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New shower list
Sporadics
Fireballs
Conferences
Radio meteors

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Front cover photo

A 2005 Perseid fireball in the morning sky over the Roque de los Muchachos observatory on La Palma, Canary Islands. *Technical data*— Camera: Canon EOS Digital Rebel XT. Lens: $f = 8$ mm, $f/3.5$ Peleng fisheye lens. 30 second exposure on a static tripod. Sensitivity setting at 800 ISO. Site: next to the Jacobus Kapteyn Telescope of Isaac Newton Group of Telescopes. Photo by Jure Skvarč (ING) collaborating in the Spanish Photographic Meteor Network coverage of the 2005 Perseids.

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Editorial — catalogues and lists

Chris Trayner

'There is nothing more wonderful than a list', says young Adso of Melk (Eco, 1983, p.73), though most of us would take a cooler view. Few would get much satisfaction from preparing a telephone directory, and very few indeed would get pleasure from reading one.

Science, however, progresses as much from steady careful work as from moments of inspiration. The aristocratic Tycho Brahe did not think it beneath him to devote his working life to making a better catalogue of stars (Hoskin, 1999, p. 95 *et seq*), or indeed to develop the accurate instrumentation needed (Chapman, 1989). He was right: the data were used by Johannes Kepler, who worked with him for the last year or two of Tycho's life (Hoskin, 1999, p. 106). Kepler's better understanding of orbital motion, which laid one of the foundations on which Newton built his physics, depended on the accuracy of Tycho's observations: the data showed orbits to be ellipses, not circles. Lists are needed, and they need to be accurate.

In the case of the IMO Meteor Shower List, published annually, the need for an accurate catalogue is at least as great as with a phone book. Many workers, both observers and theoreticians, treat this as a standard reference work. Of the academic (as against administrative) articles published in WGN last year, nearly a fifth (18%) referred to this list.

One might expect that this list-making was all done years ago, and that one needs merely to refer to a reputable reference work. Certainly there are such lists of meteor showers in textbooks: (Olivier, 1925) lists six, (and mentions shower lists going back to the mid 19th century: *op cit.*, pp. 84–90), (Lovell, 1954) lists eleven, and (Kronk, 1988) well over a hundred. This does not paint a picture of a simple and trustworthy source of information, though the last-named book is well respected.

There are two reasons why these lists keep changing. One is that showers themselves appear and disappear over time. The other is changing knowledge of what showers really exist. If a small number of meteors are observed to radiate from the same area of sky, it is often hard to decide whether this is mere coincidence or a shower. Good analytical techniques are needed. Sadly, many lists are contaminated with 'showers' that should never have been included. This can happen because they were added years ago, when techniques of analysis were cruder. It can be exacerbated when the lists come from respected meteor workers whom one would normally trust (Roggemans, this issue, p. 63). It can also happen because radiants are published by observers with more enthusiasm than discrimination; see for instance the analysis and dismissal of a 1930 observation in (Arlt, 2006).

The last major revision to the IMO shower list was in 1995, and a new one is probably overdue. Much has been published since then assessing the reality of showers, both established ones and alleged new discoveries. The Council announcement on page 62 and Paul Roggemans' letter on page 63 illustrate the discussions that have been taking place. The decision of when to issue such a revised list is surprisingly hard: inevitably, some people are involved in work based on previous versions. Readers need stability as well as accuracy, and one cannot please all of the people all of the time. In the end, it was decided to issue the list now rather than wait another year; it is recommended that the new list is used from the start of 2007.

An explanation of the new list, with justifications for the decisions, can be found on page 77. Further reasoning behind the changes to the names of antihelion sources is on page 71.

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IMO bibcode WGN-343-editorial NASA-ADS bibcode 2006JIMO...34...61T

From the IMO Council

Jürgen Rendtel and Robert Lunsford

In the past the activities within the Council have often gone unnoticed and some members may wonder exactly what is discussed among the Council Members throughout the year. We try to share this information each spring when the Council Members contribute their activities from the previous year. Unfortunately not everyone participates and those that do often neglect items that occurred nearly a year ago.

In order to alliviate this situation we wish to share our thoughts and processes as they occur throughout the year. It is our hope that sharing these items will encourage other IMO members to consider their own participation in organizing aspects and in the Council's work.

The current Council, elected last year, started its work at the beginning of 2006. Over the last months, the IMO web pages (`http://www.imo.net`) were updated with a new design. The pages provide information about the IMO and ongoing projects as well as the members and their interests. The weekly 'meteor activity outlook' is now accessible through the IMO web page and adds to the permanent information. This way one can see that the IMO is run by people dealing continuously with meteor astronomy.

We found a decrease of interest in photographic film meteor observations as more observers turn to video techniques. Nevertheless, still images are of interest for numerous observers. While the photographic film will be replaced by digital receivers, the general approach and optical limitations are basically the same. The idea of merging the Photographic with either the Video or Fireball Commissions was discussed but eventually not regarded as a useful option. The main point is that people sending enquiries about photographic observations to `photo@imo.net` receive an answer in due time. This can be achieved by a kind of technical advisory board or photographic advisory team with more than just one person involved.

One of the IMO's main aims from the very beginning was to overcome the situation of numerous (and sometimes questionable) radiant lists, meteor shower activity periods and similar misleading information. One way to achieve this is the IMO meteor shower list and our shower calendar. The list is declared as a working list and hence it is an evolving compilation of meteor shower data rather than a fixed list. We all know that there are certainly more sources. Our criterion — particularly for visual work — should be the possibility and chance to obtain physical data of each shower. If we record just 1 meteor/hour, the 'pollution' due to erroneously aligned non-shower meteors is too large for reliable results. Over the years we collected data of meteor showers, their detectability and the limits of the various observing and analyzing methods. More than a year ago, a group started working on a new handbook, and at the same moment about an updated shower list. Several papers on meteor showers have been published in WGN over the last months. In this issue of WGN we introduce the new working list. Interestingly, systematic searches among meteoroid orbits do not reveal further showers other than those included in the new list.

Another regular topic for the IMO Council is the announcement and later decision about funding possibilities for people attending the IMC. However, the support is primarily meant for projects and practical work, which may be combined with the presentation of results or new proposals at an IMC. This is often an agonizing process as we are limited in the amount of funds to be allocated. We certainly wish that we could help everyone attend but that is just not possible. We thoroughly examine and discuss each application. There are often different opinions among Council Members but we have always arrived at a suitable conclusion. In the end there are both happy and sad individuals, but we can assure you that all decisions were decided solely on the merit and value of each project as it relates to the IMC. We hope to make more funding help available by the establishment of a IMC fund, where members can donate extra at the time they renew their subscription. This would allow those less fortunate and isolated to interact with fellow meteor enthusiasts from the world over.

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Order your copy of the Radio Meteor School Proceedings 2005 now!

The Radio Meteor School Committee

Prior to the IMC 2005 in Oostmalle, IMO organized the Second Radio Meteor School. The main goal was to get acquainted with the radio meteor theory developed by professor Oleg Belkovich and his team at the observatory of the Kazan University. This theory allows one to determine the shower meteoroid flux density and mass index from properly acquired radio meteor echo counts.

The Proceedings of the Radio Meteor School 2005 will be published shortly. Those interested in getting a copy should contact Jean-Marc Wislez (`jmw@urania.be`). This will allow us to better estimate the number of hard copies to be printed.

The Proceedings are expected to be published in July, will contain around 120 pages, and will cost €15 including shipping.

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Letter — the reality of showers

Paul Roggemans [1]

How real are the 'official' showers like Northern Delta Aquarids, Southern and Northern Iota Aquarids?

The discussion about the Northern Delta Aquarids and the mentioning of the Iota Aquarids comes from the assumption that beside the well established Southern Delta Aquarids and Alpha Capricornids some other distinct radiants are present. Questions arise in the sense are there really other distinct meteor showers producing a radiant in this region of the ecliptic in August? Isn't there a mere concentration of just sporadic meteor radiants near the ecliptic and the antihelion?

Who first mentioned (invented?) the Iota Aquarids North and South? The publications based on the Super Schmidt camera data of the 1950's provided just some diffuse radiant areas. To me it looks that since some respected authors put the labels as Iota Aquarids North and South, everybody takes their existence as proven, desperately trying to confirm the stream activity. But how real are these assumed meteor streams? This question may feed some future investigations. I think of the video data perhaps to solve the complex picture of radiants near the ecliptic in July–August.

Meteor streams are named after the constellation which hosts the radiant position, e.g. Perseids, Geminids, Leonids, Orionids ... or the obsolete constellation in case of the Quadrantids, now Bootids. In some cases a specific star is used to precise the radiant, e.g. Delta Aurigids, Kappa Cygnids ... these make sense. However speaking about Iota Aquarids North and South looks silly for radiants that are so hard to detect or very scattered, if they exist at all. Why refer to a specific star when dealing with a rather complex and diffuse distribution of a radiant area?

