section with the critical mean anomaly for intersection with the Earth should just survive. For the 7-revolution trail in 2001, f_M is quite rapidly varying at the critical M. The derived ZHRs for these two trails are therefore denoted with a question mark in Table 6. No other close encounters to dust trails 6 or less revolutions old occur prior to 1999 in the current return of 55P, consistent with observations. Kondrat'eva et al. [5] do mention an 8-revolution trail on 1991 Nov 20.2 UT at $\Delta a_0 = -0.16$ and $r_E - r_D = -0.00041$. We would expect activity from this to have been low, but probably detectable.

The time of maximum is derived from the nodal longitude of the dust trails. The uncertainty of these predictions is probably better than 10 minutes (see Tables 2 and 3 and reference [14]).

ZHR predictions may be "reliable" (within a factor of 2?) for 1999 and 2002. It is in the region of Figure 3 at positive $r_E - r_D$ that the data are extrapolated with the largest uncertainty. This includes the 4- and 8-revolution trails in 2000 and the same 4-revolution trail in 2001.

Observations in 1999 may not affect the predictions for following years, due to the constraining effect of the steeply rising profile fitted through the storm data. However, the observations of the trails in 2000 should dramatically lower the uncertainty for future years. One especially interesting feature is that the same (4-revolution) trail will be encountered in 2000, 2001, and 2002. Following observation in 2000, predictions for this trail in 2001 and 2002 should be especially well-defined. The assumption that all trails are created equal is certainly the case here, although the mass distribution will probably change over the three years and will be an important observational result.

In 2006, the Earth encounters an adjoining section of the same dust trail that produced the 1969 outburst. The circumstances in these two years are almost identical, but the stretch in M is double in 2006, giving a prediction of half the ZHR of 1969. This prediction is unrelated to the profile fitted to the storm data.

The Last-Quarter Moon will reduce the observed rates in 2000 and the near-Full Moon will be a bigger problem in 2002. The highest observable rates at this epoch may be in 2001, despite the uncertain rates, as no moonlight will be present.

Encounters around the 2031 return

It has long been assumed that no significant activity could occur around the next perihelion passage of 55P/Tempel-Tuttle. However, this conclusion was based on the use of the comet's orbit alone. The data in Table 7 are for three outlying trails approached in 2033 and 2034. These are plotted in Figure 4. Unfortunately, they are probably too distant for any reasonable chance of high activity, but, again, the region is one of very uncertain extrapolation. Predictions based on this data appear in Table 8. The substantial data that can be gathered between 1999 and 2006, with seven close approaches to dust trails during that period, should allow a realistic assessment of activity to be made before this next return. In particular, the possibility of a storm in 2034 will likely be decided by the strength of activity in 2000. The prediction of zero ZHR is from an unreasonable extrapolation of the model, and it refers only to that particular dust trail and not the shower that year as a whole. Some activity from such a dust trail will probably occur, but strong activity is highly improbable. Background activity will still be present, but this will also be rather uncertain in the changed circumstances.

Table 7 – Circumstances of dust trail encounters for next return of 55P/Tempel-Tuttle. The last column indicates previous encounters with the same dust trail.

Year	Trail	Δa_0	$r_E - r_D$	f_M	Previous encounters
2033	4 rev	+0.18	+0.00161	0.35	1966 storm, 1999
2034	3 rev	+0.29	+0.00098	0.44	1969, 2006
2034	5 rev	+0.13	+0.00119	0.13	2000, 2001, 2002

Table 8 – Predictions for the next return of 55P/Tempel-Tuttle.

Time (UT)	Estimated ZHR	Trail	Moon age	Visible from
2033, Nov 17.904 (21^h42^m)	0	4 rev	26	E. Asia, W. Pacific, W. Australia
2034, Nov 18.139 (03^h20^m)	0–1000	3 rev	7	Europe, Africa
2034, Nov 19.222 (05^h19^m)	0–100	5 rev	8	W. Europe, W. Africa

7. Historical studies

The form of this analysis could profitably be carried back to examine the dust trail characteristics of Leonid storms throughout history. This would provide more data on the parameters relevant to storm production and give information on dust trail evolution. In fact, such data could locate the position of the center of the dust trail. They could also be used to check the dates ascribed to storms from historical references. Some apparent discrepancies between dates of storms as reported in different parts of the world could conceivably be the result of multiple storms separated by a day or more.

The circumstances of approaches to Leonid dust trails within 0.005 AU in the last 200 years and up to the year 2039 are given in Table 9. This lists the encounters in chronological order giving the nodal crossing time, revolution number, and the ZHR derived from the fits to the storm data using three assumed center positions. As previously mentioned, a value of zero does not indicate the Leonid ZHR was zero in that year, but only that the contribution of that specific dust trail to the overall ZHR was zero. It has also been noted that this extrapolation to well outside the storm region is unwarranted.

Table 9 – Predictions of time of nodal crossing and ZHR for individual dust trails up to 6 revolutions old (and selected older ones) passing within 0.0050 AU of the Earth. The three ZHR predictions are for the highest density in the dust trail assumed to be centered at r_D (ZHR_0), r_D + 0.0001 AU (ZHR_1), and r_D + 0.0002 AU (ZHR_2). The factor f_M represents the extent of dispersion of the trail relative to the median density of a 1-revolution trail and has been used in the calculation of the ZHRs. The symbol "*" refers to trail encounters used in the ZHR fit (Section 5).

Date (UT)	Trail	f_M	ZHR_0	ZHR_1	ZHR_2	Moon age
1798, Nov 11.431 (10^h20^m)	3	0.41	0	0	0	3
1798, Nov 11.431 (10^h20^m)	4	0.38	0	0	0	3
1798, Nov 11.772 (18^h32^m)	6	0.11	0	0	0	4
1798, Nov 12.317 (07^h36^m)	1	1.08	0	0	0	4
1799, Nov 12.306 (07^h21^m)	5	0.25	0	0	1	15
1799, Nov 12.339 (08^h08^m)	6	0.10	1 500	2 000	2 000	15
1799, Nov 12.336 (08^h04^m)	4	0.24	0	0	0	15
1799, Nov 12.377 (09^h02^m)	3	0.27	0	0	0	15
1799, Nov 12.567 (13^h37^m)	2	0.52	0	0	0	15
1799, Nov 12.575 (13^h48^m)	1	1.00	0	0	0	15
1800, Nov 12.823 (19^h45^m)	1	1.00	0	0	0	25
1800, Nov 12.856 (20^h33^m)	2	0.52	0	0	0	25
1801, Nov 13.065 (01^h34^m)	1	0.95	0	0	0	7
1801, Nov 13.211 (05^h04^m)	2	0.53	2 500	15 000	50 000	7
1802, Nov 13.344 (08^h15^m)	1	0.95	0	0	0	18
1802, Nov 13.795 (19^h04^m)	2	0.55	0	1	1	18
1803, Nov 13.737 (17^h41^m)	1	0.95	0	0	0	29
1803, Nov 14.995 (23^h53^m)	2	0.43	2	2	3	0
1831, Nov 13.244 (05^h52^m)	4	0.34	0	0	0	9
1831, Nov 13.897 (21^h31^m)	1	1.00	0	0	0	9
1832, Nov 13.076 (01^h50^m)	6	0.16	0	10	100	20
1832, Nov 13.088 (02^h07^m)	5	0.17	0	6	80	20
1832, Nov 13.091 (02^h11^m)	7	0.06	200	800	2 000	20
1832, Nov 13.103 (02^h28^m)	4	0.20	0	1	20	20
1832, Nov 13.176 (04^h14^m)	2	0.55	0	0	0	20
1832, Nov 13.175 (04^h13^m)	1	1.00	0	0	3	20
1832, Nov 13.174 (04^h11^m)	3	0.39	0	0	0	20
1833, Nov 13.429 (10^h17^m)	2	0.53	0	0	0	2
*1833, Nov 13.435 (10^h26^m)	1	0.95	70 000	70 000	70 000	2
1833, Nov 13.455 (10^h56^m)	3	0.45	0	0	0	2

Table 9 – Predictions of time of nodal crossing and ZHR (continued).

Date (UT)	Trail	f_M	ZHR$_0$	ZHR$_1$	ZHR$_2$	Moon age
1834, Nov 13.681 (16^h20^m)	2	0.52	0	0	0	12
1834, Nov 13.692 (16^h37^m)	1	0.95	0	0	0	12
1834, Nov 14.070 (01^h40^m)	6	0.07	0	0	0	13
1834, Nov 14.112 (02^h42^m)	5	0.08	0	0	0	13
1834, Nov 14.192 (04^h36^m)	4	0.12	0	1	15	13
1835, Nov 13.948 (22^h44^m)	1	0.95	0	0	0	23
1835, Nov 14.396 (09^h30^m)	6	0.10	0	0	0	23
1835, Nov 14.487 (11^h42^m)	5	0.10	0	0	0	23
1835, Nov 14.667 (16^h00^m)	4	0.13	0	0	15	24
1836, Nov 13.202 (04^h51^m)	1	0.95	0	0	0	4
1836, Nov 14.181 (04^h20^m)	6	0.09	0	0	0	5
1836, Nov 14.281 (06^h45^m)	5	0.09	0	0	0	5
1836, Nov 14.507 (12^h10^m)	4	0.12	0	0	0	5
1866, Nov 14.017 (00^h24^m)	1	1.00	0	0	0	7
1866, Nov 14.022 (00^h31^m)	3	0.40	0	9	200	7
1866, Nov 14.024 (00^h34^m)	2	0.55	0	0	0	7
*1866, Nov 14.046 (01^h06^m)	4	0.37	8 000	8 000	8 000	7
*1867, Nov 14.392 (09^h25^m)	1	1.00	4 500	4 500	4 500	18
1867, Nov 14.401 (09^h38^m)	2	0.55	0	0	0	18
1867, Nov 14.829 (19^h54^m)	6	0.08	1	1	2	18
1867, Nov 14.896 (21^h30^m)	5	0.12	0	0	0	18
1868, Nov 14.252 (06^h02^m)	2	0.54	0	0	0	29
1868, Nov 14.281 (06^h45^m)	1	0.95	0	0	0	29
1868, Nov 14.777 (18^h39^m)	6	0.10	0	0	0	30
1868, Nov 14.940 (22^h33^m)	5	0.12	0	0	0	30
*1869, Nov 14.016 (00^h24^m)	3	0.44	900	900	1 000	10
1897, Nov 14.890 (21^h22^m)	1	1.00	0	0	0	20
1897, Nov 15.498 (11^h57^m)	6	0.17	2	20	100	20
1897, Nov 15.574 (13^h47^m)	2	0.45	0	1	4	21
1897, Nov 15.907 (21^h46^m)	3	0.25	0	0	0	21
1897, Nov 16.086 (02^h04^m)	4	0.12	0	0	0	21
1897, Nov 16.184 (04^h25^m)	5	0.17	0	0	0	21
1901, Nov 15.557 (13^h21^m)	4	0.40	0	0	0	4
1901, Nov 15.790 (18^h57^m)	5	0.49	0	0	0	4
1902, Nov 15.971 (23^h18^m)	3	0.45	0	0	0	16
1902, Nov 16.391 (09^h23^m)	4	0.24	0	0	0	16
1930, Nov 17.497 (11^h56^m)	3	0.32	0	0	0	27
1930, Nov 17.657 (15^h46^m)	4	0.23	0	0	2	27
1930, Nov 17.804 (19^h18^m)	5	0.18	0	0	0	27
1930, Nov 17.917 (22^h01^m)	6	0.16	0	0	0	27
1932, Nov 17.189 (04^h33^m)	6	0.23	0	0	0	19
1934, Nov 17.628 (15^h04^m)	1	0.95	0	0	0	10
1964, Nov 16.946 (22^h43^m)	2	0.53	0	0	0	13
1964, Nov 16.944 (22^h40^m)	1	1.00	0	0	0	13
1965, Nov 17.219 (05^h16^m)	2	0.59	0	0	0	24
1965, Nov 17.215 (05^h10^m)	1	1.00	0	0	0	24
1965, Nov 17.527 (12^h40^m)	3	0.37	0	0	1	24
1965, Nov 17.653 (15^h41^m)	4	0.21	0	0	0	24
1965, Nov 17.739 (17^h44^m)	5	0.19	0	0	0	24
1965, Nov 17.786 (18^h52^m)	6	0.04	0	0	0	24
1966, Nov 17.467 (11^h12^m)	1	0.95	0	0	1	5
*1966, Nov 17.495 (11^h53^m)	2	0.52	70 000	75 000	75 000	5
1966, Nov 18.270 (06^h28^m)	3	0.19	0	0	0	6

Table 9 – Predictions of time of nodal crossing and ZHR (continued).

Date (UT)	Trail	f_M	ZHR$_0$	ZHR$_1$	ZHR$_2$	Moon age
1967, Nov 17.721 (17^h18^m)	1	0.95	0	0	0	16
1968, Nov 17.000 (23^h59^m)	1	0.95	0	0	0	26
1968, Nov 17.293 (07^h02^m)	2	0.55	0	0	0	26
1969, Nov 17.374 (08^h58^m)	1	0.95	0	0	0	7
1998, Nov 18.168 (04^h02^m)	4	0.29	0	0	0	29
1998, Nov 18.329 (07^h54^m)	5	0.18	0	0	0	29
1998, Nov 18.392 (09^h24^m)	6	0.04	0	0	0	29
1999, Nov 18.072 (01^h44^m)	2	0.53	0	0	0	10
1999, Nov 18.078 (01^h53^m)	1	0.95	0	0	0	10
1999, Nov 18.089 (02^h08^m)	3	0.38	1 200	1 400	1 500	10
1999, Nov 18.830 (19^h55^m)	4	0.17	0	0	0	11
1999, Nov 18.916 (21^h59^m)	5	0.10	0	0	0	11
2000, Nov 17.329 (07^h53^m)	2	0.55	0	0	1	21
2000, Nov 17.348 (08^h22^m)	1	0.95	0	0	0	21
2000, Nov 18.156 (03^h44^m)	8	0.27	90	1 000	5 000	22
2000, Nov 18.244 (05^h51^m)	6	0.08	0	0	0	22
2000, Nov 18.280 (06^h44^m)	5	0.09	0	0	0	22
2000, Nov 18.327 (07^h51^m)	4	0.13	80	1000	5 000	22
2001, Nov 17.559 (13^h24^m)	2	0.52	0	0	0	2
2001, Nov 17.595 (14^h17^m)	1	0.95	0	0	0	2
[1] 2001, Nov 18.417 (10^h01^m)	7	0.14	2 500	2 500	2 500	3
2001, Nov 18.505 (12^h08^m)	6	0.13	0	0	10	3
2001, Nov 18.595 (14^h18^m)	5	0.11	0	0	0	3
2001, Nov 18.763 (18^h19^m)	4	0.13	13 000	25 000	35 000	3
2002, Nov 17.842 (20^h13^m)	1	0.95	0	0	0	13
2002, Nov 19.225 (05^h24^m)	6	0.13	0	0	4	14
2002, Nov 19.274 (06^h35^m)	5	0.12	0	0	3	14
2002, Nov 19.442 (10^h36^m)	4	0.15	25 000	25 000	30 000	15
2003, Nov 18.100 (02^h23^m)	1	0.90	0	0	0	24
2003, Nov 20.425 (10^h11^m)	4	0.10	0	0	0	26
[2] 2006, Nov 19.198 (04^h45^m)	2	0.53	150	150	150	28
2025, Nov 19.582 (13^h58^m)	3	0.10	0	0	0	29
2033, Nov 17.904 (21^h42^m)	4	0.35	0	0	1	26
2034, Nov 18.139 (03^h20^m)	3	0.44	4	130	1 200	7
2034, Nov 19.094 (02^h15^m)	6	0.10	0	0	0	8
2034, Nov 19.222 (05^h19^m)	5	0.13	0	6	120	8
2035, Nov 18.379 (09^h06^m)	3	0.39	0	0	0	18
2035, Nov 18.447 (10^h43^m)	2	0.53	0	0	0	18
2036, Nov 17.691 (16^h35^m)	2	0.52	0	0	0	29
2037, Nov 17.918 (22^h01^m)	2	0.52	0	0	0	10
2038, Nov 18.143 (03^h26^m)	2	0.50	0	0	0	21
2039, Nov 18.382 (09^h10^m)	2	0.50	0	0	0	2

[1] The 7-revolution trail in 2001 has a slightly uncertain value of f_M causing the predictions for that year to be additionally uncertain.

[2] In 2006, the formal prediction based on the Gaussian fit to Δa_0 predicts a ZHR of 0 as in 1969. However, the circumstances are almost identical as in 1969 and the encounter is with the same trail. The ZHR given is from the *observed* 1969 ZHR corrected by f_M.

Most years of substantial activity in Table 9 correspond to known showers. One year does stand out, though. Some activity should have occurred in 1801 from a 2-revolution trail with low stretch in M. This is of particular interest as the circumstances are similar to both trails in 2000. The $r_E - r_D$ of +0.0006 is an intermediate value missing from the encounters since 1833 when more attention has been paid to Leonid activity. A strong shower or minor storm could have occurred as seen from western Europe or western Africa on November 13.21 UT in 1801.

An initial examination by Mark Bailey and John McFarland of the observing log of Armagh Observatory indicates that observations were in progress that night, but no mention was made of meteor activity. Examination of other records in western Europe and western Africa for that date would be useful. Reports that can put constraints on the meteor activity at that time will have a substantial bearing on what to expect over the next several years. It would seem unlikely that a major storm was overlooked in a moonless sky, and this does tend to rule out Fit 2 and possibly even Fit 1. This would unfortunately mean that activity in the next several years would be at the lower end of the predictions.

8. Threat to satellites

Should the Earth pass through the center of a 1-revolution trail at $\Delta a_0 \approx +0.17$, the predicted peak ZHR would likely be in the range 150 000–300 000. The higher rates would be predicted if the maximum density were located beyond our calculated value of $r_{\rm D}$. Whilst the Earth is 8.6×10^{-5} AU in diameter, and presents a small target (nominally, "collision" if $|r_{\rm E} - r_{\rm D}| < 4.3 \times 10^{-5}$ AU), the region inhabited by satellites is very much larger. Geostationary (GEO) satellites can pass through this dense zone of meteoroids when $|r_{\rm E} - r_{\rm D}| < 2.7 \times 10^{-4}$ AU. This will occur in 2001 and 2002, when the same 4-revolution trail is encountered.

The maximum density in the center of these trails is likely to have an equivalent ZHR of 20 000–40 000. These estimates are much lower than what was actually encountered in 1966 (about 90 000), although the effective rates in parts of the GEO region in that year could have been some 50% higher still. The risk to an individual satellite is probably much lower than in 1966, when no satellites were damaged, but GEO and low-Earth orbit (LEO) space is now much more crowded with active satellites.

In 2001, the densest part of the dust trail at the time of encounter is almost certainly near the GEO satellite belt over the Far-Eastern Pacific. GEOs over the Indian Ocean and Indonesia will be least affected. Should the densest part of the dust trail be beyond $r_{\rm D}$, GEO satellites at intermediate longitudes will be most affected.

The most threatened GEO satellites in 2002 are on the leading (South-American) and trailing (Indonesian) longitudes of the Earth. If the densest part of the trail is further out than $r_{\rm D}$, this will affect GEO satellites closer to the central Pacific. This potential "direct hit" of a dust trail with the Earth in 2002 will result in LEO satellites being directly threatened.

Given that we may be able to predict the time of Leonid maximum activity to a few minutes accuracy, and that the direction and distance of the closest approach to the dust trail are known (to a somewhat lesser accuracy), there are two strategies that satellite operators could use to minimize the threat. These are only available to satellites other than GEOs. The first is to position the satellite in its orbit furthest from the dust trail at the time of maximum. This position would be at the satellite's maximum distance towards or away from the Sun, the Leonid dust stream at its node being nearly perpendicular to the direction of the Sun. For a circular orbit, this point would be the longitude given in Table 10 for a trail that passes inside the Earth's orbit (2000, 4-revolution and 8-revolution, and 2001, 4-revolution), but would be 180° opposite (and latitude negated) for trails that pass outside the Earth's orbit (1999 and 2001, 7-revolution). If the peak flux in 2001 and 2002 is encountered on one side of the GEO belt (either towards or away from the Sun), the other side may only experience about 10% of that flux.

GEO satellites (0° inclination) will lie some 14 000 km below the ecliptic at the longitude opposite the Sun. They will experience the peak some 25 minutes earlier than the times given; so the longitude would be modified by +6°. GEO satellites towards the Sun have maximum 25 minutes later centered at a longitude $\lambda = +174°$ from that given.

Table 10 – Orientation of Earth during forthcoming trail encounters.

Date (UT)	Trail	Point opposite Sun		Center Leonid "shadow"	
		λ	φ	λ	φ
1999, Nov 18.089	3 rev	324° E	19° N	245° E	22° S
2000, Nov 18.156	8 rev	300° E	19° N	220° E	22° S
2000, Nov 18.327	4 rev	238° E	19° N	158° E	22° S
2001, Nov 18.417	7 rev	205° E	19° N	126° E	22° S
2001, Nov 18.763	4 rev	80° E	19° N	1° E	22° S
2002, Nov 19.442	4 rev	196° E	19° N	116° E	22° S

The second strategy would apply to satellites whose orbits pass into Leonid "eclipse." For satellites with this potential geometry, it is simple for the satellite to pass through this zone at the predicted time of maximum. Slight maneuvers in height are made to alter the mean anomaly to the appropriate value. The satellite would then maximize its time in the shadow, shielded from any storm. The maximum duration a satellite could be in the Earth's shadow is around 36 minutes for LEO satellites out to around 5000 km. Above this, the duration increases, reaching 70 minutes at GEO distances. However, GEO satellites, with inclinations of 0°, orbit totally outside the Leonid shadow. Estimates of several storms (given in [13]) give a FWHM of around 0°011 to 0°022 in solar longitude (15 to 30 minutes). Given a probable uncertainty in the predicted time of maximum of less than 10 minutes, a satellite with optimum geometry, placing it in the middle of the Leonid "shadow" at the time of predicted maximum, would have a vastly reduced overall threat.

One possible caveat is that, as a satellite enters and leaves the Leonid shadow, meteoroids will be encountered that have passed through the Earth's tenuous outer atmosphere. It might be expected that a dustball structure would fragment under such circumstances increasing the flux of particles in this narrow zone. The maximum gravitational deflection such a Leonid would experience on skirting the atmosphere is 1°4.

Satellites a considerable distance perpendicularly out of the ecliptic will have the time of encounter altered by 1.8 minutes per 1000 km. This is earlier than the predicted maximum if below the ecliptic and later if above. The cause is the 163° inclination of the dust trail to the ecliptic. GEO satellites at the same (opposite) longitude as the Sun during the Leonids are 14 000 km above (below) the ecliptic and will thus experience the peak some 25 minutes after (before) the Earth. GEO satellites leading (trailing) the Earth have the maximum about 40 minutes earlier (later). This interval is partly due to the GEO satellites in these directions being over 9000 km out of the ecliptic, but also being in front of (behind) the Earth in its orbit. GEO satellites ahead and behind the Earth will experience identical rates, unless passage through the near-Earth environment led to a breakup of particles. The trailing GEO satellites are well outside the Leonid shadow.

9. Conclusion

Study of the perturbed motion of dust trails from 55P/Tempel-Tuttle indicates that the Earth will begin a series of close approaches to trails starting with a possible minor storm in 1999. Storms can be expected in the years 2001 and 2002, but estimation of their intensity is strongly limited by the lack of observational data. The effect of the Full Moon in 2002 will reduce the observed rates making 2001 potentially the year of highest observed rates at this epoch.

During the next return, activity is likely to be low, but a storm in 2034 is possible. Data from the current epoch will allow a much better assessment of what may occur.

The instant of maximum appears to be predictable with around 10 minutes uncertainty or better.

Encounters with multiple trails in a single year can be separated by several hours or days. Rate analysis would require separate profiles fitted to each trail. If the time of maximum is confirmed to be very close to the prediction of when single dust trails are encountered, then, for years with multiple encounters, use of the predicted time of maximum for each trail could help fit overlapping profiles. The general background activity would require an additional profile to be fitted as the activity from the dust trails exists within the population of older Leonid meteoroids that have an indistinct or disrupted trail structure. The spatial density in radius vector can drop off by up to 40% over the radius of the Earth whilst rates are still high. This has implications for global analyses of observations. At the instant of maximum, the greatest separation in radial distance is between the point on the Earth's surface at latitude $\varphi = 19°$ N with the radiant rising, and all points with the radiant in the sky at around morning twilight. If the trail passes inside the Earth's orbit, the gradient in the profile results in the morning twilight region of the Earth having an enhanced incident flux over regions further into darkness at that same moment.

With the intensity contours plotted in Figure 3 being based on ZHRs derived from visual observations, they are directly comparable with the activity curve observed in a single shower. The observed stream duration in any year, when measured at a suitable intensity level, allows the ellipticity of the dust trail cross-section to be derived. This will be presented in a separate paper.

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Igor Stanislavovich Astapovich (1908–1976), Investigator of Meteoric Phenomena

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On the occasion of the 90th anniversary of his birth, a survey of the life and scientific work of Professor I.S. Astapovich is presented.

In one of his *Historical Miniatures*, Eberhard Hilscher says about the founder of the atomic theory, Ernest Rutherford, that his inspiration and perseverance determined his work. Of course, the investigation of meteoric phenomena, which was pursued by my scientific mentor, Igor Stanislavovich Astapovich, had far less significance than the work of the founders of contemporary physics, but, beyond any doubt, his work was also characterized by inspiration and perseverance.

Having dedicated myself to documenting reminiscences of I.S. Astapovich, I came to understand the full complexity of the task I had set myself.

A rather short biography of I.S. Astapovich was published in the journal *Earth and Universe* (1978, no. 2) on the occasion of the 70th anniversary of his birth. This paper was written by V.V. Fedynskii, corresponding member of the Academy of Sciences of the USSR. However, this article cannot, not even to a small degree, represent all aspects of Astapovich's many-sided character, vitality, and liveliness. Currently, there are almost no more people alive who spent their youth with Astapovich. As a consequence, many recollections of these days have been lost for ever. Nevertheless, there is a way to proceed into the past, even into times before I was born, to work again with my teacher and oldest friend. He was a scientist, a meteor researcher. This says all about his life—everything about him must necessarily be contained in scientific publications.

I.S. Astapovich was born on January 11, 1908, into the family of a lecturer in a Teacher Seminary in the town of Volchansk, in the Kharkov Region. That year was to become of great importance to meteor astronomy, as, on June 30, a unique event—known as the Tunguska phenomenon—occurred, which Astapovich would later study.

Astapovich's father, Stanislav Viktorovich (1864–1931), taught physics and mathematics. His mother, Elizaveta Pavlovna (1864–1943), had a diploma of house teacher. His maternal grandfather, P.I. Gorskii-Platonov, was an extraordinary professor of the Moscow Spiritual Academy. He was a specialist of archaeology and ancient languages. The mother's cousin was the well-known arctic explorer V.A. Rusanov. As to the lineage of Astapovich's father, they were of Polish birth, being related to the Counts of Tyshkevich.

The family's library, where the future scientist grew up, included books of C. Flammarion, F. Arago, F.A. Bredikhin, and K.D. Pokrovskii. Even in his later works, Astapovich referred to these books, even when Pokrovskii was designated as a "traitor of his country." Pokrovskii was rehabilitated only in July 1993 on the present author's initiative.

During 1924–1926, Astapovich studied at the school of the city of Nikolaev, with passes in joinery and mechanical workshop practice before he rose to a rank of engineer. This was before he was carried away by astronomy. A dominating role in this was played by the *Russian Amateur Society for Nature (RASN)*.

In the year that Astapovich was born, another event took place in Russia, which subsequently affected the fate of the future enthusiast of sciences. In that year, S.V. Muratov, M.Y. Moshonkin, I.O. Seletskii, and A.A. Kondiain initiated the idea of the establishment of the *Russian Amateur Society for Nature*. A group of more than 20 young people from the *Russian Astronomical Society* joined them. They had worked at the *Russian Urania* Observatory on the Mars Field in St. Petersburg. They organized the *Bureau of Astronomical Observations*.

Figure 1 – Igor Stanislavovich Astapovich with his wife, Alexandra Konstantinovna Terentjeva.

In the journal *Studies of the World* (in Russian, *Mirovedenie*), the Society published an excellent research program, including meteor observations. More than 50 observers contributed to the work of the meteor department. Among them were D.O. Svyatskii, E.J. Öpik, and A.V. Solovjev. Later V.A. Maltsev, who came from Odessa, became the secretary of the astronomical divisions of the *RASN*. V.V. Fedynskii came from Mirgorod and was at the head of a group of observers of the *Moscow Society of Amateur Astronomers* since 1926. Both these scientists became friends and co-authors of Astapovich.

The first publications of meteor observations by I.S. Astapovich date back to 1923. Since 1925, he conducted systematic observations. A series of observations of the Nikolaev period comprises data on 1594 meteors. On August 20, 1925, I.S. Astapovich and S.S. Trikotskii observed a fireball of magnitude −12 and recorded the drift of the train over 18 minutes. Acoustical and electric sound phenomena were noted as well. Later on, these phenomena were widely studied by many investigators of meteoric phenomena. The basic observations of this fireball allowed the calculation of several of its characteristics. After having determined the trajectory and geocentric orbit, its velocity was found to be 74 km/s—at that time, the observer was only a 17-year old graduate pupil...

In 1926, Astapovich entered the Faculty of Physics and Mathematics of Moscow University. In 1928, he played an active role at the 11th Congress of the *RASN*, which was held in Nizhnii Novgorod. This congress was less uplifting than the 1st Congress in Moscow in 1921. Soviet power had placed such informal organizations under strict control, and circles and societies of local historians and even amateur astronomers were dissolved. Already in 1923, the *RASN* was obliged to present lists of its members. In 1930, the society was banned. (The Odessa branch of the *RASN* continued to existed until the beginning of the war).

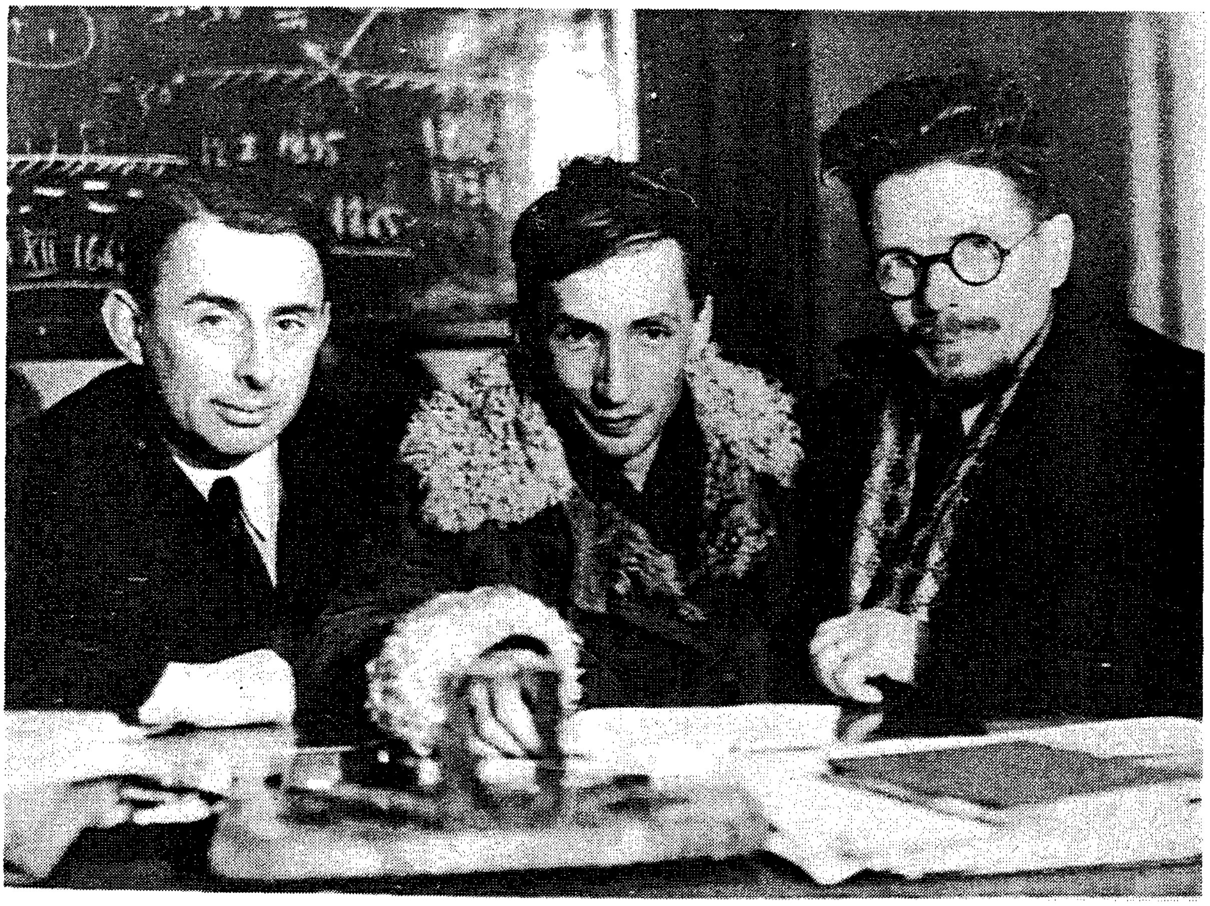

Figure 2 – In 1949, in P.K. Sternberg State Astronomical Institute (from left to right): V.V. Fedynskii, A.M. Bakharev, and I.S. Astapovich.

Many leading researchers were sent to places "not so remote": D.O. Svyatskii, for instance, was in exile in Alma-Ata, subsequently he was transferred to Aktiubinsk, where he soon died.

The well known investigator of meteorites, E.L. Krinov, was saved from arrest by participating in a prolonged expedition to the impact site of the Tunguska object.

Following his family's move to Leningrad, Astapovich went to the Leningrad University in 1928. Here, he became an active participant of the astronomical division of the *RASN*. He issued the brochure *The Task of the Amateurs in Meteor Astronomy*.

Upon request of D.O. Svyatskii, Astapovich determined the orbit of the Belozersk meteorite of 1662. He also presented the report at the General Assembly of the *RASN* on October 23, 1929. Since 1928, he worked at the Institute of Applied Geophysics, at the same time being a collaborator of the Mineralogical Museum of the USSR Academy of Sciences in Leningrad.

Astapovich completed his studies at the university in 1930, when he received a degree in astronomy. In 1930 and 1931, he became a PhD student at the Pulkovo Observatory.

Until 1932, he took part in expeditions to Eastern Siberia, organized by the Central Research Geological Prospecting Institute. He discovered a deposit of magnetite, opened new prospecting areas, and organized the Cabinet of Geophysics of the East-Siberian Geological Prospecting Management in Irkutsk.

Astronomy was not forgotten during these diverse occupations, however. Astapovich paid great attention to the study of archives of the geophysical observations of the Tunguska phenomenon. He was one of the first to assume a cometary origin for the event.

Figure 3 – I.S. Astapovich in the Caucasus, in the Kislovodsk district, during an expedition for the Leonids in 1965.

In 1933, Astapovich was appointed Director of the newly built Stalinabad Astronomical Observatory. It was created especially for the investigation of meteoric phenomena and afterwards turned into the Institute of Astrophysics of the Tadjik Academy of Science.

In Stalinabad, Astapovich continued observations of telescopic meteors, which he began in Leningrad, and of meteor trains, which he began in Nikolaev. Here, Astapovich also started spectroscopic observations of meteors which were successfully developed later (cf. *Earth and Universe*, 1986, no. 6).

In 1933, Astapovich became seriously ill with malaria and left his position for treatment. The next year, he became a senior researcher of the State Astronomical Institute of Moscow University. In 1935, the degree of candidate of physics-mathematical sciences has been conferred upon him without the defense of the dissertation. He was elected member of Commission 22 (Meteors and Interplanetary Dust) of the International Astronomical Union. Together with V.V. Fedynskii, he organized the Commission on Comets and Meteors of the Astronomical Council of the USSR Academy of Sciences. Astapovich became its head and prepared the first All-Union Conference on investigations of comets and meteors in 1935, 1937 and 1939.

In 1937, Astapovich became an associate professor at the Department of Cometary Astronomy of the Moscow University. He was the first to establish a separate course on meteor astronomy. In 1937, he gave such a course at the Faculty of Mathematics and Mechanics of the Moscow University, and, later, at the universities of Saratov, Ashkhabad, Odessa, and Kiev.

In the 30's, I.S. Astapovich began to develop his conception of the meteor phenomenon, which he described in the book *Meteor Phenomena in the Earth's Atmosphere*, published in 1958. This book, often called the "Meteor Almagest," remains one of the most frequently cited works in this field of science. In the book, aside from miscellaneous factual material, he presented ways to further develop meteor investigations. In particular, the theory of radiation, physiological possibilities of visual observations, various methods of meteors observation, celestial mechanics and astrophysical problems, and peculiarities of meteoric phenomena are mentioned and discussed.

Up to the present day, specialized scientists involved in meteor investigations make models of meteor phenomena based on the achievements of various branches of physics, for example, gas dynamics, results of which can be extrapolated for the phenomenon as a whole.

Astapovich's view on the meteor phenomenon, which he expressed in the 1930s, consists of the following. On the highest part of a meteor trajectory, several hundreds of kilometers above the surface, meteoroids collide with individual atmospheric atoms. An energy exchange takes place according to the laws of quantum mechanics. Further along the trajectory, the interaction with the air constituents increases, but the laws of aerodynamics are not applicable yet. The shape of the meteoroid can still change. Only when the free path length of molecules becomes comparable to the size of the body, an aerial pillow develops, causing aerodynamic heating, and the equations of gas dynamics become valid. At the lower part of the trajectory, the mass of the remaining meteoroid no longer changes. Processes like radiation, evaporation, and destruction of the meteoroid stop.

Some statements in his book *Meteor Phenomena in the Earth's Atmosphere* anticipate further investigations. As an example, I give only two of such statements.

> *"Given that in meteors hundreds of lines radiate simultaneously, the excitement of higher energy levels of atoms generally causes the maximum of the emission to shift to shorter wavelengths, giving rise to a Wien-like law. Therefore, meteors become whiter with increasing velocities and brightness. ." [p. 317]*

> *"The passing of the shock wave causes thermal ionization of the air, and the subsequent recombination of ions causes the luminescence of the ions, i.e. an after-glow of the air." [p. 336]*

Both statements were further developed in my book, *Spectra of Transient Atmospheric Light Phenomena: Meteors*, published in 1994.

Astapovich also described rare phenomena of meteor astronomy to let future investigators know about them. In *Meteor Phenomena in the Earth's Atmosphere*, for example, he described how "foggy slow meteors" [p. 569] confirm the theory of interaction of small comets with the Earth's atmosphere advanced by V.N. Lebedinets.

At the beginning of the Second World War, Astapovich joined the People's Guards and became a soldier in the Artillery Regiment of the 8th Krasnopresnensk Division of the 32nd Army. After demobilization in 1941, the Rector of the Moscow University, upon evacuating the university, directed him to Ashkhabad.

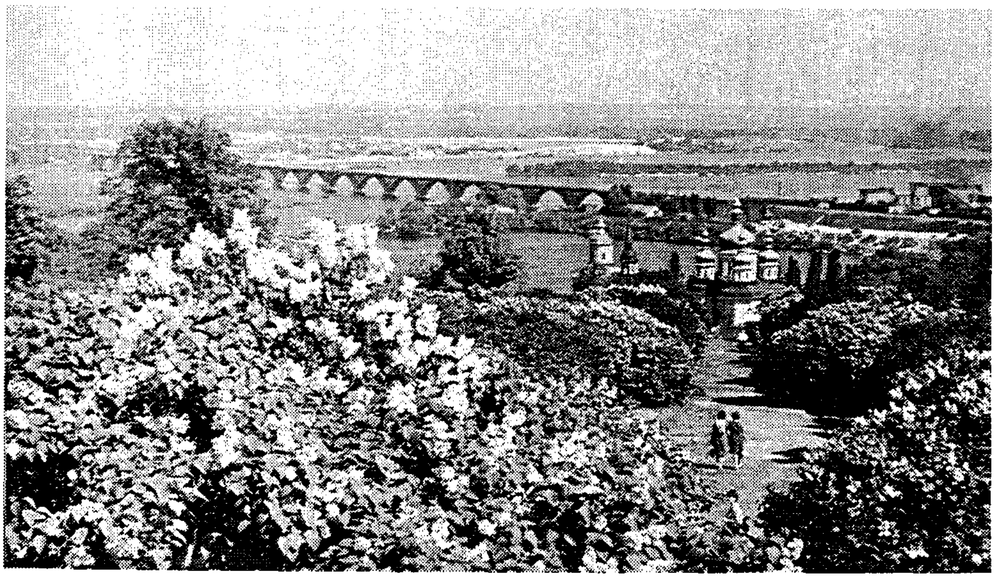

Figure 4 – I.S. Astapovich spent the last years of his life in Kiev. Shown are the botanical gardens on the slopes of the River Dnieper, where about 400 varieties of lilacs bloom.

In 1942, activity resumed at Moscow University, but Astapovich stayed in Turkmenistan, having accepted an invitation to work at the Ashkhabad Pedagogical Institute. From 1944, he worked in the Turkmen Affiliate of the USSR Academy of Sciences, where he organized the Astrophysical Laboratory in 1946.

In the period 1957–1958, the Astrophysical Observatory near Ashkhabad (more precisely, in the health resort Firiuza) was built under the guidance of Astapovich. All that time, he intensively made meteor observations. In 1124 observing hours during the period 1942–1945, he recorded 16 930 meteors. The complete archive of his observations contains data on more than 40 000 meteors. A major achievement. During the observations, Astapovich recorded a great number of details and peculiarities of each meteor.

I remember from a conversation with Krinov's wife that she wondered about the encyclopedic memory of Astapovich: "He knows, for example, the number of steps of the buildings of the Academy of Sciences in Moscow." Such a training of memory seemed unjustified to me, but, when I learned that Astapovich noted numerous details (contours, angular velocity, color, presence of wake, coordinates of the trajectory, etc.) of each meteor, it became obvious that, without an appropriate training, such detail would be impossible.

Already at the beginning of the last century, there were notes in the literature about an extremely faint elliptic luminescence in the anti-solar direction. Since July 1, 1942, Astapovich, concurrently with other investigations, began systematic observations of the *Gegenschein* (*Nature*, 1950, no. 1). This work was favored by the excellent observing conditions in the Turkmen wilderness. Astapovich selected comparison stars at the same height as the *Gegenschein*. The brightness of the luminescence was carefully noted. From his observations, he found that the intensity of the *Gegenschein* varied by 20–30%.

Simultaneous observations by I.S. Astapovich's sister, V.S. Astapovich, on the Karelian front made it obvious that an increase of the *Gegenschein* coincided with the appearance of powerful aurora. In total, 214 observations were obtained. Astapovich noticed the variability of the dimensions and shape of the *Gegenschein*. The position of the center of the brightest part was recorded with an accuracy of one degree. By making observations before and after midnight, it was possible to determine the parallax of the *Gegenschein*. At a base-line of 6400 km, the horizontal parallax of 3° corresponded to a distance from the Earth of 125 000 km. All information hinted to a gaseous model of the observed phenomenon. The width of the *Gegenschein* along the ecliptic was determined to be about 32 000 km, and its thickness to be about 14 000 *km*.

In the period of his work at the Ashkhabad Astrophysical Observatory, Igor Stanislavovich Astapovich did a lot for the development of young Turkmen science. Many Turkmen scientists were his pupils. He also befriended visitor scientists. A.P. Savrukhin, K.D. Gulmedov, and E.N. Kramer from Odessa were among his pupils. The student of the Gorkii University, Alexandra Konstantinovna Terentjeva, came to Ashkhabad during 1954–1955 to observe meteors. She eventually became his wife and friend, and with regard to his work, a co-author of many of his articles.

Astapovich took on an impressive number of public duties during all periods of his life. In 1945, he was elected Honorary Member of the Omsk branch of the *WAGO* (*All-Union Astronomy and Geophysics Society*). He occupied the post of Vice-President of the *Turkmen Geographical Society*. Astapovich was also as member of the board of the *Society of the Turkmen SSR on the Spread of Knowledge*, giving more than 1000 public lectures.

The catastrophic earthquake of 1948 which destroyed Ashkhabad deserves special mention in this overview. As Alexandra Terentjeva recalls, Igor Astapovich determined the periodicity of the occurrence of catastrophic earthquakes in the Ashkhabad district by using historical data and the destructions of the ancient constructions of the city, and predicted that "an earthquake will happen soon."

Figure 5 – Students and followers of I.S. Astapovich in Ashkhabad, in 1955. From left to right, we see I. Genkin, K. Lyubarskij, A. Suslov, A. Terentjeva, and Kh. Gulmedov.

He sent an article to this effect to an Ashkhabad journal, but the editor replied that he could not possibly accept it for publication, because he did not want to cause a panic. Astapovich did not insist, but simply replied with the following: "As a scientist, I am obliged to give an account of my conclusions, but you, as an editor, do what you believe is necessary." During the earthquake, the editor perished, but the article was extracted from the ruins, and it was found that the passages in it about the earthquake forecast were crossed out by red pencil.

During the period 1959–1961, I.S. Astapovich worked in Odessa, at the invitation of Professor V.P. Tsesevich. He continued observations of telescopic meteors and gave courses and lectures. His lectures were distinguished by their depth and the extensive description of material. Public lectures were accompanied by numerous illustrations.

As one of his former students, M. Chudnovskii, recalled, I.S. Astapovich gave intriguing tasks, for instance, to verify the accuracy of the description by Alexander Pushkin of the white nights of St. Petersburg:

> *"And not letting the darkness of night*
> *take over the golden skies,*
> *a new dawn is rushing to replace dusk,*
> *having given the night only half an hour."*

After a calculation, it was found that, at the latitude of St. Petersburg at this time of year, a night indeed lasts for half an hour.

In Odessa, I became a PhD student in meteor astronomy, with Igor Astapovich as adviser. My scientific mentor paid much attention to me, but, in 1961, he moved to Kiev, and communication was interrupted. Thereafter, I went to Kiev for consultation and advice. From his letters to me, it is clear that Igor Astapovich showed true paternal attention towards me. This was of particular value to me, because my father had died in 1938, when I was only two years old, and I grew up with and was educated by my grandmother, T.R. Zagradskaja, since I was five years old.

Igor Astapovich always tried to give me confidence to overcome all difficulties of life. To make my point, I shall give one citation from his letter to me dated May 8, 1965:

"We both are not the greatest among physicists, but people like us are necessary, too, otherwise the greatest would not know what to do! Indeed, according to Academician Krylov, a fleet cannot only exist of battleships, but must also contain slow coal boats which carry fuel for the battleships and without which these were useless! The old man understood that they are all necessary, the connecting links of a structure, of which there are hundreds, from battleships to cutters. It is the same in science and, therefore, I can by no means approve of your pessimistic conclusion: 'Is your work necessary at all?'—of course, it is! It is known that, for example, Carl Shapley achieved great success in astronomy, although never in his life he wrote a single integral. So, what does matter? The answer: dedication, with which you are already endowed! Thus you have a pledge for success, a pledge for that sooner or later you will achieve what you desire. Your aim is explicit: the spectrophotometry of meteors, a difficult task ..."

In 1963, Astapovich successfully defended his doctoral dissertation. His monograph *Meteor Phenomena in the Earth's Atmosphere* was the basis for his dissertation. As Terentjeva recalls, one speaker during the defense, a specialist of rocket technique, said that, without this monograph, launching of artificial satellites would be impossible. Probably, this is a polemic exaggeration, but, at that time, the work of Astapovich were really a novel scientific approach to the calculation of the influence of atmosphere on the behavior of artificial objects traveling at great heights.