Isn't it time to reconsider these meteor streams, their naming and the importance they got attributed? It is my impression that once meteor streams like Iota Aquarids North and South were introduced by respected authors, the data was copied over and over without questioning any of their properties. Perhaps time has come to review some of the meteor beliefs created now 50 years ago.

[Since Paul's letter was received this January, the IMO has undertaken a review of the showers to be included in the annual Shower List. His letter is therefore particularly timely. An explanation of the new list can be found on page 77. — *Ed.*]

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Conferences

International Meteor Conference 2006
September 14–17, Roden, The Netherlands

The IMC 2006 Organising Committee

25th anniversary

The Meteor Section of the Dutch Association for Meteorology and Astronomy is proud to organize the 25th International Meteor Conference that will take place in The Netherlands. The conference will take place in the village Roden, close to the city Groningen in the north of the Netherlands from September 14-17, 2006.

Hunebeds

The conference will be held at the so-called 'Groepsaccomodatie de Hullen', a youth accommodation in Roden. It's a friendly and cosy accommodation in a green area. The province of Drenthe, in which Roden lies, is famous for its hunebeds, stone tombs in which people who lived here 5400 years ago buried their dead. They consist of stones each weighing more than forty tons.

The weather

The temperature in The Netherlands is typically around 15–20 degrees Celsius (60–70 degrees Fahrenheit) in September.

Currency

The official currency in The Netherlands is the Euro (€). Foreign currency can be exchanged in banks and exchange offices.

The excursion

A traditional part of the IMC program is the excursion. This year we will visit the Low Frequencey Array (Lofar), which will be the largest radio telescope in the world. It is currently under construction; 25 000 antennas are being placed in the northern provinces of the Netherlands and in a part of Germany. Lofar will observe electromagnetic radiation with frequencies ranging from 10 to 250 MHz and is expected to detect signals of the first stars and galaxies after the Big Bang in the early universe.

Participation fee

If you wish to register, please fill out the registration form on the next page or register online at the IMC 2006 website (see below). The participation fee for the IMC 2006 is €120 for people who register before July 1st and €130 for those who register later. This fee includes lodging, meals, excursion and the Proceedings. Either a prepayment of €60 or the total amount should be sent to IMO treasurer Marc Gyssens (details inside back cover and IMC 2006 website).

Visas and invitations

We will gladly send official invitations to people who need these to get a visa, provided that they inform us about this in due time.

Two meteor courses

We proudly present two Meteor Courses this year. The first is the Radio Meteor School 2006, a three-day tutorial (Roden, September 11 to 13) in which several astronomers working in the field of meteor-astronomy from all over the world will give lectures on the physical and mathematical theory of radio meteor observations. This Radio Meteor School is a follow-up from the 2nd Radio Meteor School held in Oostmalle last year. The costs will be announced soon and will be about €120.

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The second Course is the Meteor Orbit Workshop, held on the same dates (September 11 to 13). So far, the determination of meteor orbits was mainly the domain of a few advanced research groups observing meteors with photographic techniques. Recently, more and more video camera networks appear, e.g. in Germany, the Netherlands, in Spain, Poland, Ireland, and others. These networks start to contribute to regular meteor orbit determinations. Many parallel groups are working on developing the required software for that. The aim of this workshop is to bring together all these groups and share the computational methods for determining meteor orbits. The costs for the workshop will be €120, this includes meals and accommodation. For more information on both courses, please take a look at the IMO 2006 website.

Contact information

For more information, check the IMC 2006 website at `http://www.imo.net/imc2006` or contact the organizers by e-mail at imc2006@imo.net. You can also write to us: IMC 2006 — Joost Hartman, Boschdijkstraat 36, NL-5211VD 's-Hertogenbosch, The Netherlands.

International Meteor Conference
Roden, The Netherlands, 2006 September 14–17
Registration form

Each individual participant should fill out a form and return it to IMC 2006 — Joost Hartman, Boschdijkstraat 36, NL-5211VD 's-Hertogenbosch, The Netherlands, as soon as possible. Your registration will be guaranteed only after Marc Gyssens has received the minimum pre-payment of €60. 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: ______________________________ Date of birth (YYYY-MM-DD): __________

Address: ____

____

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Phone: ______________ Fax: ______________ E-mail: ____________________

- I wish to register for the IMC 2006 from September 14 to 17.
- I intend to participate, cannot yet register, but wish to stay on the mailing list.
- I intend to travel by ________, together with ______________________________
- I need travel information from ______________ to Roden.
- I wish to stay in The Netherlands before and/or after the IMC and would like additional information.
- Vegetarian.

T-shirt: Size (S-M-L-XL): __________ Gender: __________

For participants wishing to contribute to the program:

Lecture: ______________________________________ Duration: __________ minutes

Workshop or discussion: ____

Poster presentation: __________________________________ Space: __________ m^2

Required equipment: ____

Comments:

Either the entire fee of €120 or a pre-payment of €60 should be sent to IMO treasurer Marc Gyssens. Follow the payment instructions inside the back cover or on the IMC 2006 website `http://wwww.imo.net/imc2006` . Participants making a pre-payment only have to pay the remaining €60 in cash upon arrival in Oostmalle. The registration fee increases to €130 for participants registering after July 1st.

Perseids

Modeled and observed Perseid radiants

M.G. Ishmukhametova and E.D. Kondrat'eva [1]

The article deals with locations of geocentric radiants of hypothetic particles of the Perseid stream, ejected in 1862 from the comet 109P/Swift-Tuttle. The results obtained have been compared with the data of photographic observations of Perseids in 1993-1994. The spread of location of geocentric radiants of particle models, which could be observed within the Nodal Blanket Filament in 1993–1994, may be equal to RA = $1\overset{\circ}{.}4$, Dec = $0\overset{\circ}{.}7$ under certain conditions of meteoroid ejections.

Received 2006 April 18

1 Introduction

This work is a continuation of modeling the meteoroid swarm of Perseids from the parent comet 109P/Swift-Tuttle. The authors of (Ishmukhametova & Kondrat'eva, 2004) came to the conclusion that the rates of particle ejection from the comet within the range from 0 to 300 m/s are most probable for Perseids of mass greater than 10^{-4} g. This conclusion was based on a comparison of the orbital elements of particle models with elements of orbits obtained through photographic and TV observations.

However, one should mention that such orbital elements as the meteoroid rate and the value of the orbital semimajor axis are determined through observations with considerable errors, especially for high-velocity streams, including the Perseid stream. Observations provide more reliable and precise radiant coordinates of meteors.

2 Observations

The Perseids were observed most intensively after the last return of the comet 109P/Swift-Tuttle to the Sun in 1992. For example, (Jenniskens et al., 1998) presents a catalogue of geocentric Perseid radiants obtained through photographic observations in 1993–1994. It is supposed that meteors observed at the solar longitude $139\overset{\circ}{.}4$ (2000.0), which is equal to the longitude of the orbital node of the parent comet, were ejected from the comet in 1862 and made only one rotation about the Sun. In this case the main reason for the spread of particle radiants is the initial dispersion of ejection velocities. We used the catalogue of radiant locations for comparison with radiant coordinates, which had been found for hypothetical particles.

3 Modeling

The detailed description of the modeling method of Perseid ejection from the comet 109P/Swift-Tuttle at the moment of its passing through the orbit perihelion in 1862 is given in (Ishmukhametova & Kondrat'eva, 2004). The modeling is based on the orbital elements of the comet 109P/Swift-Tuttle, obtained by B. Marsden from two appearances of the comet (Marsden, 1995).

Ejections of particles were modeled in the following directions: by the radius vector from the Sun (type I, vector S, velocity $V > 0$) at the orbital point of true anomaly 330°; perpendicularly to the radius vector against the comet movement (type III, vector T, $V < 0$) at the perihelion point of the orbit. We also calculated the orbital elements of hypothetical particles ejected at perihelion perpendicularly to the orbital plane of the comet (vector W, $V > 0$ to the North Pole). Elements of orbital models for all directions of ejection and the whole range of velocities from 0 to 1000 m/s are given in (Ishmukhametova & Kondrat'eva, 2004).

This work also presents additional calculations of the RA and DEC of the radiant for every orbit (2000.0). Tables 1–3 show orbits of only those hypothetical particles which could be observed in 1993 and 1994; coordinates of their geocentric radiants are on the interval of values, obtained through photographic observations (Jenniskens et al., 1998). Particles ejected in the orbital plane against comet movement (Table 2) make two rotations about the Sun in 131 years; that is why we also adduce the moments T of their passing through the perihelion.

4 Analysis

Let us compare the radiant coordinates of hypothetical particles and the radiants, obtained through observations in 1993-1994. Figure 1 presents the data for observed radiants as they are denoted in the original paper (Jenniskens et al., 1998).