Together with A.K. Terentjeva and the collaborators of the Institute of Theoretical Astronomy of the Academy of Sciences of the USSR in Leningrad, E.I. Kazimirchak-Polonskaja and N.A. Belyaev, I.S. Astapovich successfully solved the celestial mechanical problem of the motion of the Leonid meteoroid stream. Based on the secular motion in longitude of the ascending node of the Leonids, they predicted the time of the maximum of the meteor shower in 1966 with an accuracy of two hours. And with fantastic accuracy (to half an hour), they did a numerical integration of the equations of motion, including planetary perturbations. The authors also gave a forecast of passages through the stream up to 2000.

The last period of the the scientist's life was set in Kiev. Here, he worked as a professor at the Kiev University, continuing his active scientific work.

During meetings in the flat of I.S. Astapovich, one might have seen around the table V.V. Fedynskii and E.L. Krinov from Moscow, A.M. Bakhareva from Dushanbe, V.N. Lebedinets from Obninsk, N.B. Divari from Odessa, A.P. Savrukhin from Ashkhabad, and many another scientists. As I have mentioned above, Astapovich was connected to Fedynskii from youth by true friendship that lasted his entire life time. According to Fedynskii's words, "this friendship was darkened by nothing."

Since January 2, 1976, Igor Stanislavovich Astapovich is no more. The phenomena of meteor astronomy which were described by him keep modern researchers busy. Well-known scientists from different states appreciated Astapovich's work. In this way, his ideas remain alive.

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A Rigorous Expression for the Angular Velocity of a Meteor

Peter S. Gural

A more exact set of expressions for the apparent angular velocity of a meteor is derived, which in turn leads to a means by which radiants can be determined from single-station imagery.

An improved expression for the apparent angular velocity of a meteor as seen by an observer or instrumentation on the ground is presented. The formulation depends on only four quantities, of which three apply to any measurable point along a meteor's luminous path, and represents the instantaneous angular velocity of that point. The quantities involved are the atmospheric entry velocity of the meteor V (km/s) and, for a given point along the path, the angular distance from the radiant D, the altitude above the Earth's surface h (km), and the elevation above the horizon θ. The expressions do not account for deceleration of the meteor in the Earth's atmosphere, deviation from straight line flight, and the effects of refraction at low-elevation angles.

In the *IMO Handbook for Visual Meteor Observations* [1], just such an expression was derived as one of the criteria for shower association of hand-plotted meteors. The expression was stated to be well-defined for any point in the sky and depends on knowing various parameters at either the beginning or end points ("b" and "e" subscripts) of the luminous path as shown below[1]:

$$\omega(\mathrm{rad/s}) = \frac{V \sin D_e \sin \theta_b}{h_b}. \tag{1}$$

By solving for V and assuming a value for h_b, plugging in measurements of the meteor's track from single-station imagery, one could test a meteor's shower association by comparing the estimate of the entry velocity with the known value of V for that shower:

$$V = \frac{h_b\, \omega(\mathrm{rad/s})}{\sin D_e \sin \theta_b}. \tag{2}$$

Just such an association discriminator was developed for an automated meteor detection and radiant association program METEORSCAN used during the 1998 Leonid campaign in Mongolia/Australia. It was found, however, while testing the software prior to deployment to the field, that under very low-elevation observing conditions, the entry velocity estimate was consistently biased on the high side [2]. The test data used was a pre-recorded video tape of the 1997 Geminids taken with a video camera pointed nearly due west covering the sky from an elevation of 5° to 25°. The reason for the near-horizontal pointing geometry involved an attempt to capture on video the same meteors seen by a forward-scatter radar site several kilometers away. That particular orientation was determined to be the most favorable for coincident detections.

The bias in the velocity estimation was eventually traced to an approximation used in equations (1) and (2) that breaks down for meteors observed near the horizon. A more rigorous expression is presented in equations (3) and (4) which can be applied to any point q along the meteor's path. Details of the derivation can be found in the Appendix. Note that R is the radius of the Earth in the same system of units as V and h:

$$\omega_q(\mathrm{rad/s}) = \frac{V \sin D_q}{|\vec{q}|}; \tag{3}$$

$$|\vec{q}| = \sqrt{R^2 \sin^2 \theta_q + 2Rh_q + h_q^2} \; - \; R \sin \theta_q. \tag{4}$$

[1] To convert from rad/s to °/s, multiply by 180 and divide by π; to convert from °/s to rad/s, multiply by π and divide by 180.

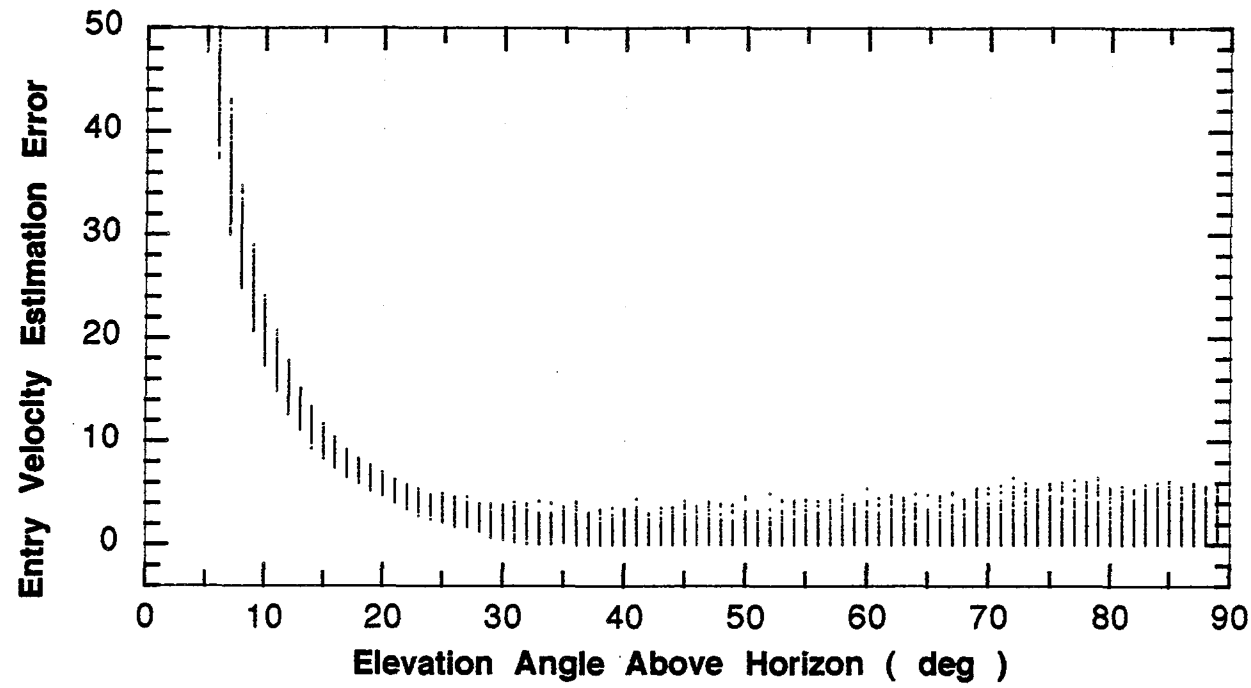

Figure 1 – Entry velocity estimation error arising from the use of equation (1) as a function of elevation angle above the horizon.

For elevation angles away from the horizon and assuming $h_q \ll R$, equation (4) can be approximated by

$$|\vec{q}| \approx \frac{h_q}{\sin\theta_q} \times \left(1 - \frac{h_q}{2R}\tan^2\theta_q + \cdots\right), \tag{5}$$

which yields an angular velocity expression similar to (1) when one includes only the first term of the expansion. Of particular note, however, is that the new expressions are valid at every point along the luminous trajectory and represent the instantaneous apparent angular velocity of each point.

Comparing equation (1) with the new equations (3) and (4), one can compute the percentage of error made in estimating either angular velocities or entry velocities versus elevation angle of the meteor. A Monte Carlo simulation of meteor trajectories was generated covering a random assortment of radiant positions, entry velocities, and meteor positions plus beginning and ending heights based on known shower parameters.

Figure 1 shows that, for meteor elevations below 15°, the error is greater than 10% and rises rapidly. Thus, for the automated radiant association software to function properly for all points in the sky, either a high error tolerance in velocity would need to be applied, or the more exact expressions be used. Note that this plot was generated for radiant elevations greater than 15°. For lower-elevation radiants, the plot looks even worse, with many high-elevation meteors exceeding 5% error.

For photographic and video cameras operating at viewing elevations of over 40°, the error amounts to less than 5% for a radiant elevation above 15°. Therefore, the approximate formulation can still be used if that error tolerance is acceptable. With the understanding that D, h, and θ should really take on their associated values at each unique point q along the path and the mixing of meteor track measurements from the beginning and end points is erroneous, the error of the older formula can be reduced to less than 1% for the typical camera operating conditions just specified. It is recommended however that the newer formulation of equations (3) and (4) be used in all cases, since it requires the same input parameters and little additional computation.

The effects of refraction at low elevation angles has not been accounted for in the formulae, but amounts to a worst-case error of 5% on the horizon at a 0° elevation angle. Typically, the refraction error is small, amounting to less than 1% in the velocity estimate for $\theta > 8°$. This error can be removed by making the standard refraction correction to the elevation measurement θ prior to using them in the expressions.

In addition, McNaught [3] has pointed out an alternative expression for the instantaneous angular velocity ω that replaces two unknowns (V and h_q) with a single unknown quantity at each measurement point along the track. The unknown is simply V/p_0, which is assumed constant for a given meteor, and where $p_0 = |\vec{q}| \sin D_q$ is the elongated track's closest point of approach to the observer:

$$\omega_q(\text{rad/s}) = \frac{V}{p_0} \times \sin^2 D_q. \tag{6}$$

This form of the expression lends itself to a solution of the radiant distance from simply two measurements of the apparent angular velocity using only a single station-photograph or video camera:

$$\tan D_m = \frac{\sqrt{\omega_2} + \sqrt{\omega_1}}{\sqrt{\omega_2} - \sqrt{\omega_1}} \times \tan(\Delta D/2), \tag{7}$$

where $\Delta D = D_2 - D_1$ is the angular separation of the measurements and $D_m = (D_2 + D_1)/2$ is the radiant distance to the midpoint between the two measurements. McNaught was under the impression that this result had been previously published in the 1980s, but neither of us has located a reference to this solution. Issues as to the practicality of this expression for radiant association in light of measurement inaccuracies, realizable meteor trajectories, and viewing geometry is currently a work in progress by the author. First indications are that image resolutions of better than $1'$ are needed to obtain radiant positions to within a few degrees. Robert McNaught is preparing a paper on a more generalized solution of the radiant distance involving more than two angular velocity measurements that he has personally derived.

Appendix—Derivation of a meteor's apparent angular velocity

In the diagram of Figure 2, a meteor is assumed to travel along a line parallel to the observer/radiant unit vector $\vec{r}\,'$, and is seen from the observer at a point in the sky given by the unit vector $\vec{q}\,'$.

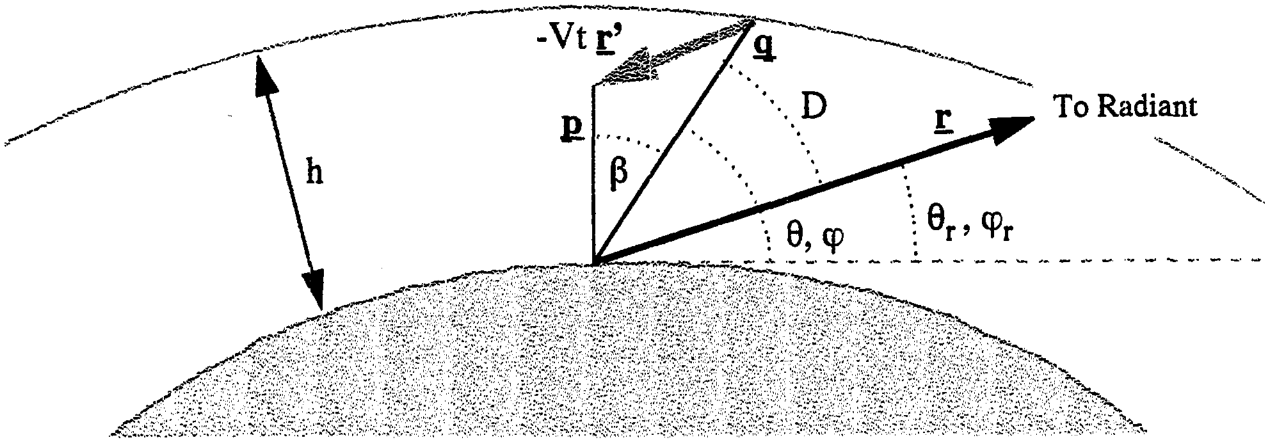

Figure 2 – Geometry of a meteor traveling through the skies. In the figure, vectors are underlined and in bold; in the text, vectors are indicated with arrows.

The angular distance D_q of the meteor from the radiant is then simply given by the arc-cosine of the dot product of the unit vectors $\vec{r}\,'$ and $\vec{q}\,'$. For the radiant, the local elevation and azimuth angles are θ_r and φ_r, and, for the point q on the meteor's path, they are θ_q and φ_q at an altitude h_q.

Hence, we obtain $D_q = \arccos(\vec{r}'.\vec{q}')$, with

$$\vec{r}' = (\cos\varphi_r\cos\theta_r, \sin\varphi_r\cos\theta_r, \sin\theta_r);$$
$$\vec{q}' = (\cos\varphi_q\cos\theta_q, \sin\varphi_q\cos\theta_q, \sin\theta_q).$$

A meteor moves from q to a new vector position p along a path anti-parallel to the radiant unit vector $\vec{r}'$. The expression for $\vec{p}$ below assumes that the meteor is moving with a constant velocity $V$and that a time period of duration t has elapsed. The meteor thus traces out an angular swath β whose time derivative is the apparent angular velocity ω as seen by the observer. The angle β can be computed from the arc-cosine of the dot product between the unit vectors $\vec{p}'$ and $\vec{q}'$. Note that R is the radius of the Earth. From Figure 2, we derive $\vec{p} = \vec{q} - Vt\,\vec{r}'$, whence

$$\vec{p}.\vec{q} = |\vec{q}|^2 - Vt|\vec{q}|\,\vec{q}'.\vec{r}' = |\vec{q}|^2 - Vt|\vec{q}|\cos D_q,$$

and

$$\vec{p}'.\vec{q}' = \frac{\vec{p}.\vec{q}}{|\vec{p}|\,|\vec{q}|} = \frac{|\vec{q}| - Vt\cos D_q}{|\vec{p}|}.$$

By some straightforward trigonometric calculations, again using Figure 2, we find

$$|\vec{p}|^2 = |\vec{q}|^2 - 2|\vec{q}|\,Vt\cos D_q + V^2t^2,$$

$$|\vec{q}| \;= \sqrt{R^2\sin^2\theta_q + 2Rh_q + h_q^2} \;-\; R\sin\theta_q\,.$$

Since $\beta(t) = \arccos(\vec{p}'.\vec{q}')$, it follows, expressing all angles in rad and using the above identities, that

$$\omega_p = \frac{d}{dt}\beta(t) = -\frac{1}{\sqrt{1-(\vec{p}'.\vec{q}')^2}}\frac{d}{dt}(\vec{p}'.\vec{q}') = -\frac{|\vec{p}|}{Vt\sin D_q}\frac{d}{dt}(\vec{p}'.\vec{q}').$$

By a tedious calculation using the same identities, we find

$$\frac{d}{dt}(\vec{p}'.\vec{q}') = -\frac{|\vec{q}|\,V^2t\sin^2 D_q}{|\vec{p}|^3}.$$

Hence,

$$\omega_p = \frac{|\vec{q}|\,V\sin D_q}{|\vec{p}|^2}.$$

In the limit, as $t \to 0$, the distance to the meteor $|\vec{p}|$ is equivalent to $|\vec{q}|$, which yields the expression for the instantaneous apparent velocity of a meteor at any point in its path:

$$\omega_q = \frac{V\sin D_q}{|\vec{q}|}.$$

The expressions for ω_q and $|\vec{q}|$ can also be solved for the meteor's velocity or altitude from measurements at a point in the path and an assumption on the height or entry velocity, respectively:

$$V = \frac{\omega_q\,|\vec{q}|}{\sin D_q} \text{ and } h_q = \sqrt{R^2\cos^2\theta_q + \left(R\sin\theta_q + \frac{V\sin D_q}{\omega_q}\right)^2} \;-\; R.$$

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Predictions of Radiants Associated with Minor Planets

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In this continuation of our meteor radiant predictions in [1], predictions are presented of meteor orbits and radiant points associated with Earth-approaching minor planets discovered between January 1997 and March 1998.

In Table 1, predicted positions (α and δ for eq. J2000.0) of radiant points and the meteors' geocentric velocities are given for the date when the heliocentric distance at a particular point on the parent body's orbit is equal to that of the Earth. The solar longitude of that date referred to the mean equinox of J2000.0 is denoted by $\lambda_\odot$. The symbol Δ denotes the separation between the orbits of the parent body and the Earth in AU. In the case of $\Delta > 0.1$ AU, the predictions are excluded. Finally, ω', Ω', and i' are the adjusted angular orbital elements of the meteoroid orbit, and q' the adopted or adjusted perihelion distance. Revised predictions for 1993 BX3 and 1996 GT (see [1]), and new ones for Periodic Comet Hartley 2 and Comet 1996 Q1 (Tabur) are added at the end of Table 1. 1991 VE is identified with 1997 WP23, but its meteor predictions given in [2] are not changed. The value of Δ for 1992 NA given in [2] is to be read 0.052, and the predictions (also given in [2]) for 1991 JG1 and 1992 AX = (5407) are to be deleted. More details on the method used for these predictions can be found in [3], and discussions on the methods of calculating meteor radiants are presented in [4–7].

Table 1 – Predictions of meteor radiant points associated with a minor planet

Object	$\lambda_\odot$	Date	α	δ	V_G	Δ	ω'	Ω'	i'	q'
1997 AE12	151.°8	Aug 26	281.°9	−44.°0	9.1	0.041	24.°3	331.°8	5.°1	0.979
1997 BQ	59.°0	May 21	88.°9	+59.°6	11.0	0.036	138.°8	59.°0	10.°9	0.931
1997 BR	118.°0	Jul 21	173.°8	+67.°5	11.6	0.014	132.°5	118.°0	17.°2	0.939
1997 CZ3	74.°5	Jun 6	253.°1	−28.°6	16.6	0.104	92.°7	254.°5	3.°4	0.641
	256.°7	Dec 9	255.°4	−16.°2	16.6	0.099	90.°4	256.°7	3.°6	0.641
1997 CD17	321.°0	Feb 11	212.°8	+73.°4	8.8	0.007	220.°8	321.°0	15.°2	0.957
1997 GH3	344.°0	Mar 5	71.°1	+08.°7	7.7	0.074	356.°4	164.°0	2.°7	0.991
1997 GK3	17.°0	Apr 7	341.°1	+65.°7	11.3	0.089	134.°8	17.°0	18.°0	0.935
1997 GL3	15.°6	Apr 6	13.°0	−02.°8	24.4	0.002	261.°1	195.°7	6.°7	0.493
	177.°8	Sep 21	359.°4	+07.°6	24.4	0.038	279.°1	177.°8	6.°3	0.493
1997 GC32	69.°8	Jun 1	240.°0	−23.°8	18.1	0.099	77.°4	249.°8	1.°8	0.700
	222.°3	Nov 5	228.°9	−10.°4	18.3	0.072	104.°9	222.°3	4.°2	0.700
1997 GD32	158.°3	Sep 1	176.°7	−01.°5	14.1	0.092	303.°3	338.°3	1.°1	0.839
	44.°8	May 6	208.°7	+01.°6	14.4	0.019	236.°6	44.°9	5.°2	0.839
1997 NC1	96.°6	Jun 29	347.°3	+64.°2	8.8	0.018	16.°6	96.°6	16.°7	0.673
1997 QK1	115.°5	Jul 19	222.°4	−28.°5	9.2	0.012	14.°2	295.°5	2.°8	1.004
1997 RT	148.°0	Aug 22	231.°8	−49.°5	7.9	0.059	4.°1	328.°0	6.°2	1.011
1997 TZ16	201.°3	Oct 15	7.°1	−07.°1	13.8	0.008	59.°7	21.°3	3.°8	0.813
	319.°1	Feb 9	336.°7	−03.°9	13.7	0.053	122.°0	319.°1	2.°2	0.813
1997 TC25	181.°2	Sep 25	230.°8	−19.°6	9.6	0.001	338.°3	1.°2	0.°2	0.976
	133.°8	Aug 7	262.°1	−23.°7	9.7	0.004	25.°7	313.°8	0.°1	0.976
1997 UR	226.°0	Nov 9	322.°9	+03.°8	4.4	0.018	188.°3	226.°0	2.°2	0.988
1997 US2	252.°2	Dec 5	74.°2	+18.°0	20.1	0.006	93.°9	72.°2	3.°2	0.566
	82.°5	Jun 14	78.°6	+27.°3	20.1	0.016	83.°6	82.°5	3.°0	0.566
1997 UA11	126.°0	Jul 30	276.°5	−22.°8	12.3	0.058	225.°0	126.°0	0.°2	0.902
	211.°8	Oct 26	242.°3	−11.°2	12.4	0.001	139.°2	211.°8	3.°3	0.902
1997 VG	217.°0	Oct 31	249.°5	+56.°2	18.6	0.082	156.°7	217.°0	31.°0	0.970
1997 VN4	224.°0	Nov 7	315.°5	−53.°2	8.7	0.086	355.°0	44.°0	7.°6	0.990
1997 VG6	42.°1	May 3	229.°4	+13.°7	18.9	0.058	261.°0	42.°1	18.°2	0.702
1997 WB21	166.°7	Sep 10	281.°5	−33.°1	4.9	0.055	16.°1	346.°7	1.°4	0.997

Table 1 – continued.

Object	$\lambda_\odot$	Date	α	δ	V_G	Δ	ω'	Ω'	i'	q'
1997 WQ23	221.°6	Nov 5	241.°2	−28.°3	11.2	0.011	310.°7	41.°6	2.°4	0.878
	118.°3	Jul 22	276.°1	−19.°9	11.1	0.038	234.°0	118.°3	1.°1	0.878
1997 XR2	70.°8	Jun 2	239.°0	−52.°4	7.2	0.000	84.°7	250.°8	7.°2	0.860
	232.°9	Nov 16	240.°3	+10.°6	7.1	0.038	102.°8	232.°9	6.°8	0.860
1997 XE10	258.°0	Dec 11	31.°5	−19.°5	7.6	0.015	19.°5	78.°0	6.°3	0.967
1997 XF11	57.°5	May 19	226.°7	−26.°2	14.0	0.029	79.°1	237.°5	3.°8	0.744
	213.°3	Oct 27	219.°9	−05.°9	14.1	0.001	103.°3	213.°3	4.°1	0.744
1997 YM3	191.°0	Oct 5	291.°3	−28.°8	8.8	0.089	6.°1	11.°0	1.°6	0.998
1997 YM9	281.°0	Jan 2	88.°1	−39.°0	4.8	0.030	45.°5	101.°0	7.°8	0.956
1998 BY7	322.°2	Feb 22	136.°6	+09.°6	14.7	0.028	59.°8	152.°2	2.°9	0.804
	95.°8	Jun 28	114.°2	+28.°3	14.7	0.027	116.°4	95.°8	2.°9	0.804
1998 BZ7	354.°1	Mar 15	143.°1	+04.°3	11.3	0.099	41.°1	174.°1	3.°1	0.907
	81.°0	Jun 13	114.°4	+38.°5	11.6	0.060	134.°5	81.°0	5.°5	0.907
1998 BB10	285.°7	Jan 7	291.°9	−47.°8	13.6	0.065	278.°1	105.°7	11.°0	0.731
	117.°1	Jul 20	294.°2	+04.°6	13.7	0.027	266.°5	117.°1	11.°5	0.731
1998 CS1	299.°2	Jan 20	119.°8	+07.°2	17.9	0.019	89.°0	119.°2	7.°7	0.629
	120.°4	Jul 24	124.°5	+32.°6	17.9	0.022	87.°8	120.°4	7.°7	0.629
1998 DV9	310.°8	Feb 1	54.°7	−26.°8	7.8	0.005	0.°0	130.°8	8.°7	0.985
1998 DX11	331.°0	Feb 20	24.°6	+40.°6	9.1	0.011	166.°2	331.°0	6.°5	0.978
1998 DV20	161.°0	Sep 4	325.°5	+23.°6	18.6	0.070	251.°7	161.°0	19.°3	0.747
1998 EC3	101.°5	Jul 4	165.°8	+38.°6	9.4	0.088	155.°0	101.°5	7.°5	0.984
1998 EE3	346.°9	Mar 8	144.°6	+34.°6	13.9	0.012	219.°3	346.°9	7.°1	0.900
1998 EP4	136.°4	Aug 10	150.°6	−06.°5	11.2	0.077	302.°9	316.°4	5.°8	0.872
	24.°0	Apr 15	192.°4	+15.°0	11.2	0.065	234.°9	24.°0	6.°2	0.872
1998 FG2	210.°5	Oct 25	21.°7	−04.°7	9.1	0.033	67.°0	67.°0	3.°6	0.836
	344.°0	Mar 5	350.°9	+11.°0	9.1	0.023	113.°6	344.°0	3.°9	0.836
1998 FX2	11.°0	Apr 1	112.°6	−23.°1	8.9	0.095	7.°4	191.°0	9.°9	0.996
1998 FL3	178.°0	Sep 22	215.°0	+60.°6	15.1	0.034	124.°1	178.°0	25.°7	0.918
1998 FW4	179.°1	Sep 23	355.°9	−08.°4	20.9	0.005	78.°4	359.°1	4.°0	0.652
	334.°8	Feb 24	340.°5	−02.°4	20.9	0.033	102.°8	334.°8	3.°5	0.652
1998 FM5	338.°0	Feb 27	33.°9	−27.°9	11.0	0.095	330.°2	158.°0	10.°9	0.943
1998 FN9	358.°0	Mar 19	65.°2	−51.°1	8.7	0.094	334.°8	178.°0	14.°4	0.977
1998 FR11	177.°0	Sep 21	194.°7	+05.°2	17.7	0.090	117.°0	177.°0	5.°4	0.777
1998 FH12	328.°2	Feb 18	318.°9	−20.°4	18.0	0.038	244.°9	148.°2	2.°9	0.476
	95.°8	Jun 28	289.°4	−17.°2	18.0	0.017	297.°5	95.°8	3.°6	0.476
1993 BX3	286.°5	Jan 8	17.°5	−02.°3	3.8	0.049	359.°0	106.°5	1.°0	0.983
1996 GT	222.°0	Nov 5	294.°5	−39.°9	5.7	0.040	350.°3	42.°0	2.°9	0.988
103P/Hartley 2	220.°0	Nov 3	297.°6	+29.°5	12.1	0.040	180.°7	220.°0	13.°6	0.992
C/1996 Q1 (Tabur)	215.°0	Oct 29	82.°6	−29.°4	44.9	0.089	56.°4	35.°0	73.°0	0.772

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A New Stream for Holidays?

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We report a discovery of a new possible stream radiating from Ursa Minor during the first part of August.

The first part of each August is the time of the Perseid shower. Many observers work under clear skies at that time. Usually, the Perseids' rates are high, and, therefore, almost all observers observe using the counting method rather than plot meteors on gnomonic maps. This phenomenon explains why we do not have a good picture of minor stream activity in the first half of August.

On the night of August 9-10, 1997, one of us (Maciej Kwinta) was observing the Perseids. Among the sporadic meteors, we detected three very slow meteors, which seemed to radiate from one point placed near Kochab (β UMi). A few other members of this possible shower were observed during subsequent nights.

We decided to pay more attention to these slow meteors in 1998. Between August 2 and 12, 1998, we totaled 19 hours of observing time plotting 17 slow and very slow meteors radiating from the vicinity of β UMi. In addition, we recorded 126 sporadic meteors.

We processed this sample using the RADIANT software. We obtained the best picture of the radiant with the following parameters: atmospheric velocity $V_\infty = 14$ km/s, angular velocity between 0°/s and 17°/sec, maximum distance from the radiant 85°, daily radiant drift $\Delta\lambda = 1^\circ\!.0$, time of maximum $\lambda_\odot = 136°$, radiant equatorial coordinates during the night of the maximum $\alpha = 223°$ and $\delta = +73°$. The output picture returned by the RADIANT software with the above parameters is shown in Figure 1.

The magnitude distributions for suspected β-Ursa Minorids and for the sporadics are presented in Table 1. From these distributions, we computed the values of the population index r. It is equal to 2.8 ± 0.4 for β-Ursa Minorids and 3.6 ± 0.3 for the sporadics.

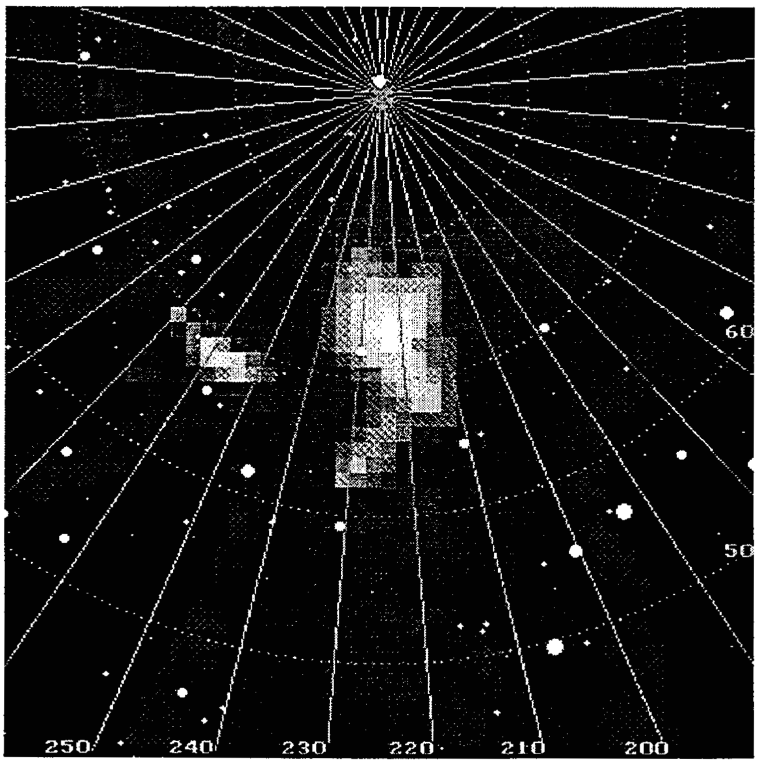

Figure 1 – Output of the RADIANT software showing the suspected β-Ursa Minorid radiant.

Table 1 – Magnitude distribution of the suspected β-Ursa Minorids and the sporadics.

Shower	−1⁻	0	+1	+2	+3	+4	+5	+6	Tot
β-Ursa Minorids	0	0	1	1	6	8	1	0	17
Sporadics	1	3.5	7.5	19	41	44	9.5	0.5	126

Knowing the values of the population index r and the coordinates of the radiant, we computed the ZHR profile of the β-Ursa Minorids. It is presented in Figure 2. The maximum was noted around $\lambda_\odot = 134°$ with ZHR $= 5.1 \pm 1.5$, but the accuracy of our points is low and it is possible that the real maximum occurred between $\lambda_\odot = 134°$ and $\lambda_\odot = 137°$.

It is clearly visible that we need to know more about this shower. We would like to encourage all *IMO* observers to pay more attention to the slow meteors radiating from Ursa Minor during the first half of August.

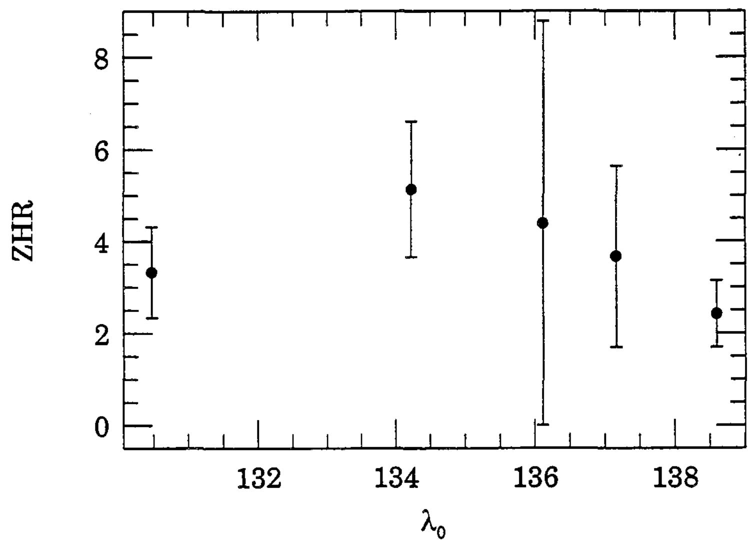

Figure 2 – ZHR profile of the suspected β-Ursa Minorids.

Acknowledgment

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On Two Double-Station Photographic 1998 Draconids

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The results of orbital calculations of two double-station bright Draconids photographed in Japan in the night of October 8, 1998, are presented. On the basis of these results, we conclude that the orbital and physical properties of the 1998 Draconids were quite identical to those photographically observed so far in the past Draconid events.

As expected by Ohtsuka [1] and by Y. Taguchi [2], a strong Draconid shower was observed, just like in 1985 [3]. Despite the less favorable observing conditions this year (the age of the Moon was 18 days), a photographic observing program was carried out by the *Japanese Fireball Network*.

For the program, an optical system was used consisting of Canon T-70 cameras with f = 50–55 mm lenses and pan-chromatic Kodak TMAX400 films.

Two double-station bright Draconid meteors were successfully obtained and precisely reduced within a positional accuracy of 20″. The results of the orbital computations are shown in Table 1.

Table 1 – Trajectory and orbital data (eq. J2000).

Meteor number	98G1	98G2
Time (UT)	October 8, 1998, $11^h42^m00^s$	October 8, 1998, $13^h11^m54^s$
Magnitude	0	−1
Corrected radiant	$\alpha = 263.^\circ40$, $\delta = +55.^\circ76$	$\alpha = 263.^\circ16$, $\delta = +55.^\circ75$
Begin height (km)	102.2	102.9
End height (km)	83.8	87.9
$\sin Q$	0.998	0.939
$\cos Z$	0.720	0.579
V(km/s)	$23.5567 - 0.02353e^{6.1t}$ $\pm\ 0.3669 \pm 0.00897$	$23.4866 - 0.04745e^{4.9t}$ $\pm\ 0.2783 \pm 0.03526$
V_G (km/s)	21.0 ± 0.4	20.9 ± 0.3
V_H (km/s)	39.1 ± 0.3	39.0 ± 0.2
e	0.721 ± 0.025	0.716 ± 0.018
q (AU)	0.9966 ± 0.0001	0.9964 ± 0.0001
a^{-1} (AU^{-1})	0.280 ± 0.025	0.285 ± 0.018
a (AU)	3.572	3.512
ω (°)	173.6 ± 0.2	173.4 ± 0.1
Ω (°)	195.0188 ± 0.0001	195.0806 ± 0.0001
i (°)	31.8 ± 0.5	31.8 ± 0.4

As can be seen from Table 1, the radiant and orbital data for both meteors are in strong agreement with each other. The small difference of $0.^\circ14$ in angular distance is probably due to inaccuracies in the radiant determinations rather than an indication for the true radiant area or the radiant drift (according to Jacchia et al. [4], the daily radiant drift was $\Delta\alpha = +2.^\circ1$ and $\Delta\delta = -0.^\circ1$ during the 1946 storm).

The pin-point-like radiant area contained with $0.^\circ1$ and the close agreement between the orbits characterize the Draconids in their early evolutional stage. Therefore, it is possible that the true radiant area was again a pin-point-like one in 1998.

The large beginning height of over 100 km, compared to an average beginning height of about 85 km for typical photographic meteors with the same velocity, the appearance of trails on the photographs indicating a high degree of fragmentation of the meteoroid, and the larger atmospheric drag coefficient are indirect evidence that these meteoroids consist of fragile material with a low bulk density.

On the basis of the above results, we conclude that the orbital and physical properties of the 1998 Draconids were quite identical to those photographically observed so far in past Draconid events [1,4,5].

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Visual Meteor Radiant Observations

Yoshihiko Shigeno

Radiants determined by visual observations reported to the *Nippon Meteor Society* (*NMS*) were studied. Plotted on star charts, they were compared with the radiants obtained by double-station meteor observations. The relationship between the visual angular velocities and the observed velocities was investigated. Furthermore, detection tests on meteor streams associated with minor planets were conducted. The results showed that the visual observation technique was sufficient to detect minor meteor streams, even though the method is simple.

1. Introduction

The *Nippon Meteor Society* (*NMS*) started listing the results of visual meteor radiant observations in its official bulletin [1] in 1970. Takema Hashimoto, Radiant Secretary of the *NMS*, made PC entries of 4905 radiants observed from January 1970 to June 1997.

Radiant charts were plotted using these data. One year was divided into 36 sections and each individual radiant position was marked with "×" on a star chart. This report summarizes the results of visual meteor radiant observations accumulated in the *NMS* over the years. There are 36 star charts in total, shown on the following pages.

We also wanted to study the accuracy of angular velocities estimated by visual observers with the naked eye. A comparison between observed and expected angular velocities was possible, because the radiants were identified with meteor showers of which the velocity is known.

Moreover, we intend to review the aim of conventional visual meteor radiant observation. The significance of visual meteor radiant observation in an age of widespread photographic observations and TV observations is discussed.

2. Observation

A visual meteor radiant can be derived from the following procedure:

1. the apparent path of a visually observed meteor is plotted on a star chart;
2. each meteor trail is prolongated backwards;
3. from the intersection of a number of meteor paths, a radiant is derived.

Komaki [2] recommended the following standard when making a report. Unfortunately, many reports fail to meet the standard.

1. An observation should not exceed four hours a night by one observer.
2. Four meteors or more should be observed.
3. If only three meteors were observed, add two meteors to be observed the next day.
4. The respective visual angular velocities of the meteors should be similar.
5. The spread of the crossed meteor paths should be 5° or less.[1]
6. In case of a stationary meteor, the radiant is determined by a single meteor.

The main observers were Tomioka (310), Yabu (251), Sekiguchi (242), Osada (202), Kawagoe (179), Tonomura (155), Shioi (133), Izumi (131), Oikawa (106), and Shimoda (99). Figures in brackets indicate the number of radiant points reported.

3. Visual angular velocity

Visual angular velocities are recorded in visual meteor observations. The apparent meteor speeds ranging from very slow meteors to very rapid meteors are classified into seven classes of visual angular velocities. In some cases, additional bands are inserted between the classes, and in such cases the visual angular velocities are recorded in 13 classes. Incidentally, visual angular velocities were recently published in the bulletin of the *NMS*. Therefore, 1018 radiants were described.

[1] Originally, 2° was specified by Komaki. However, Hashimoto proposed 5° to the *NMS*, because 2° was thought to be too narrow.

Visual angular velocities tend to show considerable errors, but they suffice to outline the speeds. Meteor showers were associated using the positions of the observed radiants and the visual angular velocities. I then compared the visual angular velocities with the atmospheric velocities of the same meteor showers. The atmospheric velocities were determined based on the orbits of Kronk [3] using the method of Hasegawa [4]. The results of the comparisons are shown in Table 1. The atmospheric velocities are seen to increase together with the visual angular velocities, except for the interval between "Rather Rapid" and "Rapid." The atmospheric velocities increase gradually up to "Rather Rapid". On the other hand, they increase radically after "Rather Rapid."

Table 1 – Estimated visual angular velocities and atmospheric velocities (all data).

Vis. ang. vel.	No. obs.	Meteor shower (V_a, km/s)	$\overline{V}_a$ (km/s)
Very Slow	2	none	–
	6	α-Capricornids (24), χ-Orionids (26), etc.	23.6 ± 4.1
Slow	69	α-Capricornids (24), χ-Orionids, (26), Piscids (29), etc.	24.9 ± 4.7
	43	κ-Cygnids (29), Piscids (29), N Taurids (31), etc.	27.0 ± 3.5
Rather Slow	76	Oct Cetids (28), N Taurids (31), Geminids (37), etc.	30.5 ± 6.4
	71	Oct Cetids (28), κ-Cygnids (29), etc.	31.8 ± 6.9
Medium	130	S ι-Aquarids (32), N δ-Aquarids (37), etc.	33.1 ± 10.8
	74	Geminids (37), Quadrantids (43), etc.	34.6 ± 8.3
Rather Rapid	131	N δ-Aquarids (37), Nov Monocerotids, etc.	46.1 ± 16.2
	92	σ-Hydrids (60), Orionids (67), Leonids (72), etc.	63.9 ± 10.9
Rapid	255	Geminids (37), Lyrids (49), Perseids (61), η-Aquarids, Orionids (67), Leonids (72), etc.	59.8 ± 10.0
	30	σ-Hydrids (60), Orionids (67), ε-Geminids, etc.	65.6 ± 5.2
Very Rapid	39	η-Aquarids (65), Orionids (67), Leonids (72), etc.	68.2 ± 3.5
Total	1018		

There is considerable scatter on the estimated visual angular velocities, as estimates vary among observers. For instance, the records of the Geminids are scattered from "Rather Slow" to "Rapid." In addition, the radiant of the Geminids moves all night on a large scale. The visual angular velocity also changes largely depending upon the radiant positions, i.e., near the horizon, or near the zenith. At present, Kazuhiro Osada is the most active visual observer in the *NMS*. In 1997, Osada made observation reports on 275 nights, totaling 421 hours and 13 minutes of observing time. He started visual meteor radiant observations in 1991 and reported 202 radiants. Among them, 182 radiants are accompanied with visual angular velocities. The results of comparisons between the visual angular velocities observed by Osada and the atmospheric velocities of the same meteor showers are shown on Table 2. The atmospheric velocities increase gradually up to "Rather Rapid". On the other hand, they radically increase after "Rather Rapid". The result is identical to that of other observers.

4. Radiant charts

Radiant charts were plotted to make the distribution maps of visual meteor radiants easier to understand. Each month is divided into three ten-day intervals, i.e., the 12 months were divided into 36 sections. Each of the detected radiant positions is marked with "×", and the size of "×" is varied according to the observed velocities estimated from the visual angular velocities. Unknown velocities were marked with a small "×". For comparison, the radiants obtained from double-station meteor observations were charted, too. For these, 12 months were also divided into 36 sections. The sizes of the "×" marks vary according to the geocentric velocities. In total, 5273 double-station meteors were used as shown below:

1. McCrosky and Posen [5]: 2413
2. Babadzhanov, Ceplecha [6]: 1926
3. Our TV observations [7]: 934

Table 2 – Estimated visual angular velocities and atmospheric velocities (Kazuhiro Osada).

Vis. ang. vel.	No. obs.	Meteor shower (V_a, km/s)	$\overline{V}_a$ (km/s)
Very Slow	2	none	–
	4	α-Capricornids (24), Ophiuchids (27), etc.	25.1 ± 2.4
Slow	10	γ-Piscids (21), ω-Scorpids (23), N Taurids (31), Ursids (36), etc.	27.6 ± 8.3
	12	κ-Cygnids (29), N Taurids (31), etc.	29.7 ± 2.3
Rather Slow	10	Geminids (37), etc.	37.0
	30	κ-Cygnids (29), Oct Arietids (31), α-Pisces Australids, etc.	32.2 ± 6.6
Medium	29	N Piscids (28), Oct Arietids (31), S δ-Aquarids (42), Lyrids (49), etc.	38.8 ± 8.5
	33	S ι-Aquarids (32), S δ-Aquarids (42), Lyrids (49), etc.	39.2 ± 8.0
Rather Rapid	17	none	–
	25	Perseids (61), Orionids (67), Leonids (72), etc.	66.6 ± 5.0
Rapid	7	Orionids (67), etc.	67.0
	4	Leonids (72), etc.	72.0
Very Rapid	1	none	–
Total	182		

The respective charts with these radiants are shown at the end of this article. Using these charts, the visual meteor radiant positions can be compared with the radiants obtained from the double-station meteor observations. The results are in good agreement with regard to the main meteor showers. However, the visual meteor radiants tend to deviate somewhat.

A number of radiants was observed near Aquarius towards the end of July. However, it is difficult to visually classify these radiants. In the middle of December, the Geminids were visually observed, not only near α Geminorum, but also in the vicinity of β Geminorum. Strangely, none of the latter was ever confirmed by a double-station observation. This can be attributed to the visual observers' preconception that some other radiants must exist near β Geminorum as well.

5. Meteoroid streams associated with a minor planet

A detection test for meteor showers associated with minor planets was conducted using the visual meteor radiants. In total, 368 predictions were investigated referring to the Hasegawa [8–10]. Actually, the visual radiants yielded 85 coincidences. However, there were not many reliable results, since the greater part of the observations lacked visual angular velocities. Examples of comparatively reliable observing results are the three meteor showers shown in Table 3, which were observed by Osada. The prediction made in Table 3 is based on the q-adjustment method proposed by Hasegawa [4]. "Δ" is the distance (AU) between the Earth and the orbit of minor planets. The velocity of visual observation is converted to geocentric velocity (V_G) after obtaining the atmospheric velocity (V_a) from Table 2. The difference between the predicted and the estimated velocity is significant. Nevertheless, some meteor showers can be assumed to be associated with a minor planet, because of the large errors in visual velocities.

6. Conclusions

Visual meteor observing and radiant determination from the visual data is a simple technique which requires no instrumentation. Nevertheless, a great deal of information can be obtained from this kind of observations. As shown by some examples of meteor showers associated with minor planets, visual observations of minor meteor showers of Earth-approaching comets or minor planets is a worthwhile activity. Of course, great care in the analysis and interpretation must be taken. I hope that this paper will help to overcome the observers' preconceptions. It is also obvious that any improvement of the accuracy of positional data and angular velocity estimates is worth the effort. I look forward to seeing further successful visual meteor radiant determinations in the future.

Table 3 – Predicted radiants and observed radiants

Object	Date (UT)	α	δ	V_G	Δ	e	q	ω	Ω	i
1991 BA						0.682	0.713	70.°7	118.°9	2.°0
Predicted		108.°3	+18.°9	18.6	0.041	0.682	0.685	75.°5	114.°1	2.°0
Observed	1997 Jan 14.21	108°	+21°	25	4 meteors, rad. width = 2°, HR = 4.0					
1996 JG						0.661	0.612	279.°7	53.°4	5.°3
Predicted		243.°6	−13.°2	19.8	0.030	0.661	0.627	267.°6	65.°5	5.°2
Observed	1995 May 27.18	241°	−15°	27	6 meteors, rad. width = 4°, HR = 1.5					
1996 SK						0.797	0.494	283.°4	198.°3	2.°0
Predicted		24.°7	+12.°7	24.7	0.012	0.797	0.488	278.°6	203.°1	2.°0
Observed	1996 Oct 16.10	28°	+12°	37	3 meteors, rad. width = 3°, HR = 1.4					
Predicted		25.°2	+12.°9	724.5	0.004	0.797	0.495	277.°7	204.°0	2.°0
Observed	1996 Oct 17.06	30°	+11°	37	3 meteors, rad. width = 4°, HR = 1.5					

Acknowledgments

Mr. Takema Hashimoto readily opened his 4905-records visual meteor radiant observation data to the public. In addition, the author is grateful for his good advice. The author also thanks Dr. Ichiro Hasegawa for his valuable advice.

A total of 2924 visual meteor radiants observed in Japan from 1928 to 1969 were introduced by Mr. Kawamura [11]. These data were not included in this paper.