As Figure 1 shows, in 1993–1994 one could observe particles, ejected from the orbital plane of the comet in the direction from the Sun with rates up to 470 m/s, on the node longitude of the orbit of the parent comet (members of the Nodal Blanket). Obviously, the Perseid Filament is mainly formed by particles, ejected perpendicularly to the orbital plane with rates up to 400 m/s and in the direction of the tail III against the comet's movement with rates up to 250 m/s. In this case the spread of locations of geocentric radiants of particle models is RA = $1\overset{\circ}{.}4$, Dec = $0\overset{\circ}{.}7$ (according to the data of the paper (Jenniskens et al., 1998), the observed spread is RA = $1\overset{\circ}{.}9$, Dec = $0\overset{\circ}{.}7$).

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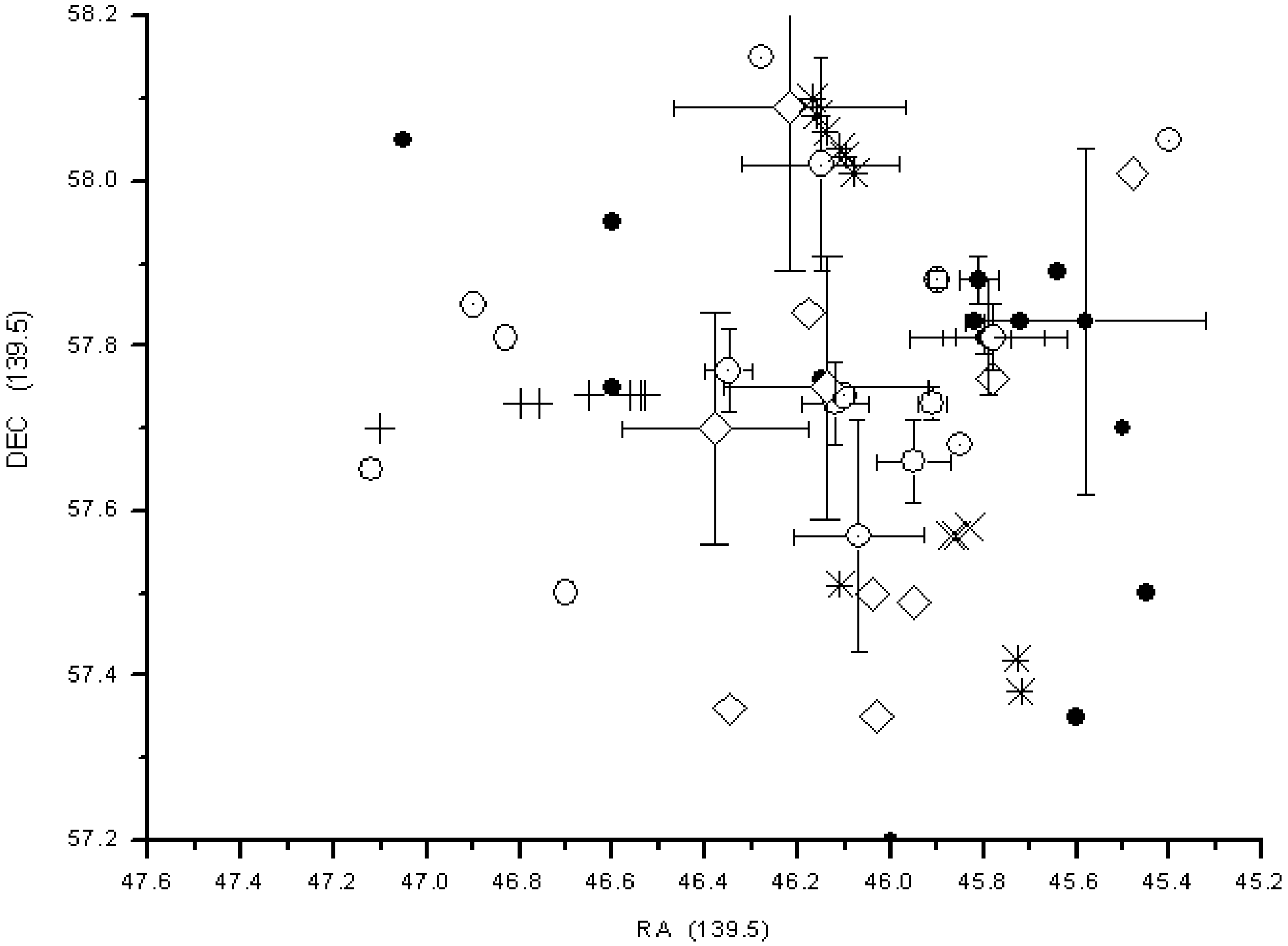

Figure 1 – Observations from (Jenniskens et al., 1998): Nodal Burst: filled circle; 1993 Filament: open circle; 1994 Filament: diamond; hypothetical geocentric radiant position (Tables 1-3): type I tail, vector S, $V > 0$: plus; type III tail, vector T, $V < 0$: cross; vector W, $V > 0$ and $V < 0$: star.

Table 1 – Orbital elements and radiants of the hypothetical particles: type I tail, vector S, $V > 0$.

Number	V (m/s)	e	a (AU)	Ω	RA	DEC
1	+348	0.964	26.545	139°.43	46°.53	57°.74
2	+350	0.964	26.546	139°.43	46°.53	57°.74
3	+370	0.964	26.557	139°.43	46°.56	57°.74
4	+400	0.964	26.572	139°.43	46°.65	57°.74
5	+450	0.964	26.590	139°.44	46°.76	57°.73
6	+470	0.964	26.595	139°.45	46°.80	57°.73

Table 2 – Orbital elements and radiants of the hypothetical particles: type III tail, vector T, $V < 0$.

Number	V (m/s)	e	a (AU)	Ω	RA	DEC	Perihelion passage dates T	
1	−233	0.941	16.411	139°.37	45°.86	57°.56	1928 Sep 20	1993 Nov 25
2	−234	0.941	16.385	139°.37	45°.88	57°.57	1928 Jul 26	1993 Oct 25
3	−235	0.941	16.356	139°.31	45°.83	57°.58	1928 May 31	1993 May 10

Table 3 – Orbital elements and radiants of the hypothetical particles: vector W, $V > 0$ and $V < 0$.

Number	V (m/s)	e	a (AU)	Ω	RA	DEC
1	+340	0.964	26.530	139°66	46°11	58°04
2	+360	0.964	26.542	139°67	46°14	58°06
3	+380	0.964	26.553	139°68	46°16	58°08
4	+400	0.964	26.561	139°70	46°17	58°10
5	−360	0.964	26.541	139°19	45°73	57°42
6	−380	0.964	26.551	139°18	45°72	57°40
7	−400	0.964	26.563	139°17	45°72	57°38

Table 4 – Planetary perturbations of Perseid orbital elements for 131 years.

Number	V (m/s)	$\Delta\omega$	$\Delta\Omega$	Δi	Δa (AU)	$1/a$ (AU^{-1})	Δe
1	+346	+0°116	+0°071	−0°235	+0.583	0.001	+0.0008
2	+348	+0°115	+0°071	−0°235	+0.583	0.001	+0.0008
3	+350	+0°114	+0°061	−0°236	+0.583	0.001	+0.0008
4	+354	+0°111	+0°072	−0°237	+0.583	0.001	+0.0008
5	+360	+0°107	+0°072	−0°239	+0.583	0.001	+0.0008

Following the example of (Jenniskens et al., 1998), we give one of the plots of changes of orbital elements of Perseids. Figure 2 represents the dependence of $1/a$ (AU^{-1}) upon the argument of the perihelion ω for observed particles (Jenniskens et al., 1998) and particle models (Tables 1–3). It should be mentioned that the spread of coordinates of geocentric radiants for RA (Figure 1) and values of $1/a$ (Figure 2), obtained through photographic observations, is greater that the spread of these values for hypothetical particles.

Gravitational and non-gravitational perturbations of Perseid orbital elements are not essential in the interval of 131 years. Table 4 shows changes of orbital elements of hypothetical particles, ejected in 1862 at perihelion of the comet orbit (type I tail, vector S, $V > 0$), as a result of perturbations of major planets. If the dissipation of the observed values of $1/a$ is assumed to be of 0.12 AU^{-1} (Figure 2), the planetary perturbations are about 1%. Non-gravitational perturbations of semimajor axes for Perseids (the Poynting-Robertson effect) are very small even for 1000 years – about 10^{-4}AU. That is why the spread of the observed locations of Perseid radiants and orbital elements is caused, first of all, by inaccuracies of observations.