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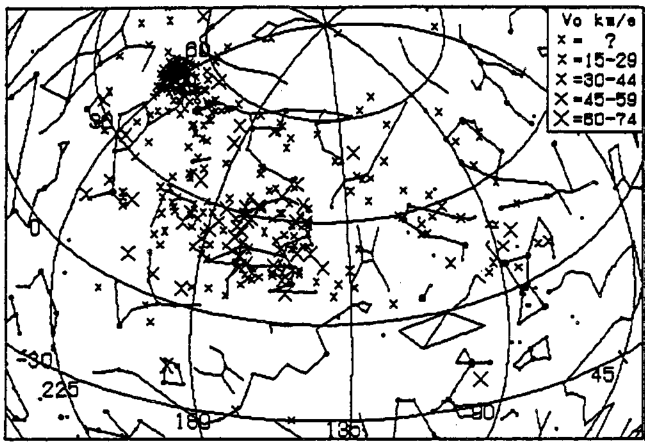

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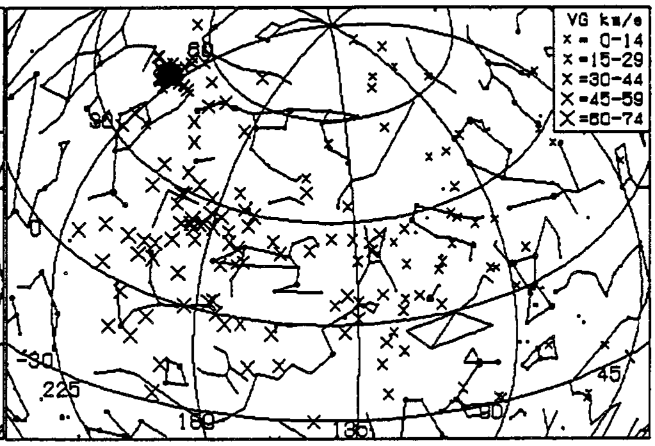

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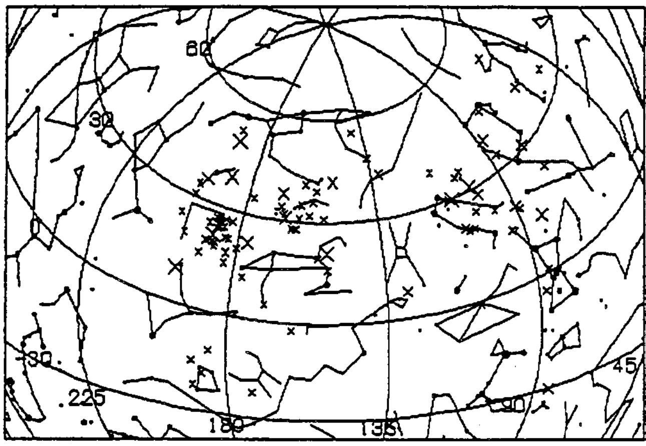
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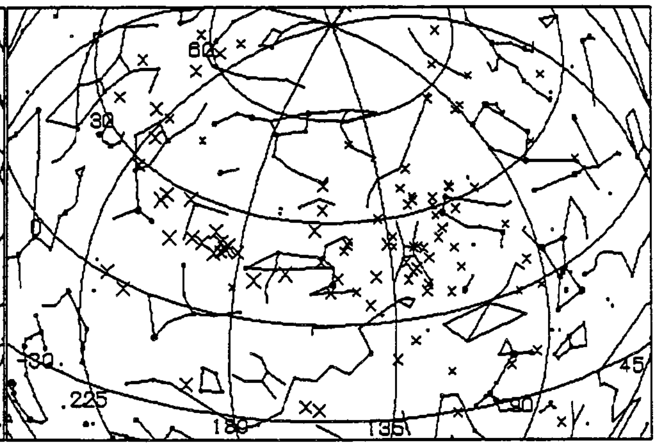
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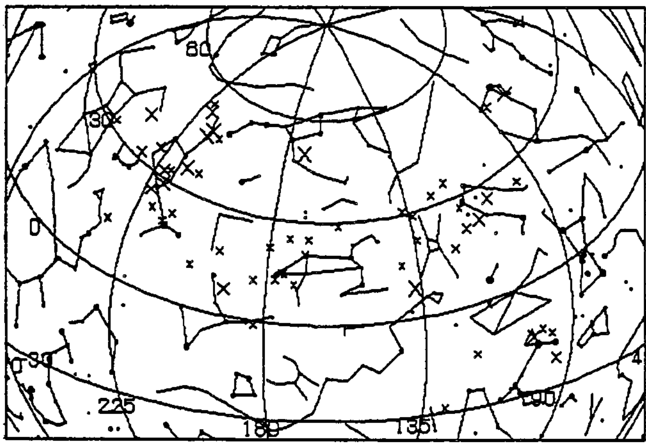
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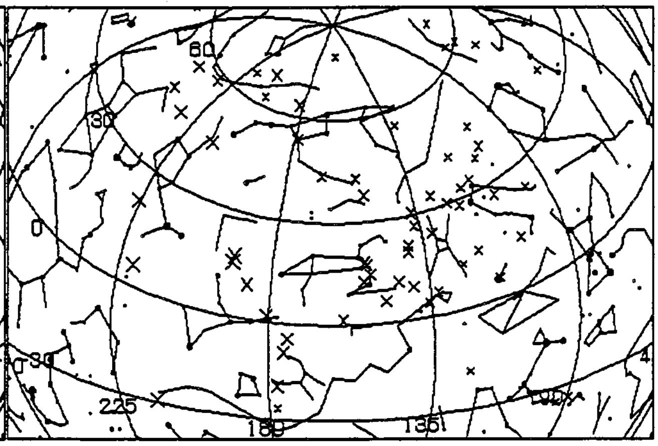
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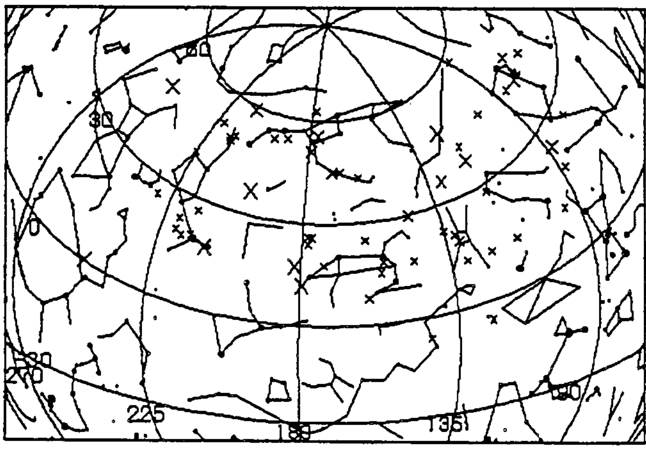
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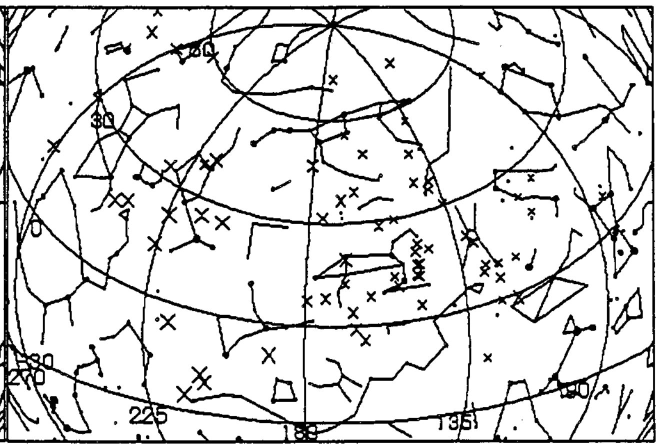
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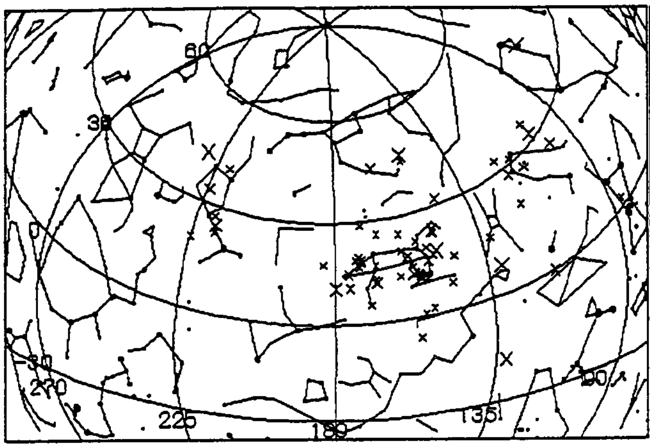

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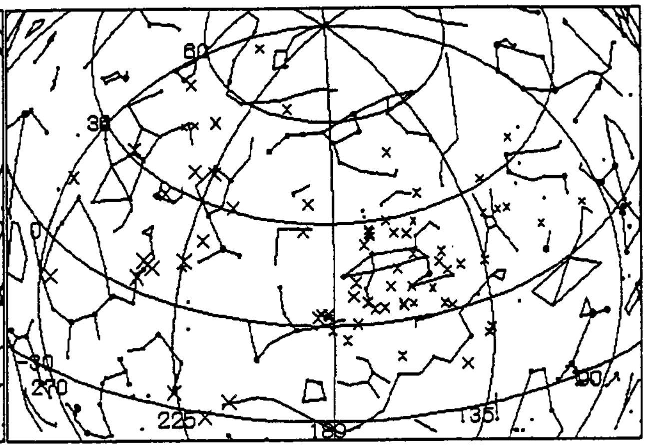

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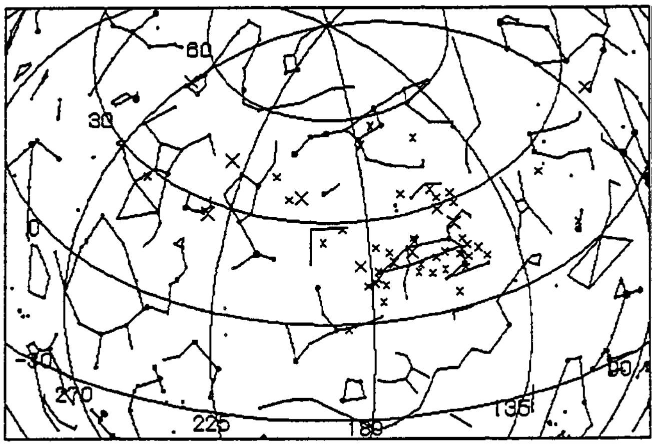

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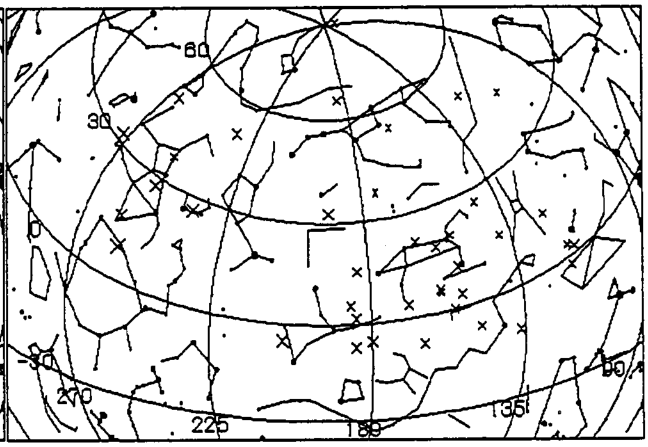

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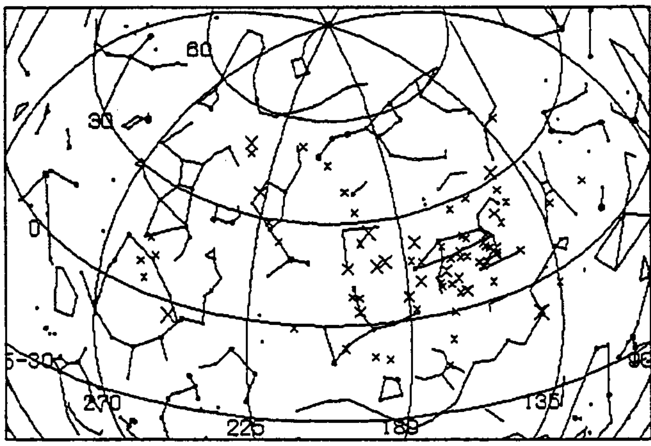

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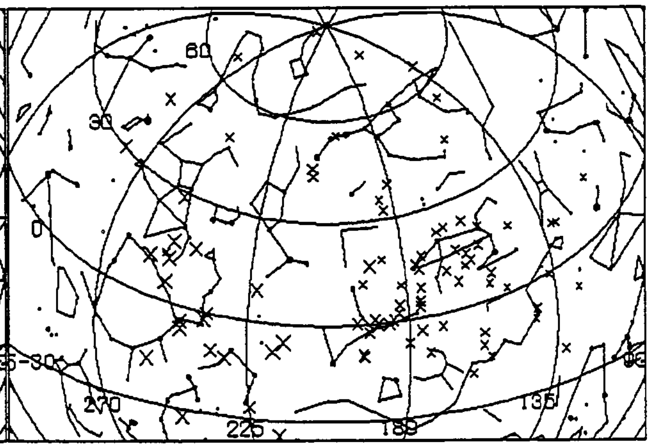

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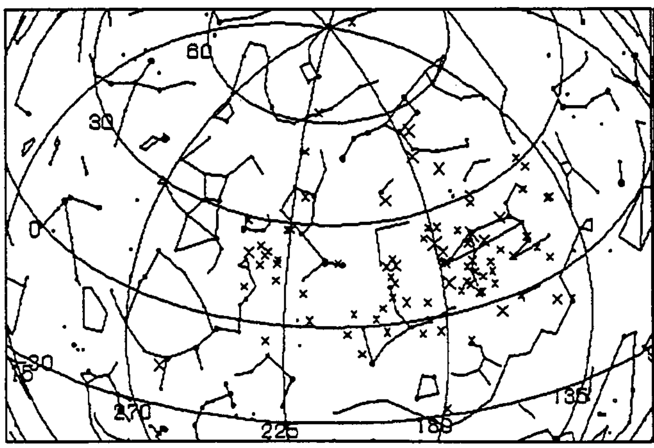

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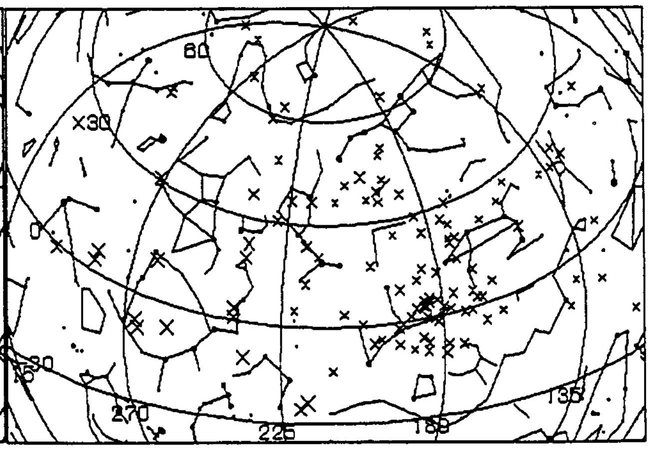

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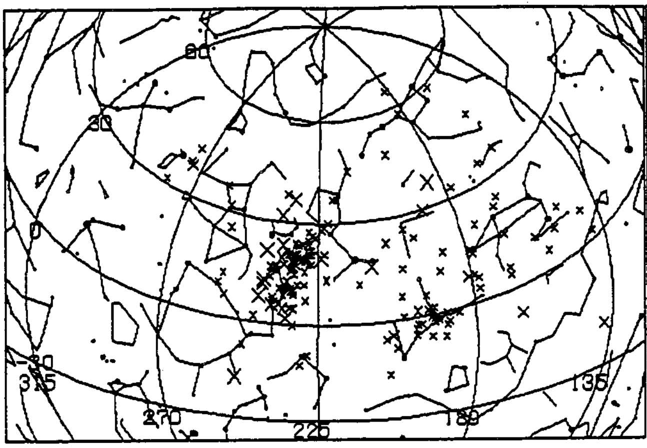

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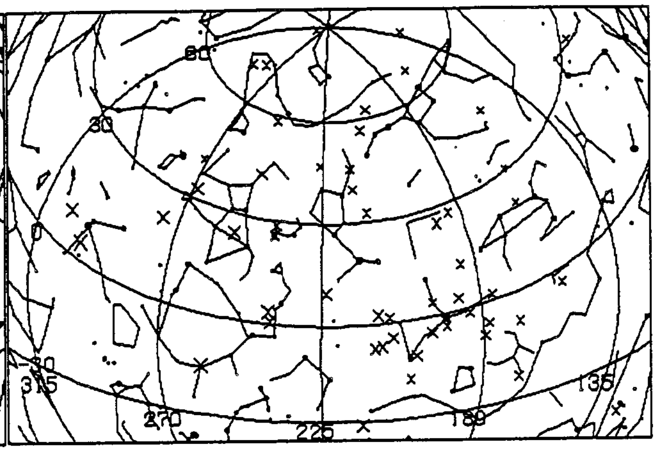

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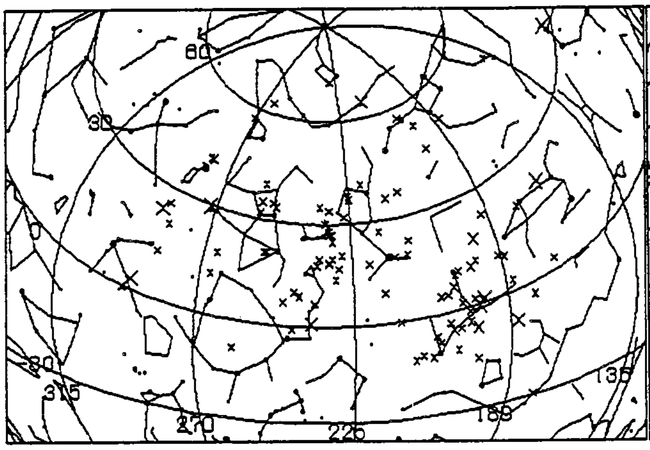

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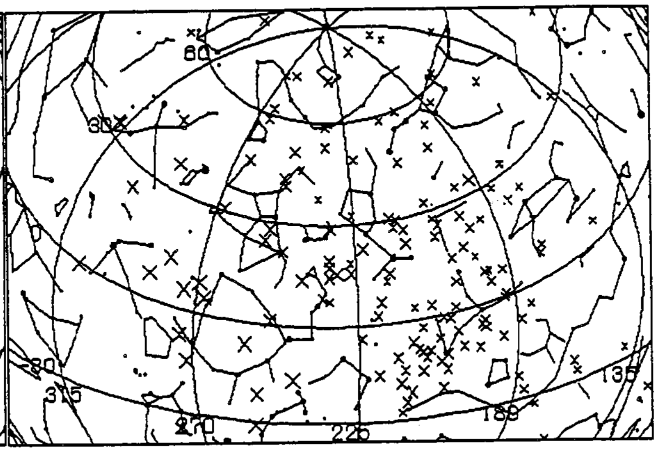

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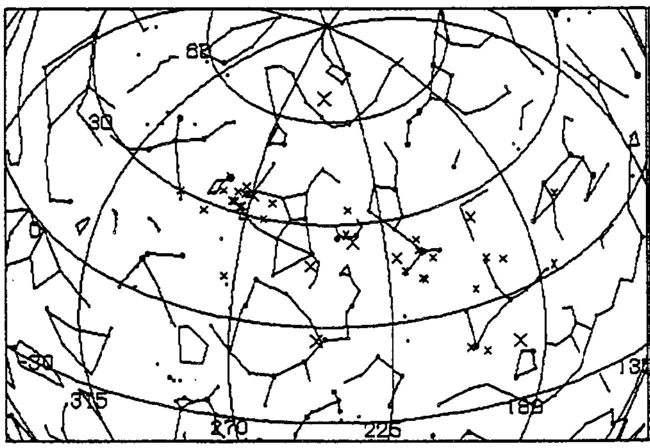

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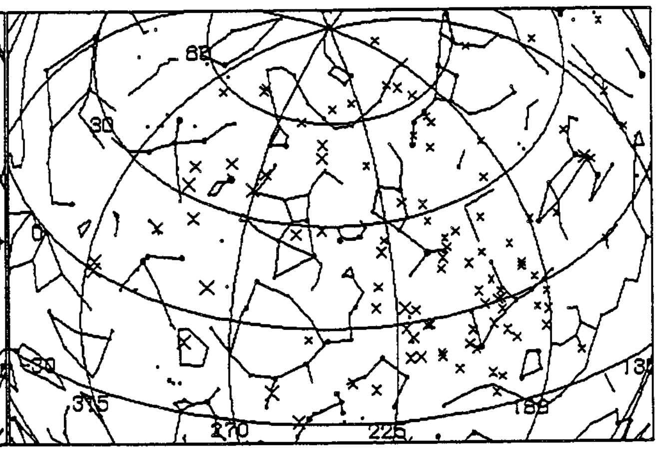

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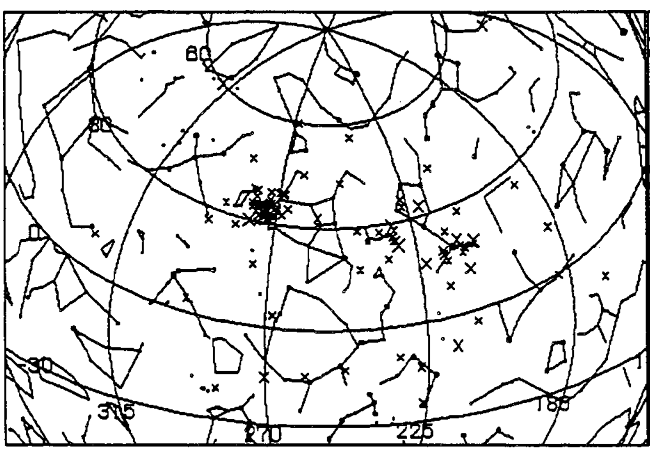

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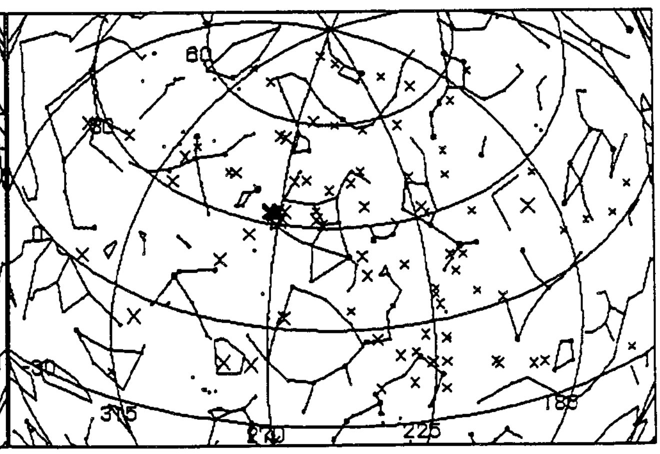

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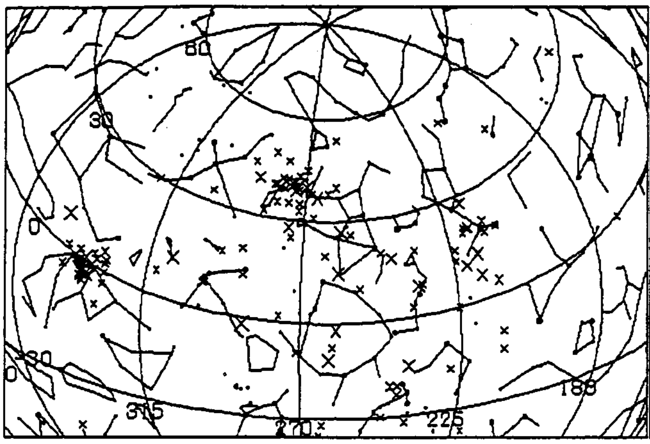

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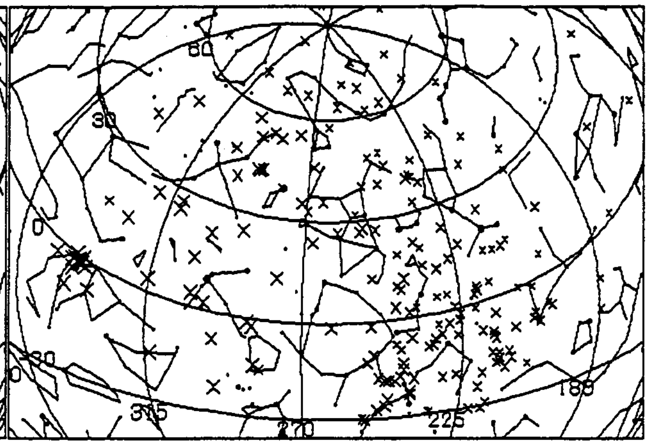

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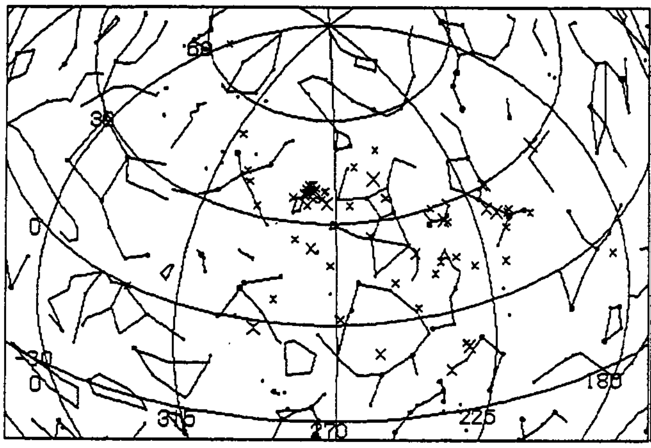

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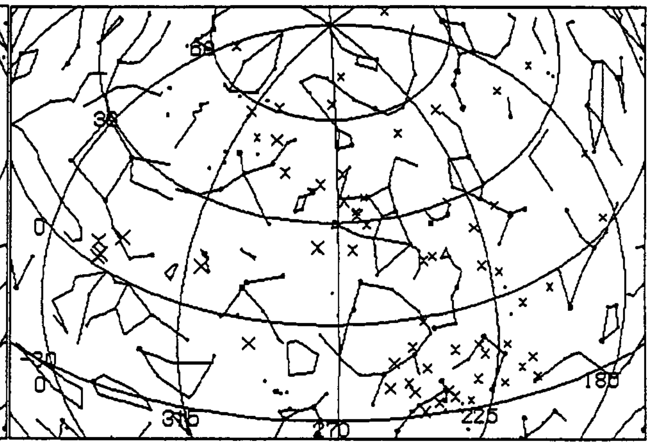

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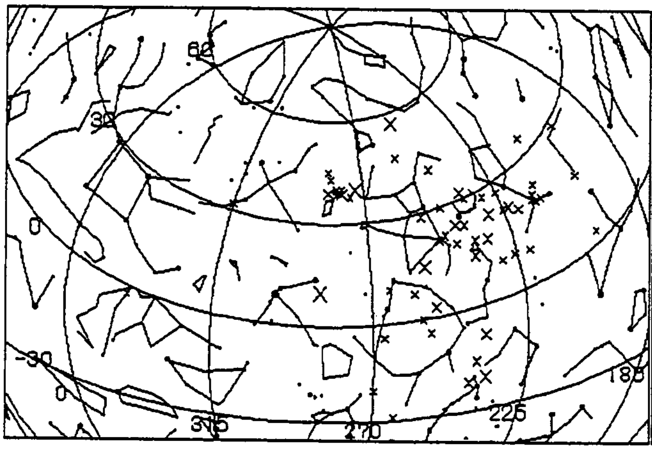

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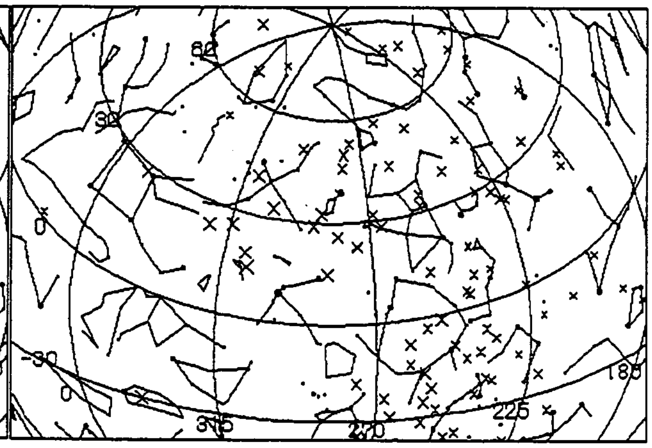

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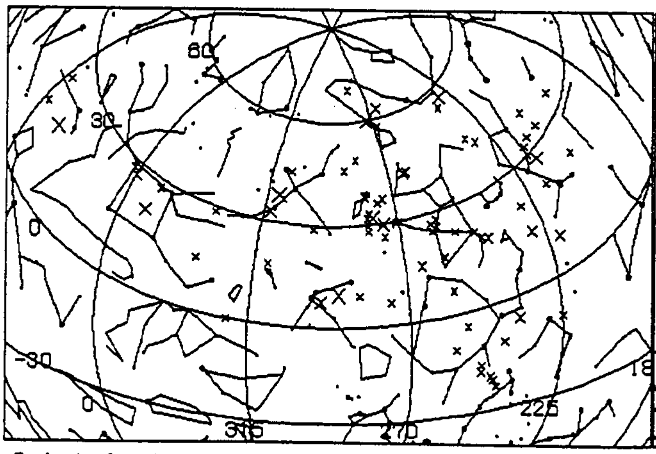

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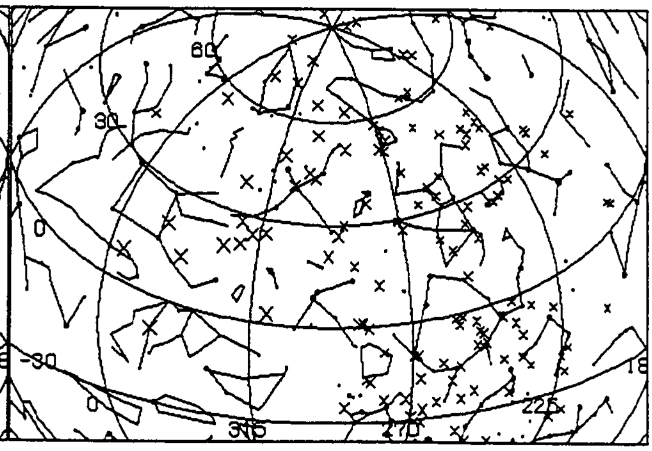

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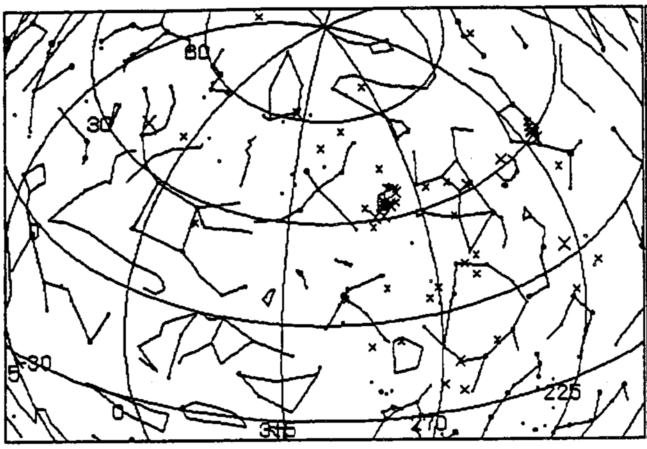

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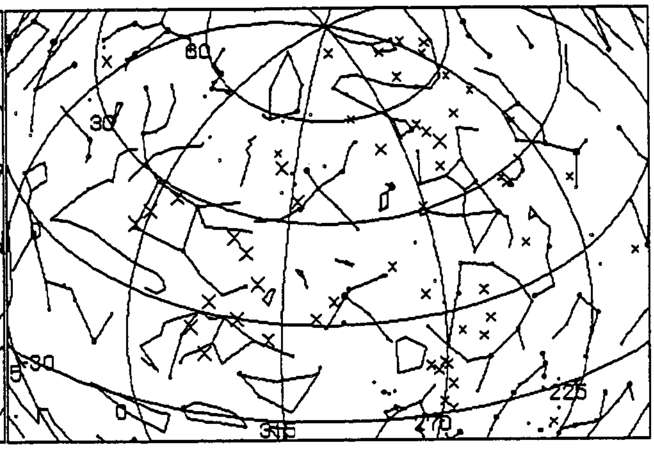

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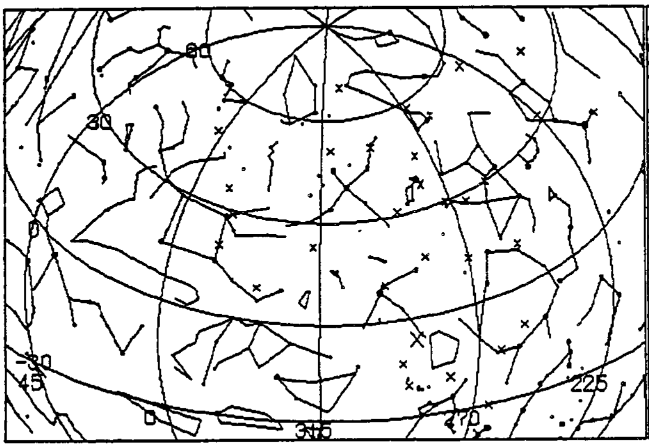

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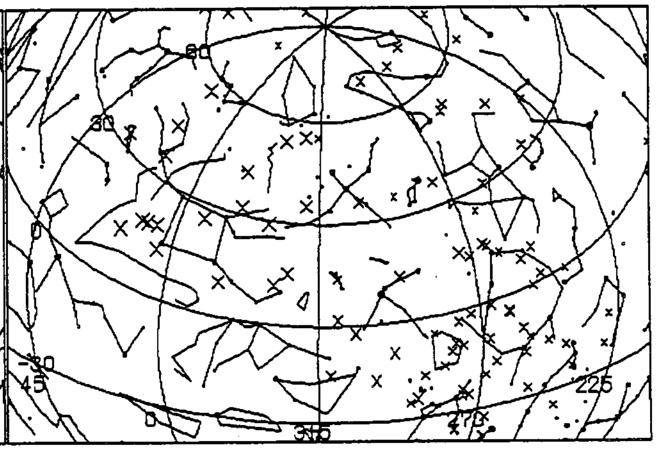

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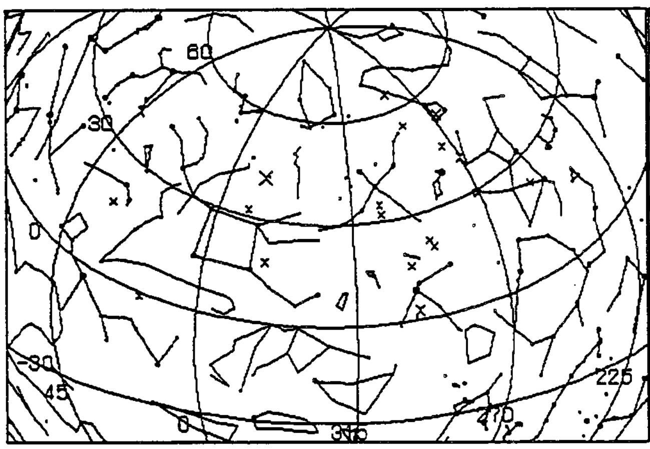

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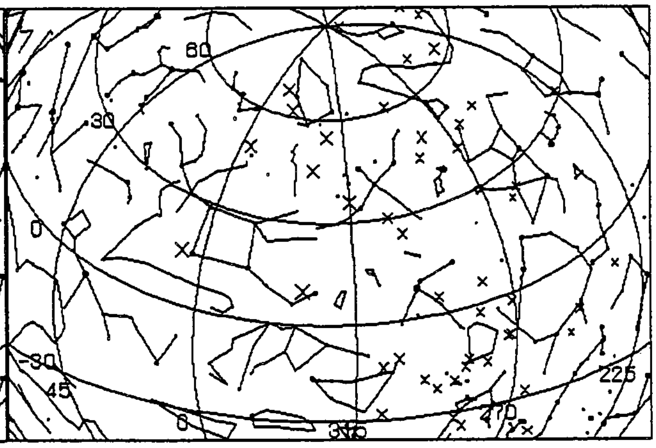

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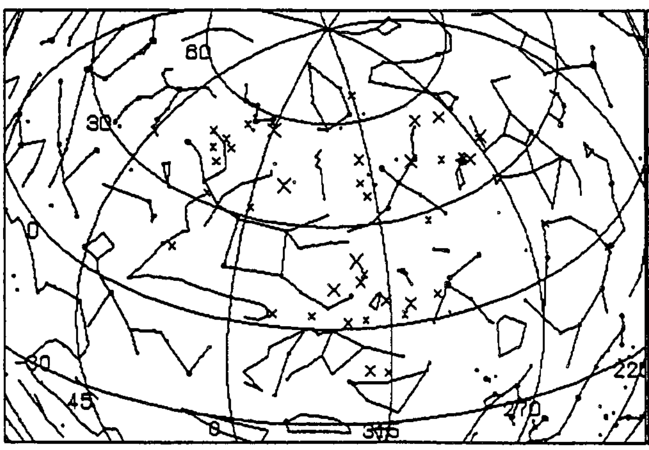

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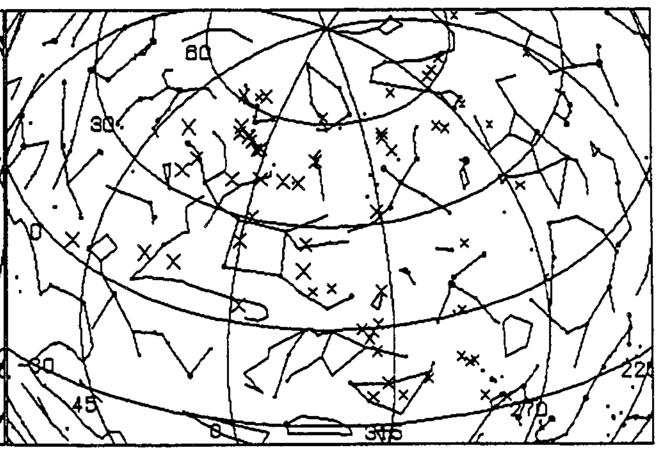

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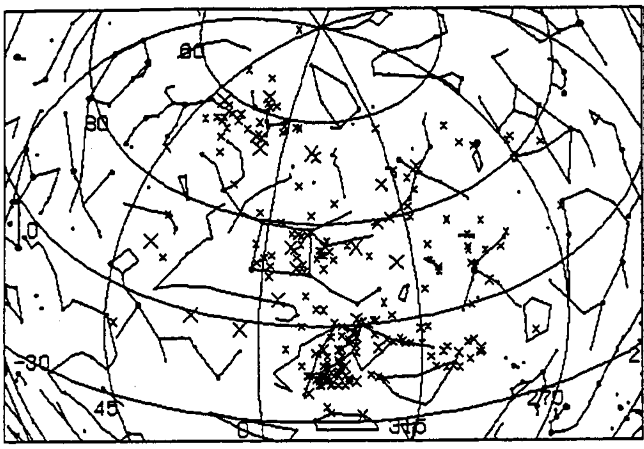

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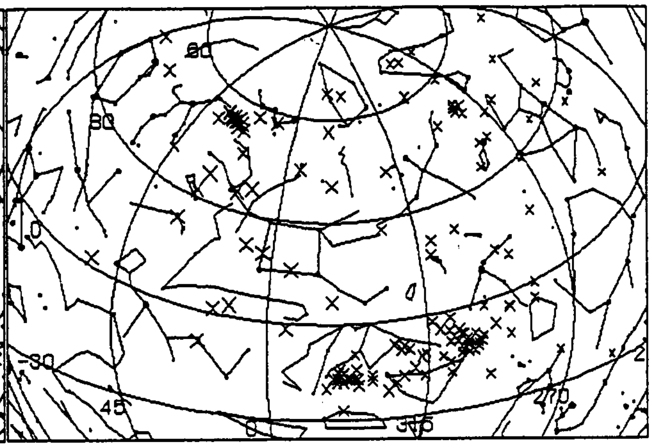

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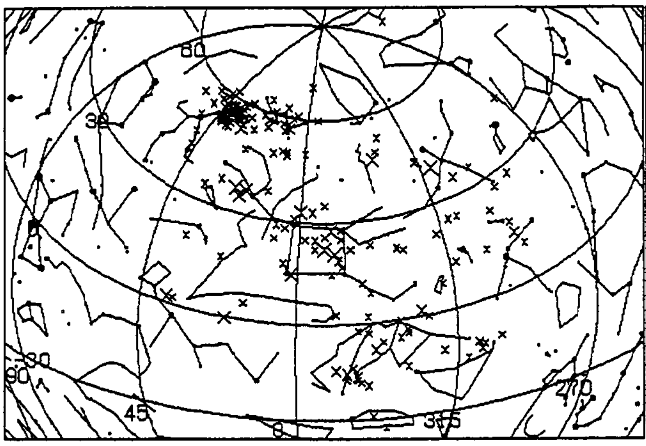

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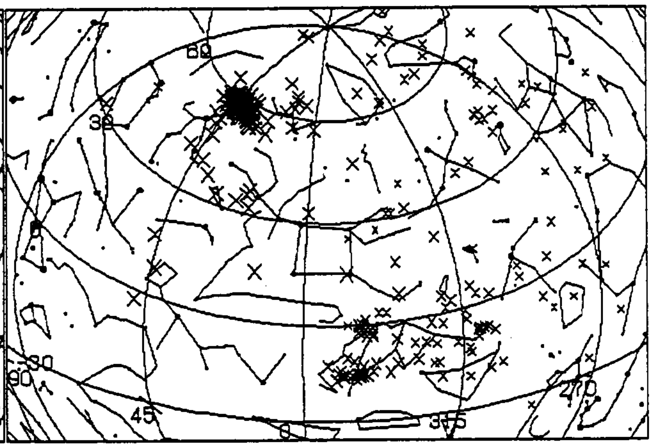

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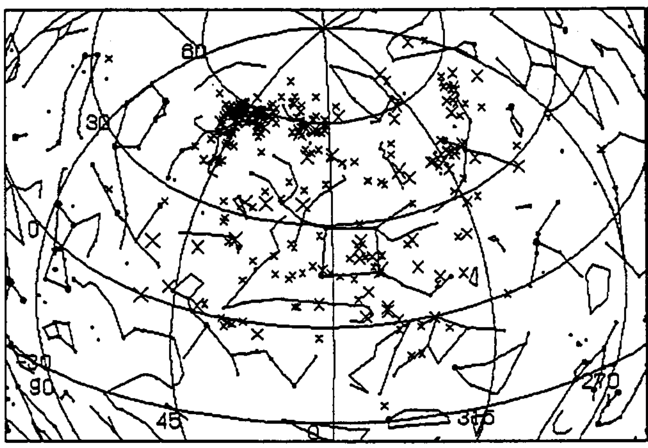

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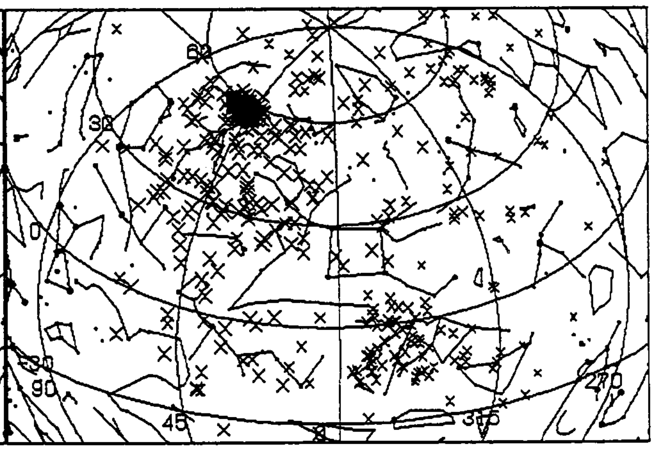

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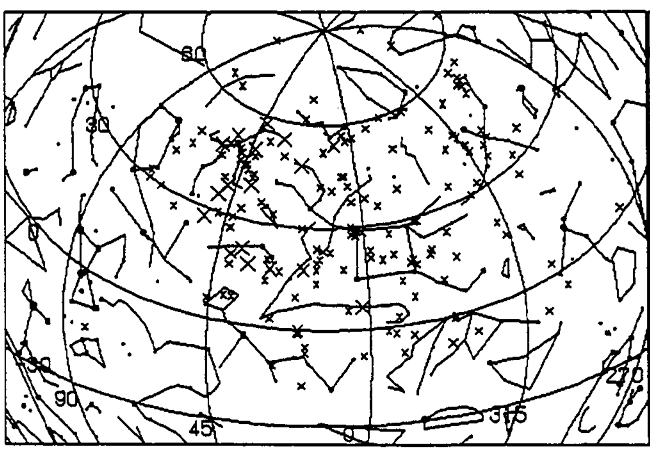

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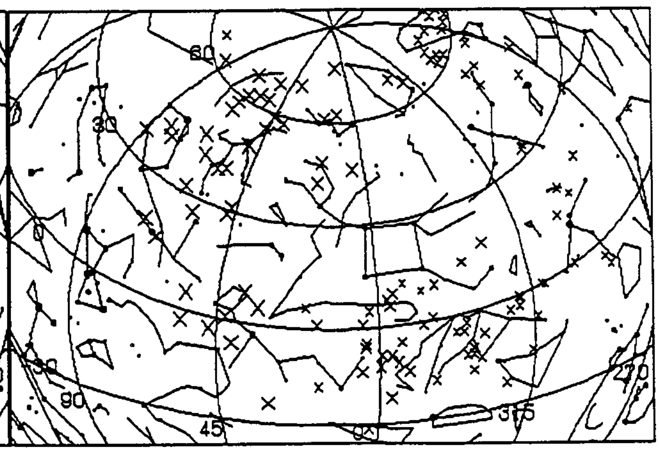

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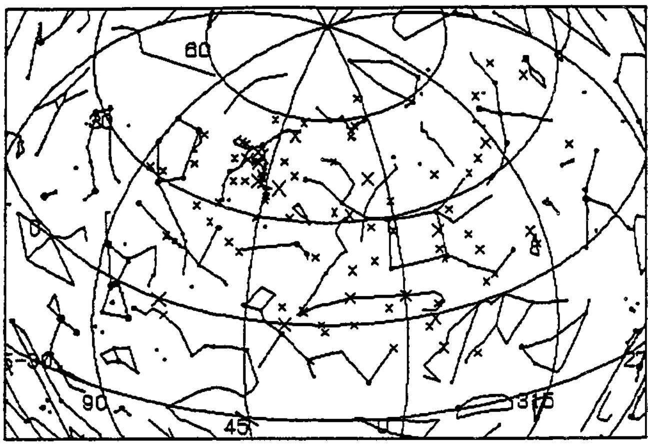

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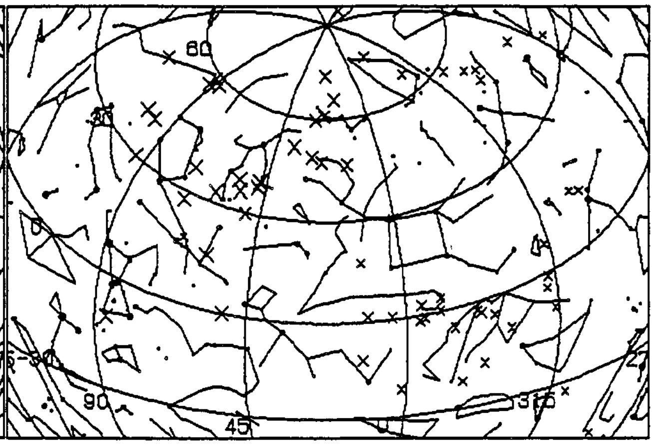