5 Conclusion

Comparison of the results of Perseid meteor stream modeling with observed orbits and locations of Perseid radiants confirms a conception about principal directions (by the radius vector from the Sun; perpendicularly to the radius vector against comet movement; and perpendicularly to the orbital plane of the comet) and sufficiently high ejection velocities of the meteoroids from the comet 109P/Swift-Tuttle in 1862 published earlier by the authors (Ishmukhametova & Kondrat'eva, 2004).

Acknowledgment

We would like to thank editor-in-chief Chris Trayner for attention to authors and valuable advices.

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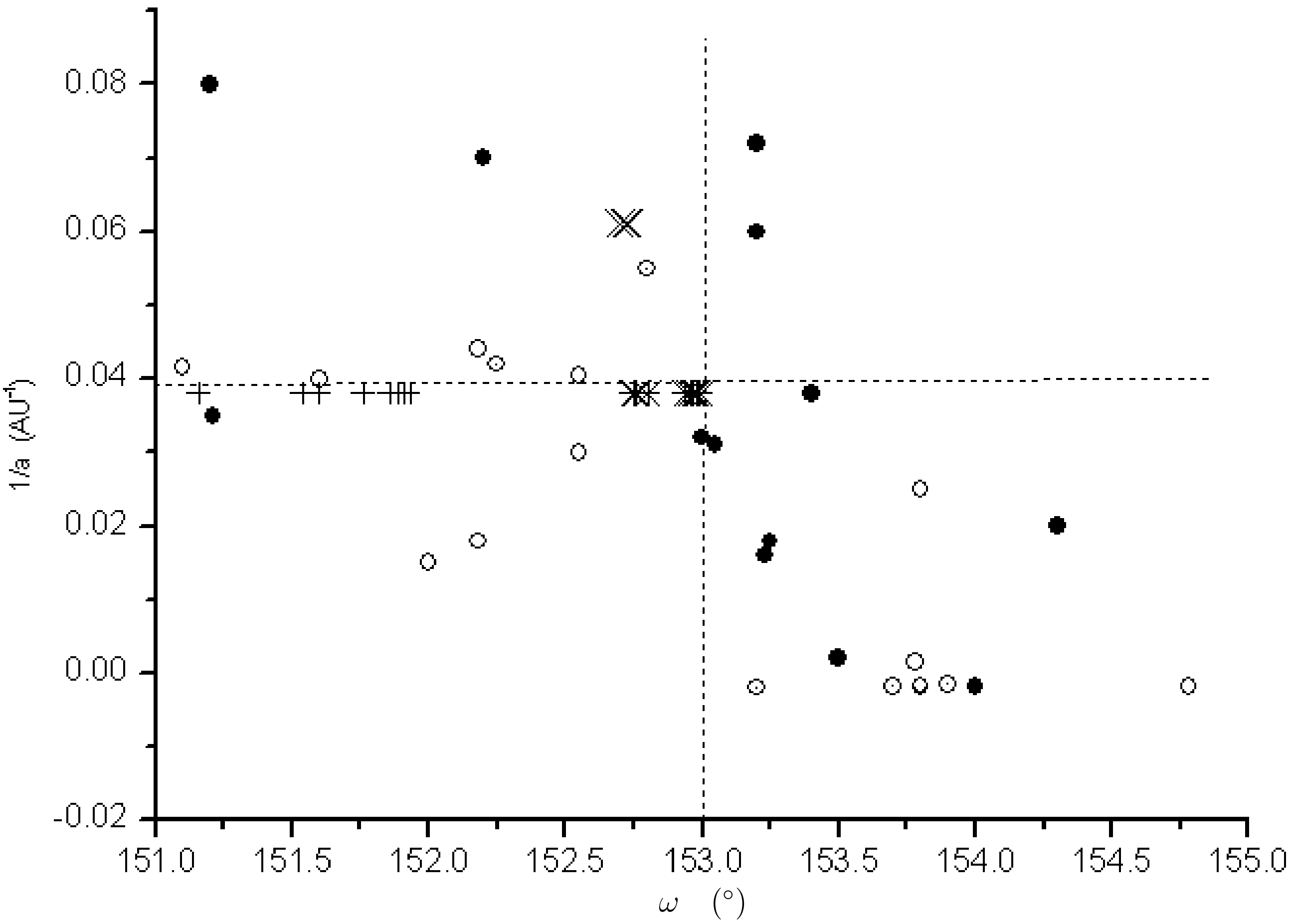

Figure 2 – Orbital elements of observation and hypothetical radiants shown in Figure 1. Dashed lines give the orbital elements of the 109P/Swift-Tuttle orbit at the return of 1992 (Marsden, 1995). Nodal Burst: filled circle; 1993 Filament: open circle; hypothetical geocentric radiant position (Tables 1-3): type I tail, vector S, $V > 0$: plus; type III tail, vector T, $V < 0$: cross; vector W, $V > 0$ and $V < 0$: star.

Fundamentals of meteor science

Visual Sporadic Meteor Rates

Jürgen Rendtel [1]

Activity from the antihelion region can be regarded as a series of ecliptical showers with the Taurids being a special case (lower population index $r = 2.5$ instead $r = 3.0$ and higher ZHR of 5.3 as compared to 2.5 for the other periods of the year). For sporadic meteors we find an annual average of $r = 2.95 \pm 0.15$ with a minimum near $\lambda_\odot = 80°$ and a maximum near $\lambda_\odot = 270°$. Meteors associated with the region of the apex of the Earth's orbital motion yield an annual average ZHR of about 22. Despite the significant differences between recently published radar flux profiles and visual data due to different magnitude ranges (+8 and +3, respectively), we find coinciding features of the flux and ZHR around $\lambda_\odot = 85°$ (minimum) and maxima around $\lambda_\odot = 150°$ and $\lambda_\odot = 290 - 300°$.

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1 Introduction

Sporadic meteors is a term which is normally used to classify meteors which cannot be associated with known showers. Such meteors can be observed at any time and at a first glance their trails appear to have no systematic direction. This so-called sporadic background includes meteoroids moving on random orbits which may be disturbed former stream members or interplanetary/interstellar dust particles as well as unresolved minor streams. Nevertheless, an analysis of the observed distribution shows some apparent sources and pattern in the sporadic background.

The best known source appears close to the apex of the Earth's orbital motion, approximately 90 degrees west of the Sun's position in the sky. It is no solid radiant but rather a number of dispersed radiants scattered over a considerably large area (Jones & Brown, 1993). Obviously, this radiant is mainly caused by particles moving on highly inclined orbits and the radiant effect is due to a focussing effect of the relative motion of the Earth through the interplanetary dust. Hence the meteoroids becoming visible from the apex region cannot be considered as a true particle stream.

Further radiant areas of sporadic meteors are found close to the Sun's position (helion source, see Figure 1), close to the antihelion area as well as at high ecliptical latitudes, called the toroidal source (Jones & Brown, 1993; Campbell-Brown & Jones, 2006). The helion and antihelion sources are caused by meteoroids with aphelia in the main belt of minor planets (see, e.g. Jones & Brown, 1993; Arlt & Rendtel, 2006).

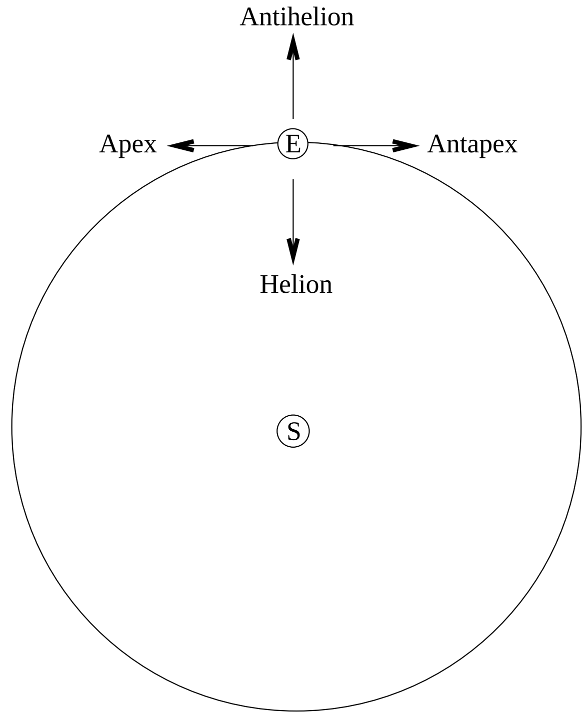

Figure 1 – Geometry of the Solar System, showing the terms used. S: Sun, E: Earth. This view is looking down onto the north pole of the system, i.e. of the Sun and the Earth. Thus the Earth is rotating anticlockwise and proceeding anticlockwise along its orbit (the largest circle). (The term antapex is not used in this paper.)

2 Antihelion source

2.1 Data sample

In the IMO's visual meteor database, VMDB, we currently store data for a number of minor showers with their radiants close to the ecliptic and slightly east of the antihelion direction of the Sun. Traditionally, these are named after the constellations of the Zodiac. These radiant areas appear not as concentrated radiants as in the case of distinct meteor showers with meteoroids moving on closely aligned orbits. They are rather wide fields of radiants of about 30° length in right ascension and about 15° width in declination—better: in ecliptic longitude and latitude, respectively.

These radiants are caused by meteoroids associated with minor planets and some short period comets. The meteoroid orbits have been disturbed many times and thus they are forming a rather continuous background with a few exceptions. The only prominent shower

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NASA-ADS bibcode 2006JIMO...34...71R

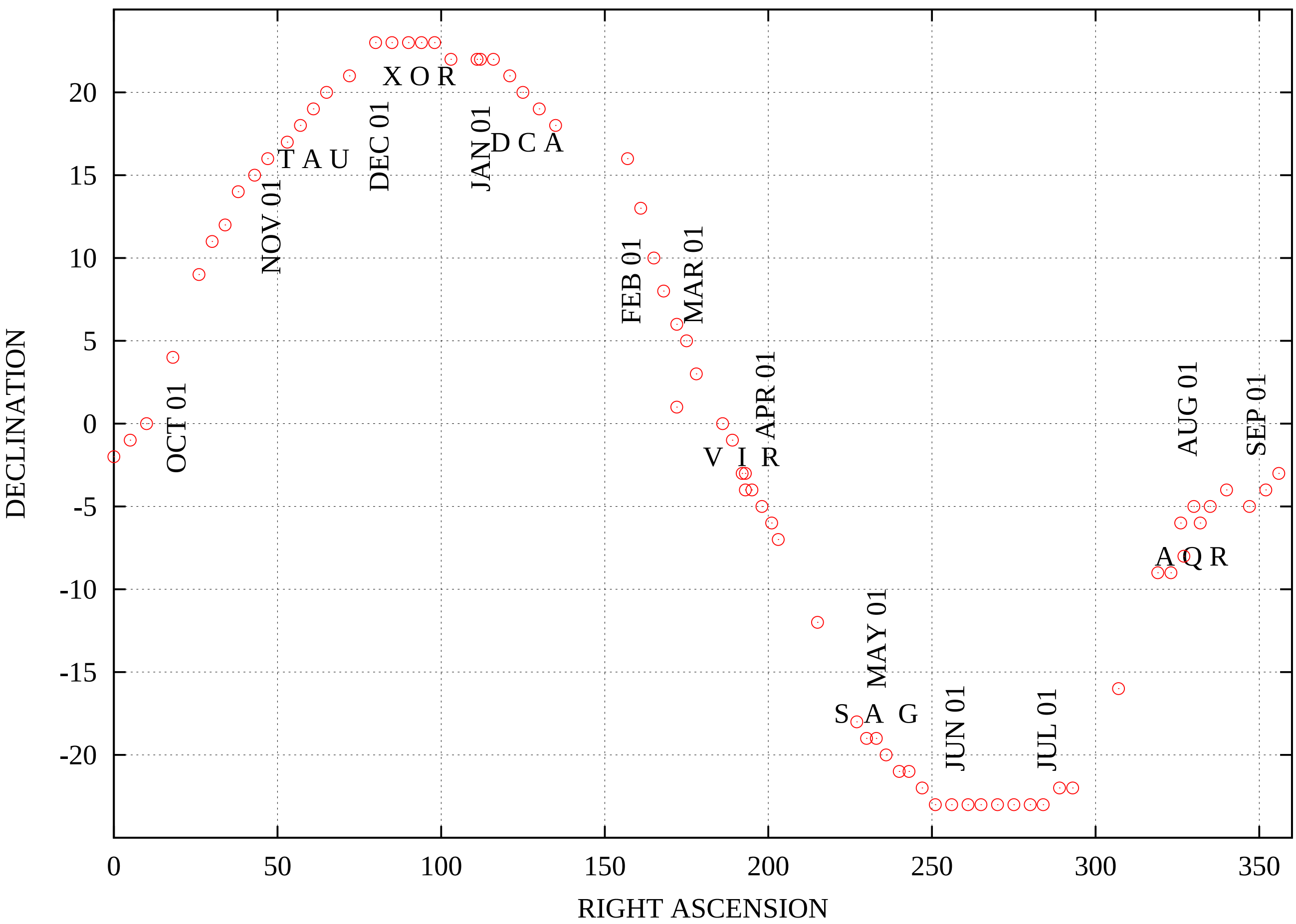

Figure 2 – Radiant positions of the showers listed in Table 1. 'Aqr' is the average of NDA, SIA, and NIA. Note the 'jump' between DCA and VIR (February 01) and again between VIR and SAG (April 15).

form this complex — the Taurids — is discussed below. Other showers can hardly be distinguished from the sporadic background but were part of radiant searches in the past with the result of numerous minor showers in the vicinity of the ecliptic. The centers of these radiants are used in the current working list.

For various reasons, the centers of the radiant area as used in the current working list of meteor showers and in numerous publications are not continuously moving along the ecliptic throughout the year. One historic reason is that the last working list was established with the intention of keeping the known radiants and shower designations such as Virginids etc. This fit causes some inconsistencies which become most obvious at the times of transition between two successive ecliptical showers. This is clearly visible in Figure 2.

Table 1 – Ecliptical meteor showers which are now subsumed as the antihelion source.

Ecliptical shower	Abbreviation	Activity period
δ-Cancrids	DCA	Jan 01–Jan 31
Virginids	VIR	Feb 01–Apr 15
Sagittarids	SAG	Apr 15–Jul 00
Northern δ-Aquarids	NDA	Jul 15–Aug 25
Southern ι-Aquarids	SIA	Jul 15–Aug 25
Northern ι-Aquarids	NIA	Aug 11–Aug 31
Piscids	SPI	Sep 01–Oct 01
Northern and Southern Taurids	NTA, STA	Oct 01–Nov 25
Northern χ-Orionids	XOR	Nov 25–Dec 15

Recent radar observations suggest that the center should be close to 12° east of the antihelion direction with no specific deviation over the year. This complex will be named antihelion source for the VMDB data storage from 2007 onwards (Arlt & Rendtel, 2006). In the past the antihelion data is subsumed as a sequence of ecliptical showers listed in Table 1.

Detailed information about the inclusion and exclusion of certain showers, especially in the summer period, is discussed by Arlt & Rendtel (2006). In the present analysis of sporadic meteor activity the summary of showers as listed in Table 1 was used to represent the antihelion source. The northern and southern branches of the Taurids were summarized as the Taurids for this study.

2.2 Rate variations of the antihelion source

First, we need to know the variation of the population index r. Here we may use the values found from the analysis of the listed ecliptical showers. In fact, the values differ only little from $r = 3.0$, except for the Taurid period where $r = 2.5$ was used. Hence we used $r = 3.0$ for all periods except the interval from October 1 until November 25. With this figure we were able to