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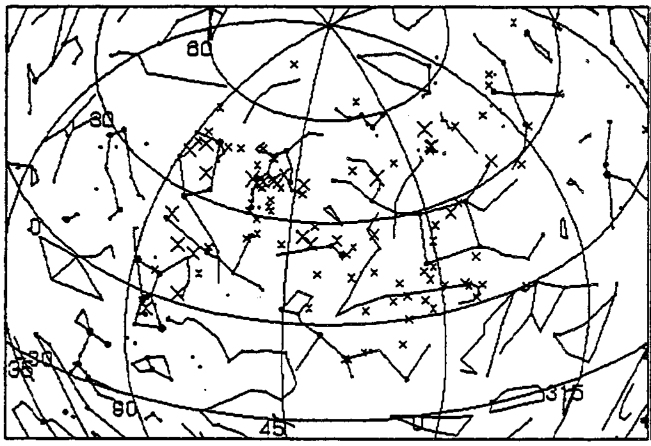

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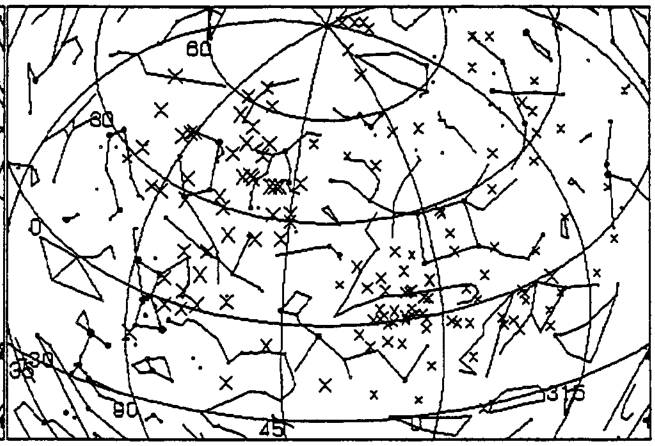

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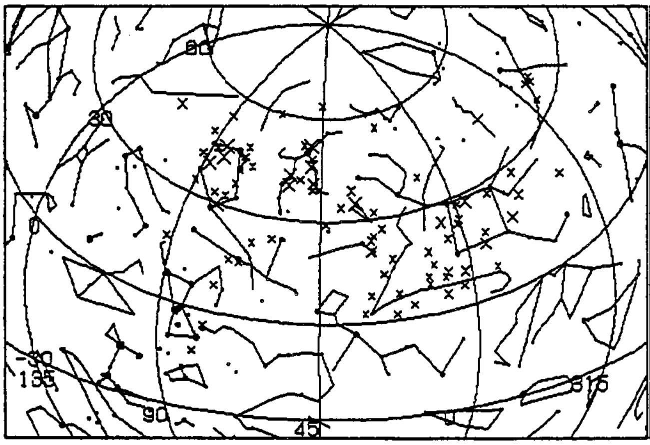

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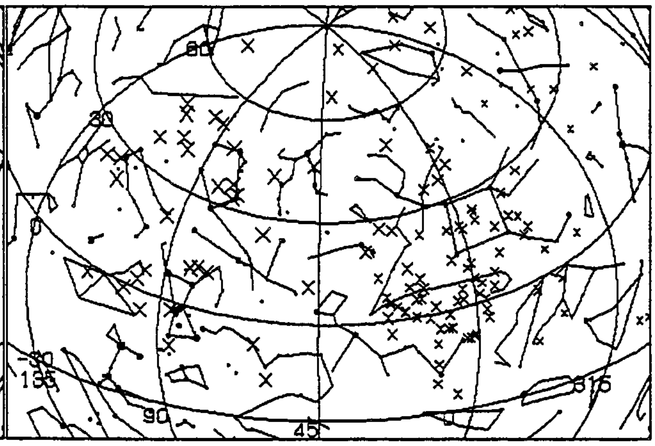

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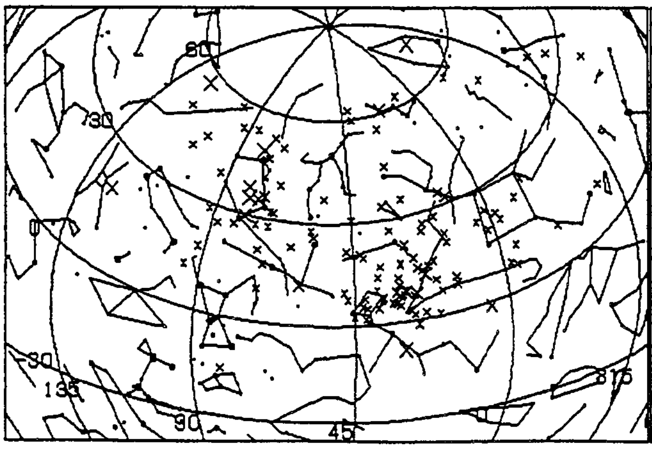

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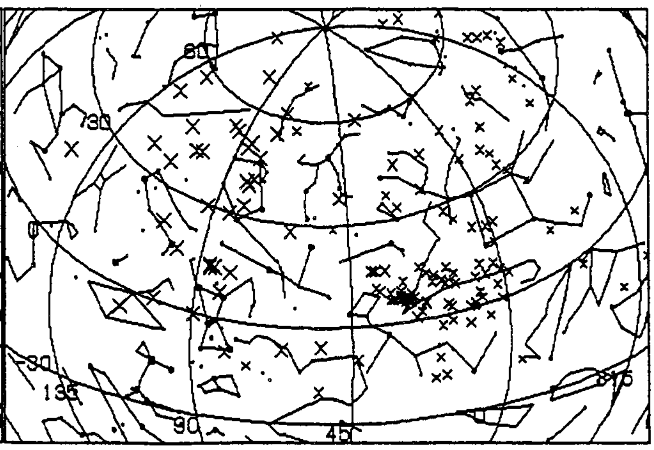

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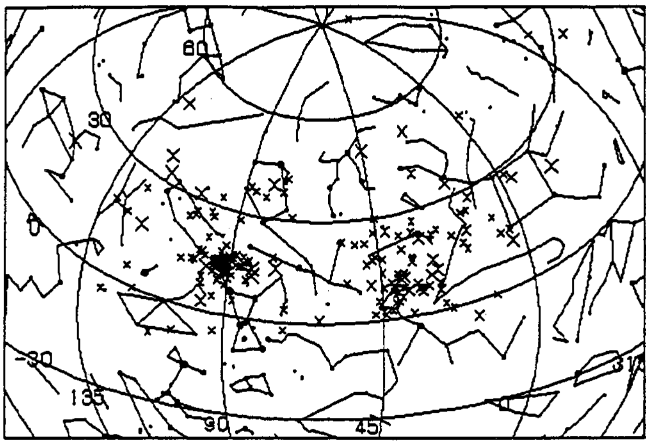

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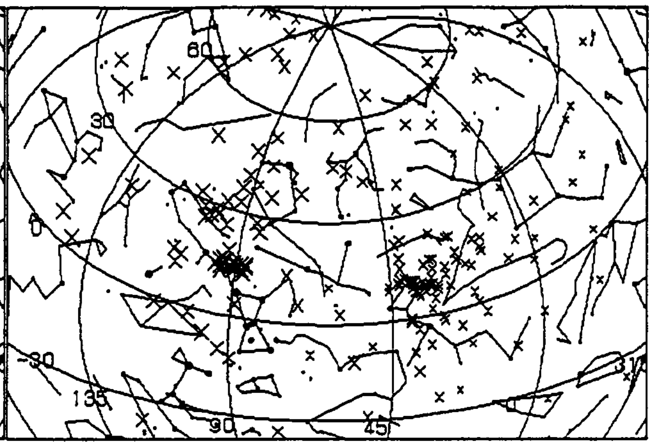

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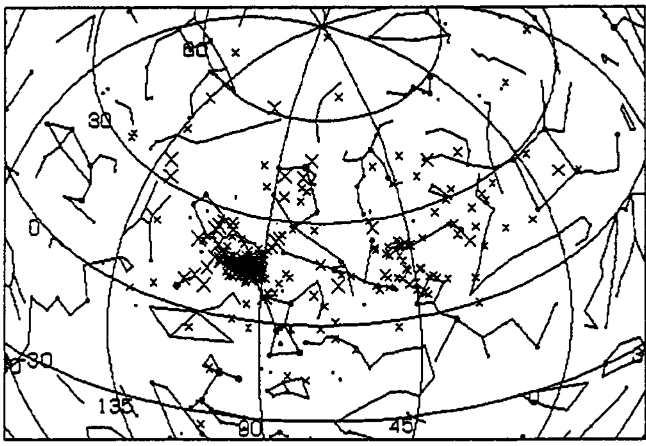

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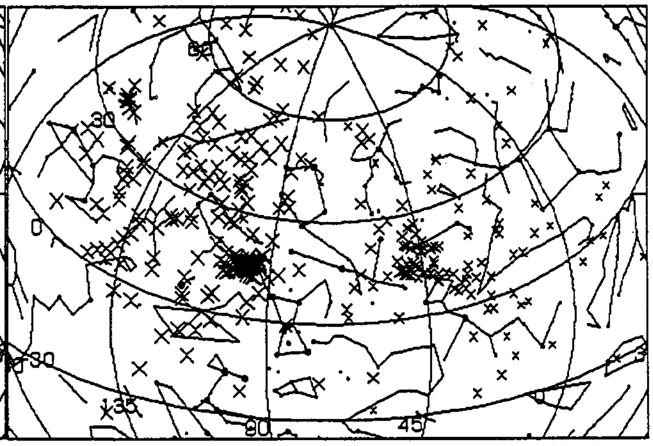

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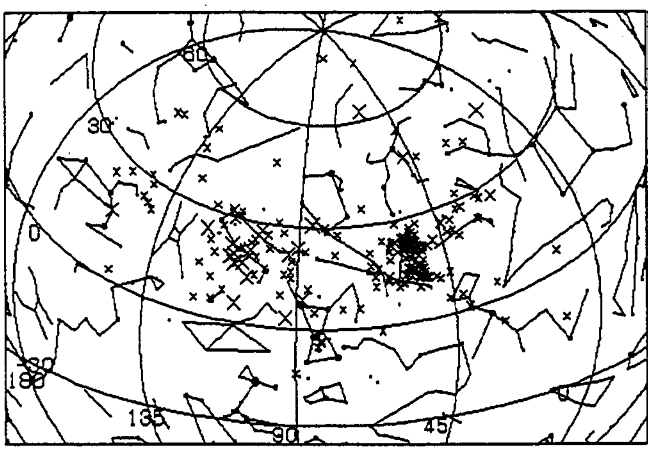

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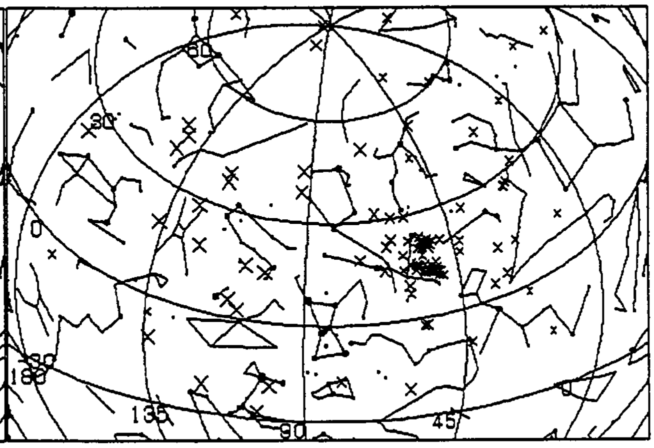

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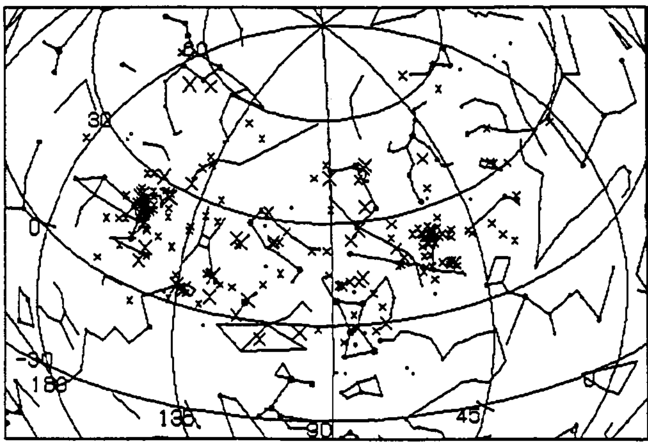

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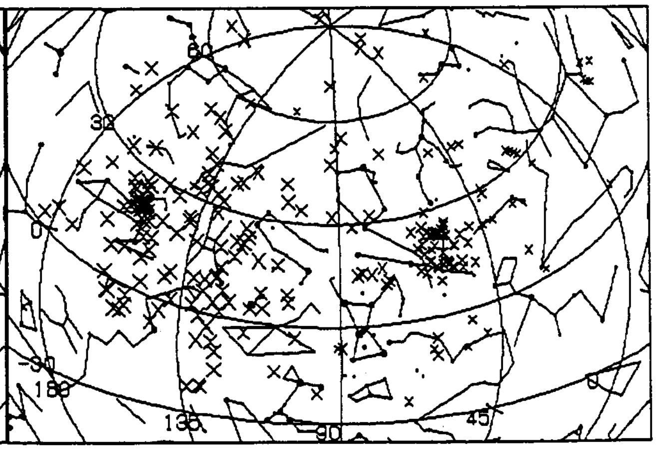

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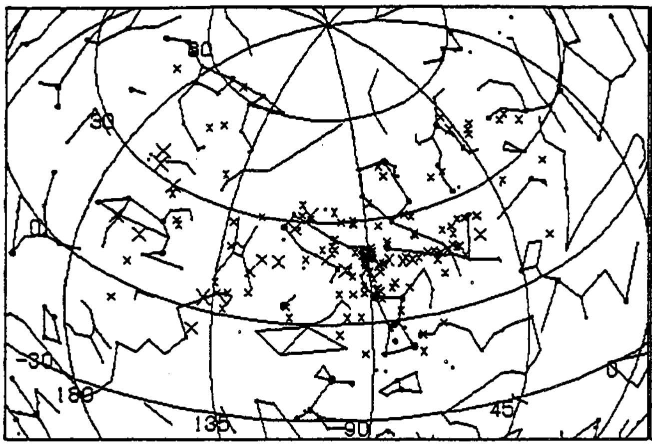

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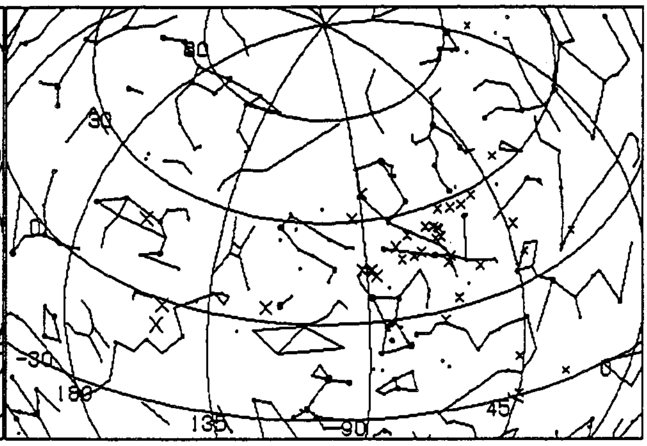

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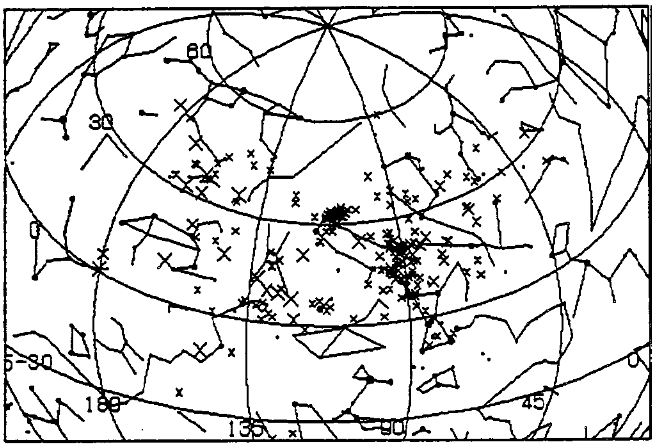

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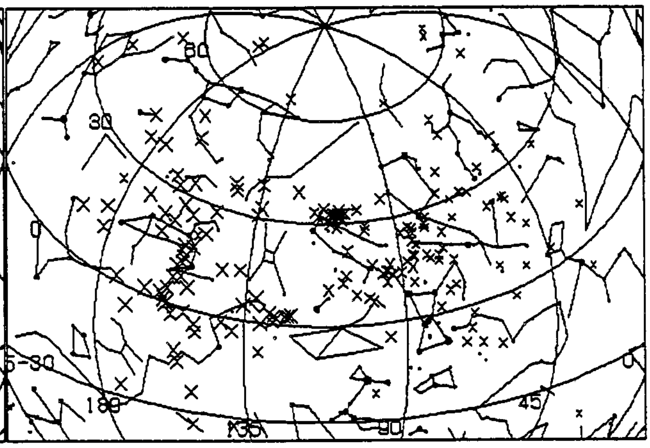

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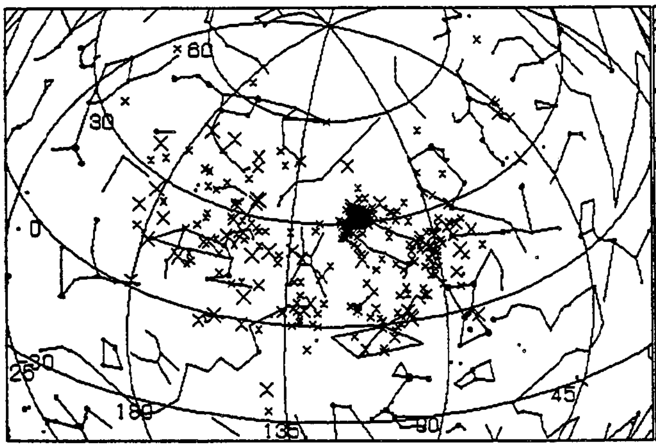

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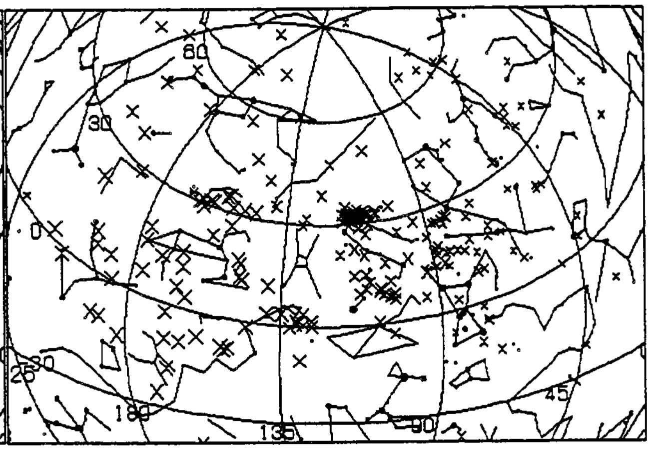

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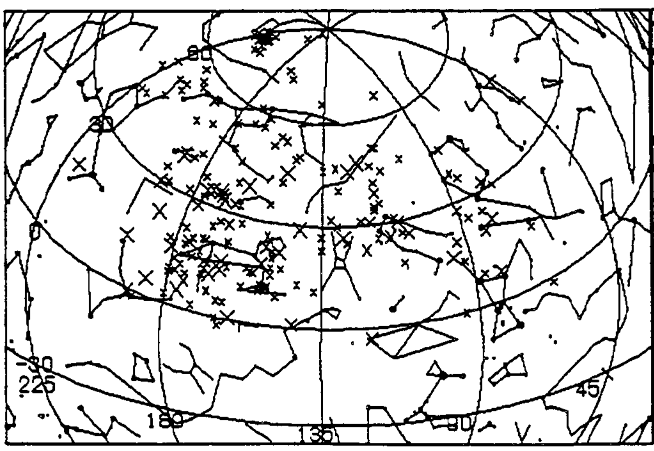

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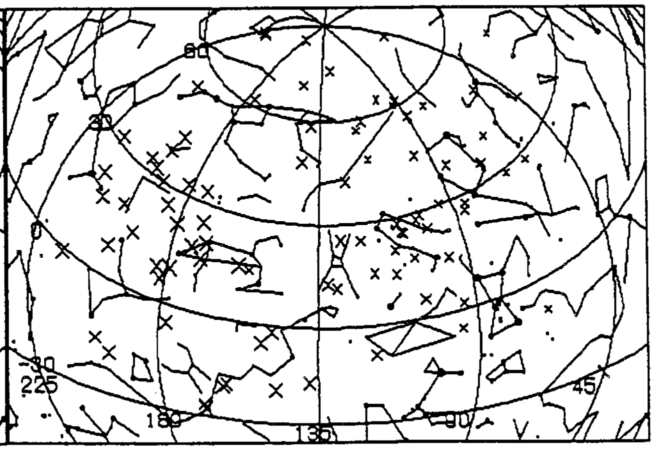

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Fireballs and Meteorites

A Block of Ice Falls on Rue, Switzerland

Bruno Mancusi

The fall of a block of ice was observed in Rue, Switzerland, on July 26, 1998. The author went to the scene to write the account of the witnesses and to take a few measurements. The nature and origin of the block have not been elucidated.

1. Description of the event

On Sunday July 26, 1998, at around $9^{\rm h}45^{\rm m}$ Central European Daylight-Saving Time ($7^{\rm h}45^{\rm m}$ UT), a Rue farming couple were in front of their house when they heard a whistling sound *"like a big rocket on August 1"* (Swiss national holiday). They just had time to see a block of ice the size of a *"football"* pass in front of their field of vision and crash onto the tarred path near to their farm. The block broke up into thousands of pieces and the witness recuperated the largest, which was *"the size of a skittle."* The ice was *"very hard"* and *"snow-colored."*

The witness estimated the weight of the ice block at 7–8 kg and the piece that he was able to recuperate at 6–7 kg. Unfortunately, he did not think of conserving the block in the freezer, and let it melt near his house after having shown it to his neighbor, who had also heard the noise. Thinking that it must have fallen from an airplane, the witness telephoned the Geneva-Cointrin Airport, where he was advised to write to the Federal Office for Civil Aviation (FOCA) and send a copy of his letter to the airport. A few days later, the witness received the reply: the FOCA declared that it was incapable of identifying the device responsible because of incertitude over the time of the incident.

The witness also telephoned a journalist from the Fribourg daily newspaper *La Liberté*, and a short article appeared on July 28.

I only learned about this incident on August 18, when a column mentioning it appeared in *Le Démocrate de Payerne*. After having found out the name of the witness, I was able to go to the scene on September 18. The witnesses, who were aged around sixty, seemed credible to me and were very cooperative.

The trajectory of the block had an azimuth of 38° (northeast to southwest) and an inclination of 50° to 70° relative to the horizontal. There was no abnormal radio-activity at the point of impact or where the witness left the block to melt, but a month and a half had gone by, and, in the meantime, it had rained. The layout of the place would have made a practical joke at the witnesses' expense difficult. On the other hand, a complete hoax played by the witnesses is possible (the block had disappeared), but, in my opinion, unlikely.

2. Some data

Crash site

The block of ice fell in the town of Rue, in the Swiss Canton of Fribourg, $\lambda = 6°49'25''$ E, $\varphi = 46°37'06''$ N, $h = 636$ m.

Meteorological conditions [1]

The weather was sunny, with a temperature of 20° C and light winds, 5 km/h, from southwest to northeast.

Altitude winds (Payerne): at 1000 m, at $23^{\rm h}$ UT of the preceding night, northeast, 30 km/h; at $11^{\rm h}$ UT, southwest, 10 km/h; at 2000 m, at $23^{\rm h}$ of the preceding night, northeast, 10 km/h; at $11^{\rm h}$ UT, southwest, 40 km/h.

Generally, there was a very leveled distribution of pressure over Switzerland.

Verification of the values estimated by the witness: Are the size of the block and its mass as estimated by the witness compatible with ice (density of 0.9168 g/cm^3)? To find out, we calculated the radius of a perfect ball of ice for different masses (Table 1).