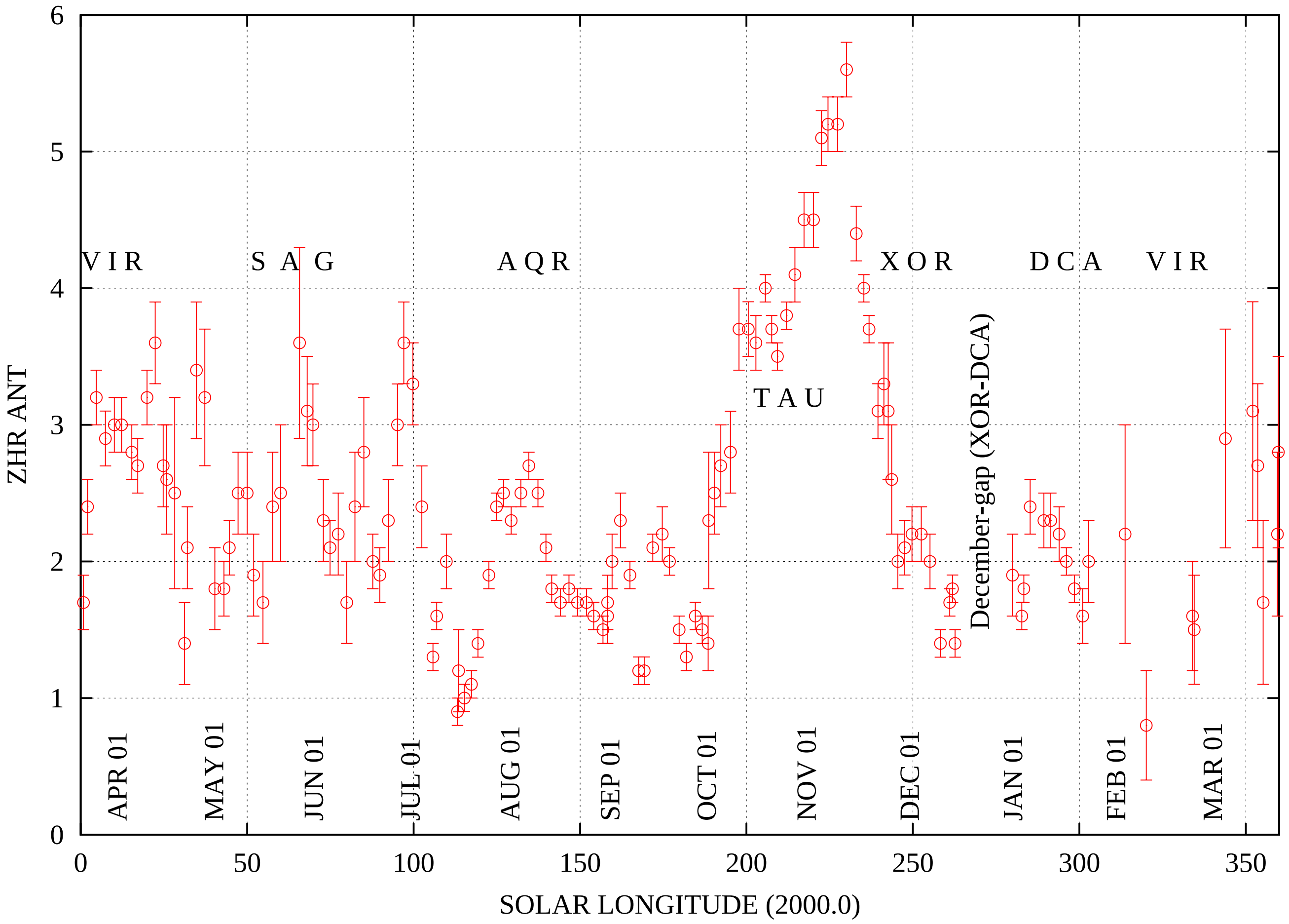

Figure 3 – ZHR of the showers now summarized as antihelion source based on visual data observed between 1984 and 2005.

calculate the ZHR of the entire series of showers from the antihelion region.

It is known that the accuracy of visual meteor observations suffers from errors of the shower association. While the effect is negligible for major showers in the vicinity of their peaks, all minor sources are affected. This is considered by the assumption of a radiant area rather than a point. Its size should compensate the loss of true shower members and non-shower meteors erroneously associated with the radiant. Close to the peaks of major showers observers apply the counting method so that a careful check of the shower association as in the periods of generally low activity is not possible. This does not harm the major shower's data, but the lost shower meteors now classified as sporadic do change both the numbers and the magnitude distribution (as most showers have a lower value of r around their peaks). For an analysis of the antihelion ZHRs shown in Figure 3 we therefore omitted the immediate major shower peak periods (Quadrantids, Perseids, Leonids, Geminids). The effect was found to be largest near the Leonid peaks with their exceptional ZHRs in the years between 1998 and 2002.

Except for the Taurids, there is no significant rate enhancement visible. This may be due to unresolvable structures in the antihelion region, but radar data show a similar scatter (Campbell-Brown & Jones, 2006). For the δ-Cancrids and the Aquarid period a profile with a maximum occurs. This could be an artefact as the position of the 'true' antihelion source moves through the assumed ecliptical shower radiant and thus increasing the number of meteors fitting the assumed radiant position. But it is also possible that there is indeed some structure in the antihelion meteoroid orbit distribution which led to the definition of the ecliptical showers in the past. This is not unlikely, as the majority of orbits of sporadic (antihelion) meteors is associated with comet 2P/Encke (Štohl, 1987), and there is a large number of similar objects which are possible or established parent objects for minor streams. A third possibility cannot be ruled out: an observer's bias 'supporting' a shower association in the vicinity of a predicted maximum.

The annual average ZHR from the antihelion region amounts to approximately 2.5 (using $r = 3.0$). The Taurids being exceptional with a ZHR up to 5.3 ($r = 2.5$).

The shapes of the rate and flux profiles between the visual data analysed here and the radar fluxes as shown in (Campbell-Brown & Jones, 2006) are not identical. However, we have to bear in mind that the radar fluxes consider meteors typically of magnitude +8 while the visual meteors represent mainly the magnitudes +3 or +4 and hence a different mass range. This may also explain the lack of a Taurid maximum in the radar flux data (Campbell-Brown & Jones, 2006).

3 Apex source

3.1 Data sample

A visual meteor observer checks whether a seen meteor fits any radiant position (plus length and angular velocity) of the working list. The remaining meteors are classified as sporadic with no further distinction. Therefore meteors stored as 'SPO' in the VMDB files include those from the region around the apex of the Earth's orbital motion (abbreviated to apex here), the toroidal sources and those moving on other orbits including minor, unresolved sources. The composition of the SPO-sample will of course vary in the course of the night. In particular, meteors of the apex region will dominate towards the morning, while the toroidal meteors should contribute with a rather constant amount over the entire night. Contributions from other sources are likely very small as they are not explicitely identified as radiants.

Using all meteor trails plotted or recorded by video meteor cameras, one can search for a 'radiant' among the sporadic meteors. Accepting a range of velocities between 40 and 70 km/s as found from radar data (Jones & Brown, 1993) does not show any significant hint on a radiant in the apex region. Obviously, the radiant area is extremely smeared over the region in the sky. The main reason, however, may be the nature of this activity. It is caused by meteoroids on almost retrograde orbits. Their movement is superposed by the Earth's motion which leads to a focusing effect. Consequently, it is not a real source like a stream originating from a parent, but rather an effect of the relative motion of the meteoroids and the Earth.

3.2 Population index

First, we need to know the variation of the population index of the meteors labelled 'SPO'. The assumed standard value is $r = 3.0$. The sample collected as SPO is not completely identical with the apex meteors outlined before as it includes pre-midnight non-apex meteors.

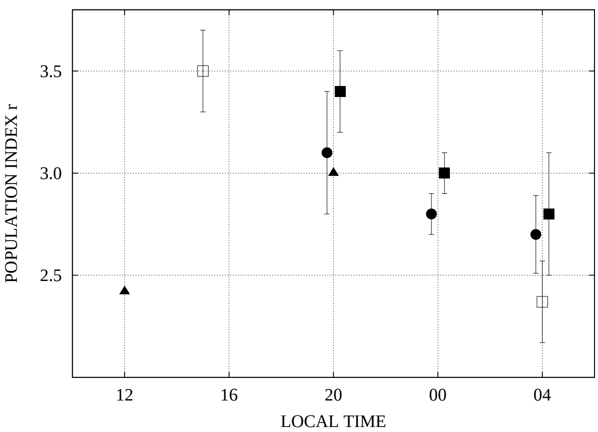

Figure 4 – Diurnal variation of the population index r of sporadic meteors from the VMDB data in February (filled squares) and October (filled circles). These points actually occur exactly on the hour, but are offset sideways slightly for visibility. Other values are from radar data (Babadzhanov & Bibarsov, 1992) (triangles) and from optical data (Hughes & Stephenson, 1972) (open squares).

Generally, the value of r is higher in the evening sector (around 18^{h}local time) and decreases towards dawn (Figure 4). If we assume that the mass distribution is almost identical among all sources of sporadic meteoroids (as explained at the beginning), the larger number of high-velocity retrograde meteors towards the morning may account for this effect.

However, the expected differences by mixing other than the apex meteors into the sample are smaller than the scatter found in the individual intervals. The result shown in Figure 5 has already been published by Rendtel (2004). The annual average value is $r = 2.95 \pm 0.15$. Not surprisingly, this general value is quite similar to the one found for the antihelion meteors. Variations may occur at a seasonal scale as well as in shorter periods, as discussed by Rendtel (2004). However, the data is not sufficient to test whether these are r-variations indeed recur at fixed positions (which could hint at some persistent structures among the apex meteoroids) or just random variations.

3.3 Apex rate

The standard procedure to calculate a rate of sporadic meteors includes a value of $r = 3.0$ and no radiant position. This gives a 'global' hourly rate only corrected for the limiting magnitude of 6.5. Recall that calculating a true ZHR from raw data includes a correction for the zenith angle of the radiant. However, we may determine a rough estimate for the ZHR of the apex source if we assume the position which is obtained by the radar data (Campbell-Brown & Jones, 2006). In fact, this will mainly include data obtained after local midnight when the apex region appears above the horizon. This allows to combine data from different locations as in normal meteor shower analyses. We may account for the rate caused by other sources by subtracting a constant value but, as already pointed out, the contribution of the toroidal and other minor showers is negligible. This way we should be able to follow the number density in the apex region including the possibility of detecting intervals with higher spatial particle densities if these exist at all.

We now calculate the ZHR of the sporadic meteors using a value of $r = 2.95$ and the northern apex position as found by Campbell-Brown & Jones (2006).

Again, we find increased ZHRs during the activity of a few major showers. Not surprisingly, the η-Aquarids seem to cause enhanced sporadic (apex) rates with their radiant close to the apex. The effect during the Perseids and the Geminids may be of more general nature, i.e. shower meteors not correctly associated increase the number of meteors noted as 'SPO' in the visual data. Some further shower maxima are indicated in Figure 6. There is no such obvious increase of the rate during the Quadrantids and the Orionids, for example. The annual average ZHR of the apex source is 22 with higher ZHRs (exceeding 25) in August and September as well as end-January and lowest ZHRs in June — again supposing that there is no systematic effect from the toroidal source superposed on the rates.

As in the case of the antihelion source, we see dif-

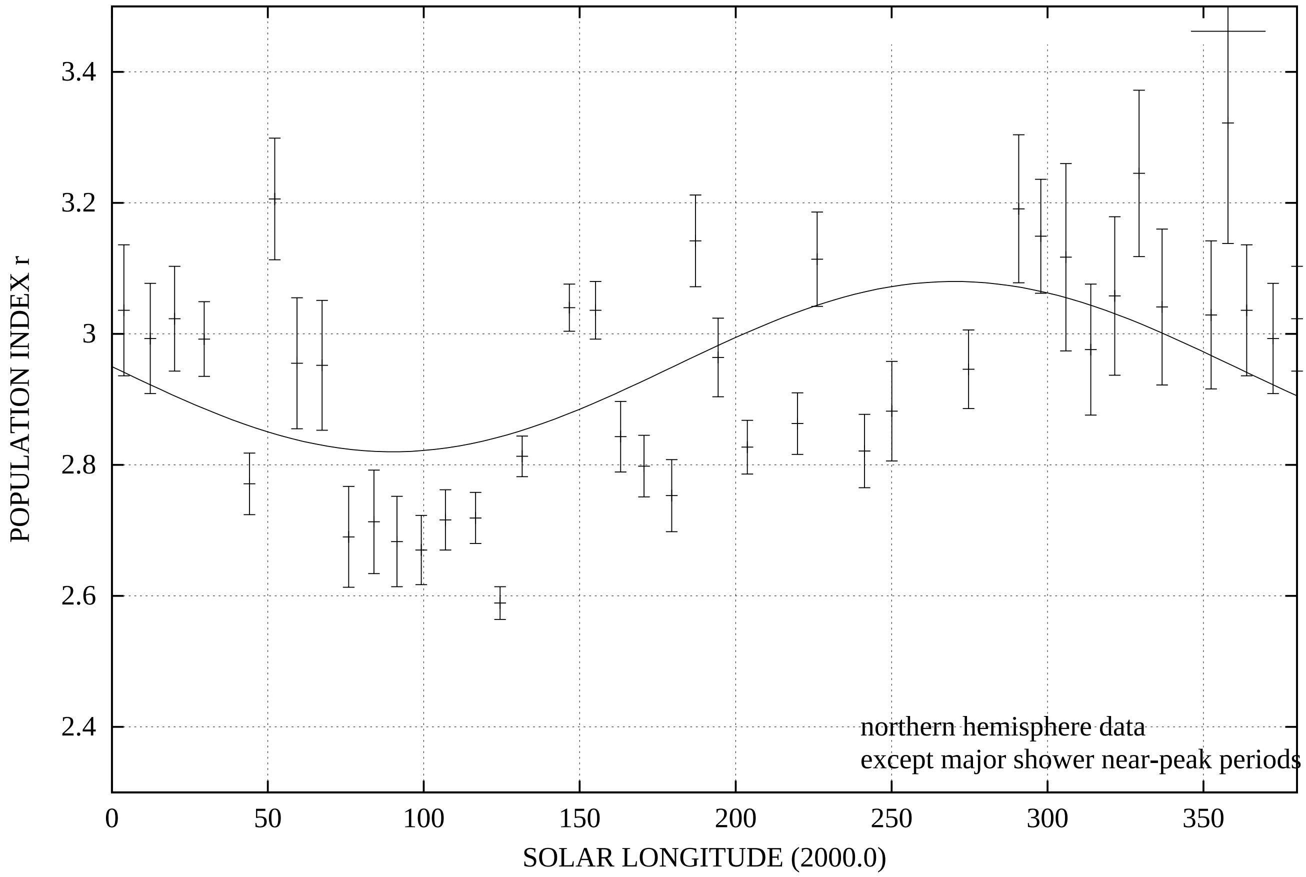

Figure 5 – Population index r of meteors labelled as 'SPO' in the VMDB. The sample includes visual data from the northern hemisphere collected between 1988 and 2003 and excludes the near-peak periods of major showers. The curve is an attempt to fit the annual variation with a sinusoid independent of whether this is appropriate to the particle distribution along the Earth's orbit. The general shape does not correlate with the declination of the apex region and thus hints at other reasons for its variation.

ferences between the radar flux as found by (Campbell-Brown & Jones, 2006) and the visual ZHRs which certainly are determined by the different particle populations contributing to the samples. Notably, there are coinciding features of the radar flux and visual ZHR, i.e. a minimum around $\lambda_\odot = 85°$ in June and maxima around $\lambda_\odot = 150°$ (second half of August until September) as well as $\lambda_\odot = 290 - 300°$ (January/February). In a next step we try to find out whether the features in the profiles are stable and present in subsets of the sample. The time covered by the data collection (1984–2006) should be sufficient for this purpose.

4 Conclusions

The analysis of the activity from the antihelion source leads to the replacement of a series of apparently independent ecliptical showers by one continuous source with the exception of the Taurid period. This is introduced in the new working list of meteor showers published by Arlt & Rendtel (2006). This antihelion source continues throughout the year and hence provides a radiant in Gemini in the second half of December. This period virtually had no ecliptical radiant in the previous list.

Although there is no explicit information about meteors associated with the apex region stored in the VMDB, it is possible to calculate the population index r and a ZHR for these meteors summarized as sporadic (SPO). Contrary to the antihelion source, which is associated with short-period comets and minor planets, the apex source is merely a focussing effect of almost retrograde meteoroid orbits. We find an annual average of $r = 2.95 \pm 0.15$ with a minimum near $\lambda_\odot = 80°$ (June) and a maximum near $\lambda_\odot = 270°$ (end of the year). The ZHR of the northern apex region yields enhanced values at the peaks of three showers, the η-Aquarids, the Perseids, and the Geminids. Structures in the rate profile may exist. We find significant differences between the radar flux profiles (Campbell-Brown & Jones, 2006) and the visual data which have to be attributed to the different magnitude ranges covered by the two methods. Some coinciding features of the radar flux and visual ZHR can be found: a minimum near $\lambda_\odot = 85°$ in June and maxima around $\lambda_\odot = 150°$ (second half of August until September) and $\lambda_\odot = 290 - 300°$ (January/February).

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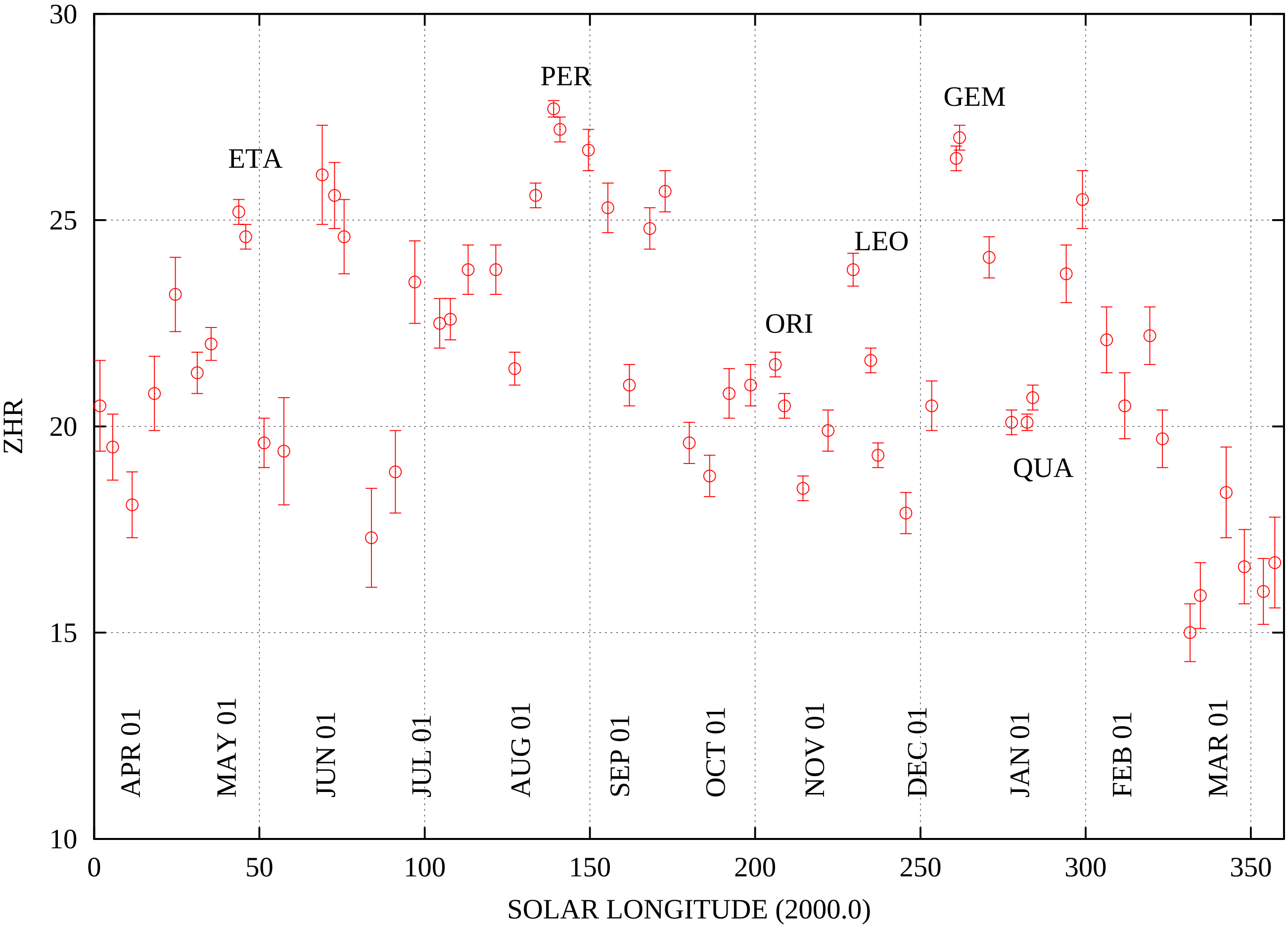