Table 1 – Radius of a perfect ball of ice for different masses

Mass	Volume	Radius
5 kg	5454 cm^3	10.9 cm
6 kg	6545 cm^3	11.6 cm
8 kg	8726 cm^3	12.8 cm
10 kg	10 908 cm^3	13.8 cm
15 kg	16 361 cm^3	15.7 cm
20 kg	21 815 cm^3	17.3 cm

The witness's estimate is therefore correct, but we notice that the radius increases little in relation to the increase in mass (proportional to its cube root). We therefore have the following choice: if we base our calculation on the mass as estimated by the witness (7–8 kg), the block should have a diameter of around 25–26 cm. On the other hand, if we consider the size (a football with a diameter of 22 cm), the mass could vary between 5 and 10 kg.

3. Origin of the block

As the block no longer exists, it is unfortunately impossible to determine its origin. It is very unlikely that it came from the toilets of an airplane as, in that case, it would have been blue or green-colored. Was it a hailstone? That does not correspond with the weather conditions. There remains the hypothesis of an ice meteorite. Falling blocks of ice have been reported for centuries [2], long before the invention of aviation. Ice is commonly found in space, it is one of the constituents of comets and the rings of Saturn. It is therefore not impossible for a piece to arrive on the Earth's surface.

Falling blocks of ice are relatively frequent. In Switzerland, the other cases that appear in my archives are the following: Yverdon-les-Bains (1978), Oftringen (1982), Lützelflüh (1982), and Renens (1986). The latter probably fell from the toilets of an airplane as it was blue in color.

It seems that the best documented fall of an ice block took place on April 2, 1973, in West Didsbury, Manchester, England. The block weighed around 2 kg, and consisted of 51 layers of ice but, even in this case, the origin was not determined [3]. A more recently investigated fall occurred on March 23, 1995, at Yaodou, in the Zhejiang Province, China. According to the Xinhua News Agency, the three chunks of ice were sent to Purple Mountain Observatory for analysis [4]. Unfortunately, the results are unknown, and my efforts to obtain a response from this observatory are, so far, unsuccessful.

References

[1] Swiss Meteorological Institute, *personal communications*, October 1, 1998.

[2] W.R. Corliss, "Tornados, Dark Days, Anomalous Precipitation, and Related Weather Phenomena", *The Sourcebook Project*, Glen Arm, USA, 1983, pp. 40–44.

[3] S. Welfare, J. Fairley, "Arthur C. Clarke's Mysterious World", Collins, London, 1980, pp. 42–43.

[4] `http://www.jpl.nasa.gov/sl9/news56.html` and `http://www.knowledge.co.uk/frontiers/sf102/sf102g15.htm`.

Observational Results

SPA Meteor Section Results: July–August 1998

Alastair McBeath

We present news and details from reports submitted to the *SPA Meteor Section* from July and August, 1998. Another spectacular fireball was widely seen across western Britain around 23^h UT on July 10, possibly producing an unusually persistent train (about 45 minutes). Radio reports suggested an unexpected spike in rates between 1^h and 2^h UT on July 18 from an unidentified source, while the Southern δ-Aquarid and α-Capricornid maxima in late month both received useful radio and visual coverage. August produced some atrocious weather conditions, which coupled with bright moonlight meant the Perseids were not well-observed, except by radio. Another possible "spike" in radio rates was found on August 21-22.

1. Introduction

July and August brought no respite from the generally poor weather conditions experienced in many places in 1998, with August especially proving unexpectedly dismal for many. The bright waning Moon for the Perseid maxima did nothing to assist visual watchers either. Radio observers again encountered difficulties from Sporadic-E (Es) events, but were generally more successful in covering the meteor activity. However, late July provided a chance for some observers to see the best from the δ-Aquarids and α-Capricornids. The overall observing totals are shown in Table 1.

Two *Arbeitskreis Meteore* (*AKM*) photographers, Jürgen Rendtel and Jörg Strunk in Germany, and *SPA* member Terry Holmes in England, provided all the photographic data, but unluckily caught no trails. All the *AKM* data used here was extracted from *Meteoros* issues 9 and 10 (1998), thoughtfully submitted by Ina Rendtel.

A large part of the radio data was extracted from *Radio Meteor Observation Bulletins* (*RMOB*s) 60 and 61 (August and September 1998, respectively), kindly provided by Christian Steyaert. We should note too that *RMOB* 61 marked the fifth anniversary of the publication of the *RMOB*s in the wake of the 1993 Perseids, to which we happily add our congratulations here, along with good wishes for the continuation of these publications and the observer efforts they represent. The *RMOB* reporters are as follows:

> Enric Fraile Algeciras (Spain), Mike Boschat (Canada), Eisse Pieter Bus (Netherlands), Maurice de Meyere (Belgium), Ghent University (Belgium), Ou Yang Tian Jing (China), Will Kelsey (California, USA), Werfried Kuneth (Austria), Sadao Okamoto (Japan), Ton Schoenmaker (Netherlands), Chikara Shimoda (Japan), and Ilkka Yrjölä (Finland).

In addition, forward-scatter data sets were also received directly from Alan W. Heath (England), R.B. Minton (New Mexico, USA), and Robert S. White (England). Our standard procedures for analyzing raw forward-scatter data were followed as usual, with graphs representative of those available shown here.

The visual observers are as follows:

> *AKM* members Rainer Arlt (Germany and Slovenia), Pierre Bader, Franziska Böttcher, Michael Funke, Robert Gehlhaar, Mathias Growe, Udo Hennig, Danielle Hoja, Andreas Krawietz, Rhena Krawietz, Ralf Kuschnik, Sylvio Lachmann (Germany and Slovakia), Richard Löwenherz, Hartwig Lüthen (England only), Sirko Molau, Sven Näther, Mirko Nitschke (Slovakia only), Ina Rendtel (Israel and Wales), Jürgen Rendtel, Thomas Schreyer (Germany and Slovakia), Harald Seifert (Germany and Slovakia), Hendrik Sielaff, Manuela Trenn, Roland Winkler, Nikolai Wünsche, Oliver Wusk (Germany, Poland and Slovenia), Hans-Georg Zaunick (Germany and Slovakia; all in Germany only, except where noted), Jay Brausch (North Dakota, USA), Tim Cooper (South Africa), Shelagh Godwin (England), Peter Grego (England), Valentin Grigore (Romania), Alan Heath (England), Terry Holmes (England), Trevor Law (England), Tony Markham (England), Alastair McBeath (England), Graham Pointer (England), Vanja Rodiger (Croatia), and Robin Scagell (England).

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

Month	Visual	SDA	NDA	CAP	KCG	PER	Meteors	Photo	Radio
July	120^h	84	88	87	–	253	1402	63^h	3133^h
August	182^h	76	83	36	141	1046	2591	106^h	3955^h

2. July

The bulk of visual observations were concentrated in the closing twelve days of the month, but interesting events had already been taking place before that. Around 23^h UT on July 10, a brilliant meteor was observed from parts of western and central Britain. The very approximate ground track was probably from south-west England or south Wales, moving roughly northwards, ending over the Irish Sea near the Isle of Man. The object may have been in the magnitude range -12 to -20, and it probably fragmented during its flight. Comments regarding its speed and flight direction in the few eye-witness sightings are unfortunately contradictory, a problem compounded in the media reports received subsequently. The object left a persistent train visible for some tens of minutes, which showed a significant distortion over time, as long-duration trains often do. Many reports commented on this train forming an "S," "Z," or "Q" shape, all of which would be exactly as expected. One sighting suggested the train was still visible up to 45 minutes later, and some witnesses only saw the train, not the meteor. The train was suggested as a brief noctilucent cloud display created by a rocket launch from Wales in one report. There is no evidence to support such a launch taking place at the time, however, although noctilucent clouds have been seen following rocket launches in the USA, for instance. As one witness at least saw the meteor, and the train form in its wake, then watched it distort with time, there seems little reason to invoke such an exotic explanation in this case. Along with various other Section correspondents already mentioned, I am most grateful to Gloria Dixon, Jacqueline Mitton, Dave Newton, and Don Simpson for forwarding reports, cuttings and other details on this event.

On July 18, three of the four active European radio observers detected a short-lived increase in meteor echo count rates around 1^h–2^h UT, equivalent to $\lambda_\odot = 115\overset{\circ}{.}25$–$115\overset{\circ}{.}29$ (eq. J2000.0). In the Japanese data, there is a very marginal suggestion of slightly heightened overall activity on July 17-18 (UT), but this is not conclusive, though it recurs in the longer duration echo counts (see Figures 1–3). There is no clear timing peak in the overall Japanese results compared with dates immediately adjacent, nor is there an enhancement around 1^h–2^h UT. In *RMOB* 60 (August 1998), Christian Steyaert reproduced an announcement from the `meteorobs` e-mailing list which mentioned a single observer, John Holtz, on the east coast of the USA (exact location unstated), who had noted meteor rates of 1–2 per minute from 1^h50^m to 2^h15^m UT on July 18 ($\lambda_\odot = 115\overset{\circ}{.}28$–$115\overset{\circ}{.}3$). His comments seem to suggest he saw the meteors in Ursa Major, Draco, Bootes, and Hercules, and that all were moving due south, but he could not give a radiant position, nor any other details about them.

Chris repeated another suggestion that the near-Earth asteroid 1997 BR, closest orbital approach expected on July 19 with a theoretical radiant in Ursa Major, some degrees north of the body/bowl of the seven-star Plough/Big Dipper asterism ($\alpha = 175^\circ$ and $\delta = +65^\circ$, eq. J2000.0), could be a possible source. The atmospheric velocity for such potential meteors was quoted as 16 km/s. As no activity has yet been definitely detected from any of the theoretical near-Earth asteroidal meteoroid streams, this event could have been very important. Requests for further information from any observers in correspondence, regular publications, and by personal contact at the *Meteoroids* Conference and the *IMC* in Slovakia in August have so far drawn no response, so the event and its possible source remain unknown.

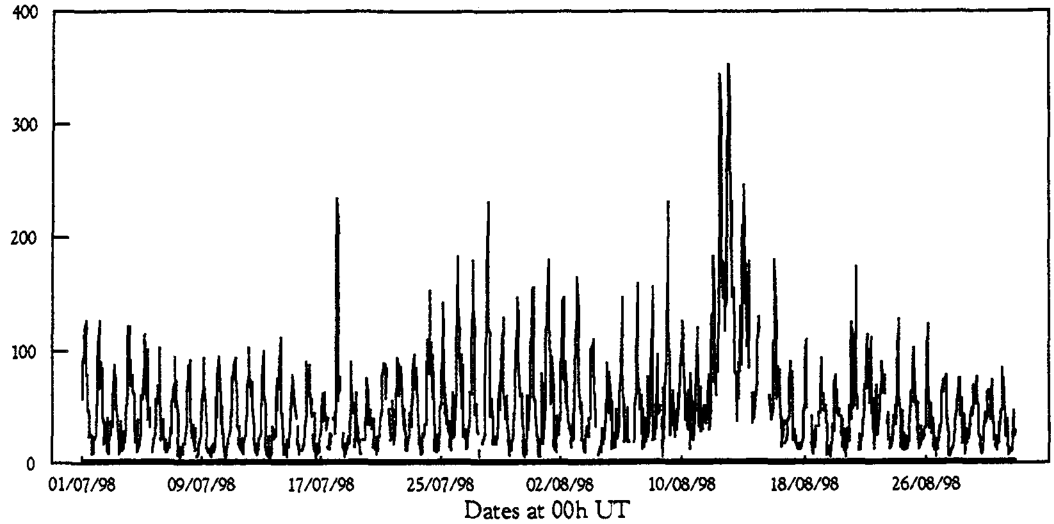

Figure 1 – Raw hourly radio meteor percentage reflection time echo counts (×10) from July and August, 1998, in data collected by Ghent University. This equipment was operated continuously, with most data breaks due to Es. The activity "spike" on July 18 is especially clear in the Ghent data. Note too the "bulge" around the July-August border due to activity from the Capricornid and Aquarid showers. The Perseid maximum is by far the most noticeable feature, however. Note that y-axis scales vary between the graphs shown here.

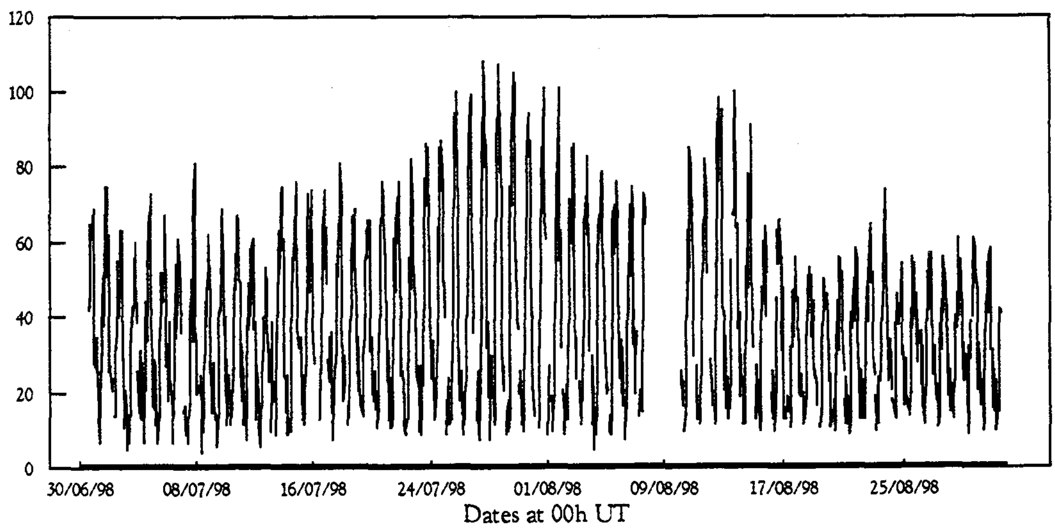

Figure 2 – Raw hourly radio meteor echo counts (all echoes) from July and August, 1998, recorded by Sadao Okamoto, whose equipment was operational 24 hours a day. Again, the gaps are due to atmospheric interference, except between August 8 and 10, which was due to a transmitter failure. Notice the Aquarid-Capricornid "bulge" is significantly more obvious in this data than the Perseids. There is a possibly weakly enhanced signature in echo counts on July 17-18 (UT).

Checking the radio records for this time from recent years [1] revealed no exact correspondence. A weak echo enhancement has been previously noted around $\lambda_\odot = 111°–114°$, along with one instance (in 1996) of another weak event at $\lambda_\odot \approx 116°$. In 1998, most data sets confirmed a weak enhancement around $\lambda_\odot = 111°–113°$, while the $\lambda_\odot \approx 116°$ event showed weakly in half the available results. For some reason, the Ghent University data shows the July 18 "spike" much more significantly than any of the other European data sets, perhaps suggesting the geometry was near-perfect for their set-up.

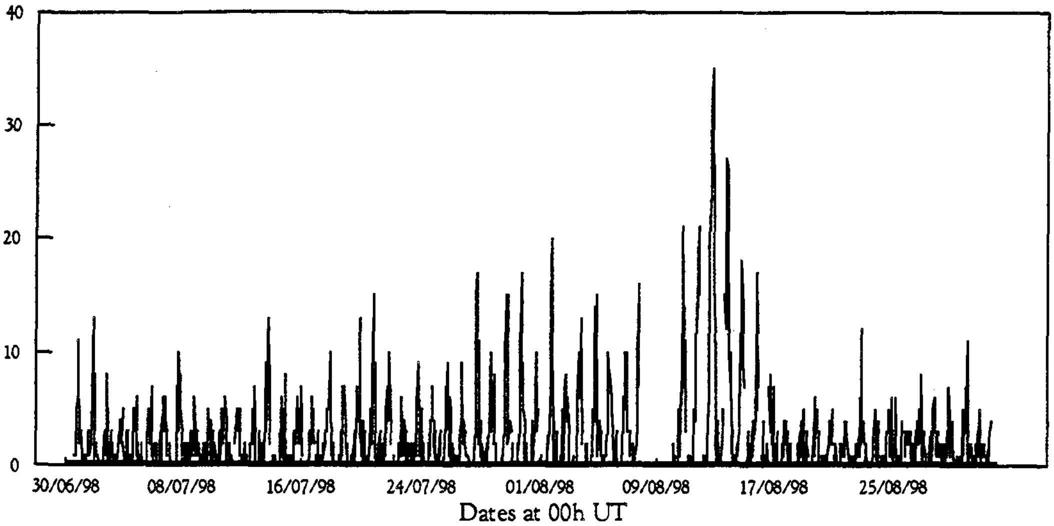

Figure 3 – Raw hourly radio meteor echo counts (of duration longer than 5 s) from July and August, 1998, extracted from Sadao Okamoto's data, for comparison with Figure 2. In these data, the Perseids are the single most significant source, with the Aquarid-Capricornid complex showing far more weakly. There remains a slight sign of enhancement on July 17-18. The "peak" time for this is 21^h–22^h UT on July 17, but a similar "peak" in long-duration echoes is seen again at this time on every day from July 17 to 21, inclusive.

The Japanese all-echo data (see Figure 2) shows the "bulge" in echo counts due to the Aquarid and Capricornid complexes in late July into early August very well, though it is far less impressive in Sadao Okamoto's longer duration echo counts, which is not unreasonable, given the Aquarid and Capricornid showers have lower atmospheric velocities than, for instance, the Perseids, which show up very distinctly in these longer duration counts. Visual observers were also able to cover these showers quite well, though their low radiant declinations meant Tim Cooper in the southern hemisphere had a far clearer view of them than observers in North America and Europe. The Southern δ-Aquarid maximum on July 28 was readily detected, with ZHRs around 10–20, while the α-Capricornid peak on July 30 was reasonably apparent too (ZHRs around 5–8). Too few magnitude and train data were available for further analyses, however.

As might be appreciated, the radio graphs shown here are those least affected by Es. Elsewhere, others were far less fortunate, and several observers also ran into equipment problems as well, so coverage was not as complete as might have been hoped for. Even so, all of the previously detected enhancements in echo counts from [1] could be confirmed in all the available data, except where noted above. The only new activity enhancement was that on July 18.

3. August

After the interest of the previous two months (June Bootids and various events in July), August was disappointingly tame, by contrast. The bright Moon and poor weather conspired to hamper visual observations of the Perseid maximum in mid-month, despite most observers putting in their strongest efforts then.

Estimated ZHRs on August 11-12 and 12-13 were no better than 50–70 and 70–80, respectively, in the data submitted to the Section, while even the *IMO*'s preliminary Perseid results [2] show much worse scatter near the peaks than normal. *SPAMS* observers were not well-placed to catch the primary Perseid peak, but did see rates in line with the preliminary *IMO* findings for the traditional maximum's timing and approximate strength. Complete magnitude and train details could not be determined this year, but the corrected mean magnitudes for the Perseids and August sporadics, respectively, were +1.2 and +2.4.

As Figures 1 and 3 demonstrate, the radio observers enjoyed the best "view" of the Perseids this year. Almost all data sets with the radiant above the horizon show an especial enhancement around 13^h–15^h UT on August 12, in time to the expected primary peak, and several were again enhanced around and after 22^h UT on August 12. The secondary peak was not so sharply defined, however, much as has been seen before.

Of the previously found radio enhancements, all were confirmed in the majority of available datasets, but the $\lambda_\odot \approx 135°$ weak increase was poorly noted. Most data sets suggested a blending of this enhancement with the extended $\lambda_\odot = 137°$–$142°$ spell (from $\lambda_\odot = 133°$–$142°$), with two sets of results favoring $\lambda_\odot \approx 136°$ as especially prominent. One new enhancement was also found around $\lambda_\odot = 148°$–$149°$ (August 21–22). This was quite strong in the European data, but recurs at a lower level in the Japanese as well. European data suggest a possible peak around 3^h–5^h UT on August 21, but the data are not clear on this point, and the Japanese results show no significant enhancement at any specific timing. Pierre de Groot at Ghent University suggested in *RMOB* 61 that $9^h - 11^h$ UT on August 21 was perhaps the maximum time for whatever was happening, but this is not confirmed by the other data sets available then.

Very few late-month visual data sets are to hand, and no further sightings of the possible new Arietid shower radiant discussed from last August [3] were made, unfortunately, largely due to poor skies. The radio data showed a somewhat extended enhancement from $\lambda_\odot = 154°$–$156°$ (the $\lambda_\odot \approx 155°$ period; in a few cases this continued to $\lambda_\odot \approx 157°$), which latter parts are roughly coincident with a repeat of the activity noted on August 29–31, 1997. More data are needed on the Aurigid, Perseid, and Arietid showers in late August and September.

Acknowledgment

Many thanks go as normal to all observers and correspondents for their contributions. Clearer skies, and less Es, for your next observations!

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

[2] R. Arlt, "First Impressions of the 1998 Perseids", *WGN* 26:5, October 1998, pp. 218–219.

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What Have Stars to Do with Mosquitos?

Marcin Konopka

The *Comet and Meteor Workshop* operates in Poland. For some time, the organization has been supplying the *IMO* with observational data. Our observers take care of the data quantity (in 1997, we ranked first in terms of it), as well as their accuracy. Obviously, you could not get much inside information about our work looking only at its results (for which, by the way, we often pay in our own blood—but I will come to it later).

For some time, our coordinator and leader has been Arkadiusz Olech. During his term, the workshop has seen a rapid development. He "set out the nets" in Polish astronomical magazines, and was soon surprised to see them crowded with eager beavers. In the course of time, as they had been offered an opportunity to participate in seminars and camps, they became even more eager.

Well, the camps... They are organized at the Warsaw University observational post in Ostrowik: a secluded spot deep in the woods with a couple of houses nearby. The camps are held in July, at the time of New Moon. Every year, groups of young astronomers arrive at the Celestynow train station and, from there, force their way through the forest. Finally, exhausted (as one could be having walked a couple of kilometers) they are happy to have reached their destination.

The mosquitoes, however, observing the observers with big interest and excitement, are even more happy. And more numerous, too, in the course of time (those of us who have developed a closer relationship with them can give you the details). There is another thing concerning the number of insects. The local people have noticed a strange phenomenon: the more mosquitoes there are, the less berries and mushrooms can be found in the forest. They are working on the explanation.

How do we spend our time at these camps? Apart from routine tasks, we play volleyball and soccer. We devote a lot of time to the two games, so do not be surprised to see us winning some championship in Sydney one day.

When it is getting dark, we prepare the equipment and go out for observations. The session lasts as long as possible. Except for relaxing waiting for a stray meteor and admiring the beauty of the Universe, our work includes furtive glances cast at dark bushes: the home of the blood-thirsty gang of mosquitoes.

What do we do when the night is cloudy? "You sleep," you may think. Well, we do not. We keep waiting for clear skies, at the same time improving our observational condition. Occasionally, we make a fire: after all sparks resemble stars, do they not? Sometimes, a brilliant idea crosses somebody's mind. That is what happened at the last camp. One night, the astronomers caught axes and... competed in logging.

Our second official meeting during the year is the seminar held at the Copernicus Astronomical Center in Warsaw. We tackle mainly organizational matters. We listen to lectures delivered by professional astronomers. The seminars do not give such opportunities as at the Ostrowik Observatory, but they are interesting, too. These two annual events are not all there is to it. They do not include our private observations, and we spend a lot of time on them. Analyzing 1997 reports, we did not miss a single clear night in April of that year: there were always a couple of us watching the sky. And we will keep up watching, I assure you.

Figure 1 – Group photo of *Comet and Meteor Workshop* members that participated in the astronomical camp of the observational station of the Warsaw University in Ostrowik. The camp took place from July 13 to 27, 1998. The picture was taken in the dome of the 60-cm Cassegrain telescope, which is equipped with a 512 × 512 pixels CCD camera. *Sitting, from left to right*: Michał Jurek, Luiza Wojciechowska, Aleksander Trofimowicz, Marcin Gajos, Katarzyna Kałużna, Andrzej Skoczewski, and Konrad Szaruga. *Squatting, from left to right*: Paweł Brewczak, Marcin Konopka, and Mariusz Wiśniewski. *Standing, from left to right*: Krzysztof Socha (with a hat), Arkadiusz Olech, and Jarosław Dygos.

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