Figure 6 – ZHR of the meteors labelled as 'SPO' in the VMDB, which are representative of the activity of the north apex source. The sample includes visual data from 1984 to 2005. Peaks of some showers are marked, with ETA, PER and GEM obviously 'polluting' the SPO sample.

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Ongoing meteor work

A new Working List of meteor showers

Rainer Arlt [1] *and Jürgen Rendtel* [2]

After the last revision of the working list of visual meteor showers in 1995, an updated version is proposed to be used starting in 2007. The list is meant to provide a collection of showers which are both visually observable and scientifically interesting for meteor astronomy. Major changes are the introduction of an all-year Antihelion Source comprising a number of ecliptical meteor showers. Showers new to the list are the η-Lyrids in May, and the October Leo Minorids. The former δ-Aurigids have been recognized as two individual sources, the September Perseids and the actual δ-Aurigids. A full listing of radiant motions in 5-day steps is also given.

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1 Which showers are relevant?

The main goal of a working list of meteor showers is to collect observing records of showers which are supposed to deliver enough data for meaningful studies of meteoroid streams in the solar system. As a first prerequisite, a shower in the list should provide a minimum of activity and should be distinguishable from the general ('background') activity. Otherwise, the data collected over decades will not be enough to yield insight in dynamics of particles in the inner solar system. In the same respect, it seems worthwhile to emphasize meteor showers which originate from known comets or present asteroids, because those are the ones most likely offering information about minor bodies in general. If no parent is known, it should at least be possible to associate it with a set of orbits in space. There is a huge difference in reliability between a shower which is only known by virtue of a radiant in the two-dimensional sky, and a meteoroid stream which manifests its existence by a set of orbits in the three-dimensional solar system.

The working list of meteor showers is not meant as a list of potential showers in a search for radiants. It is obvious that millions of comets have entered the inner solar system during its existence. They have left behind the same number of meteoroid streams which will disperse gradually. It is thus natural that we will observe very many meteor showers in different stages of aging. We are not seeking a 'complete' list of meteor showers which does not exist as there is no sharp boundary between meteor showers and sporadic meteors.

The updated Working List of Meteor Showers is given at the end of this Paper in the Conclusions. There is also a full list of radiant positions in 5-day steps for all the showers of the Working List. The following Section will deal with the major changes in the shower list, ordered by the time of the year.

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NASA-ADS bibcode 2006JIMO...34...77A

2 Shower list amendments

2.1 Antihelion source

There has been little evidence for individual meteor showers forming a sequence of radiants positioned a few degrees east of the antihelion direction. The exception is the Taurids showing very concentrated northern and southern radiants during October and November. The embedded Comet 2P/Encke and resonance effects with Jupiter make the Taurids an interesting source on their own which requires the separation from the ecliptical background activity which is essentially sporadic (Triglav-Čekada & Arlt, 2005). A further paper on this topic will appear in the next WGN.

A smooth radiant drift over the rest of the year is proposed to account for the general activity from about 15° east of the antihelion point. The 'shower' will be called 'Antihelion Source' and abbreviated as `ANT`.

The Antihelion Source will thus replace a number of meteor showers which have hitherto represented the ecliptical background activity from the region near the antihelion point. The δ-Cancrids, Virginids, Sagittarids, Northern and Southern ι-Aquarids, Piscids, and χ-Orionids will be omitted from the new Working List.

2.2 γ-Normids

Only a little information is available for this southern shower. An analysis of 2005 data (Trigo-Rodríguez et al., 2005) shows a maximum close to $\lambda_{\odot} = 350°$, i.e. about three days before the previously assumed time. Rates seem to vary slightly from one year to the next with peak ZHRs reported between 2 and 6 with a probable median ZHR of 2–3. Recent rate data is shown in Figure 1.

Positional video data is not yet sufficient for final conclusions. The result obtained from two cameras of the video network (Molau, 2005) is shown in Figure 2. Interestingly, this position also fits the radiant position derived from two data sets of visual plotting observations. Further, the orbital databases do not supply support for this minor shower which makes it the weakest candidate in the shower list. However, we leave it in our Working List with an urgent request for detailed observations. The radiant position is fitted with the location derived from the recent video and visual data.

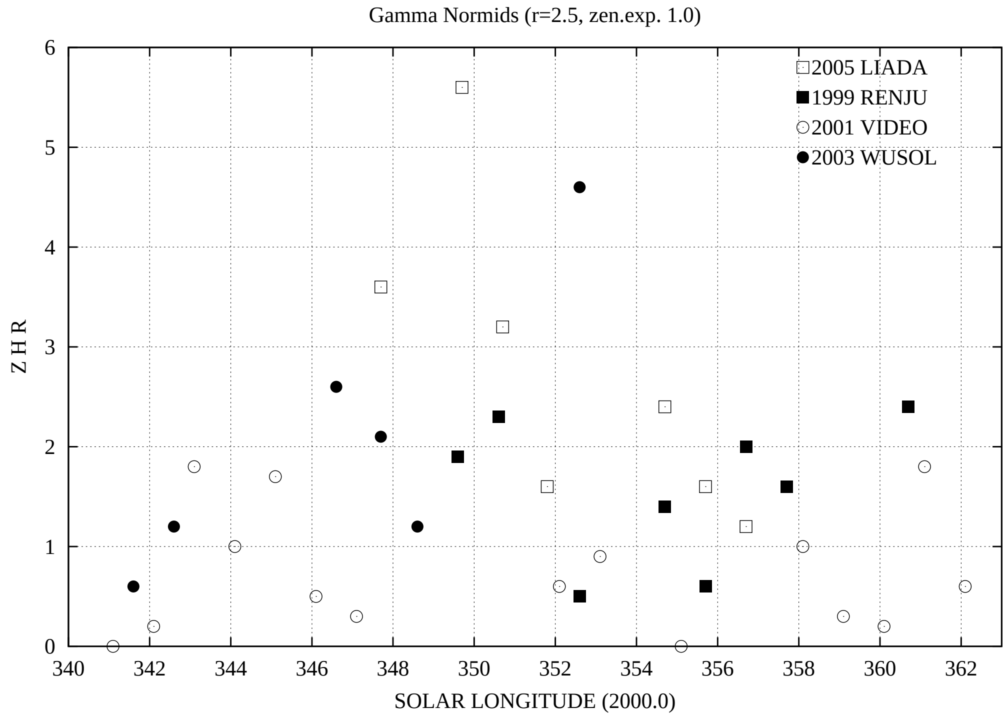

Figure 1 – Activity of the γ-Normids derived from visual data (Trigo-Rodríguez et al., 2005; and Rendtel – visual data 1999; Wusk – visual data 2003) and video data (relative rate (GNO/SPO)×10 from March 2001; sso1 camera).

2.3 η-Aquarids

The only thing which was updated is the radiant motion. Video data of the IMO video network up to 2005 were used to determine the radiant positions in 5-day steps. The results are very close to the old list values, and changes were $\leq 2°$.

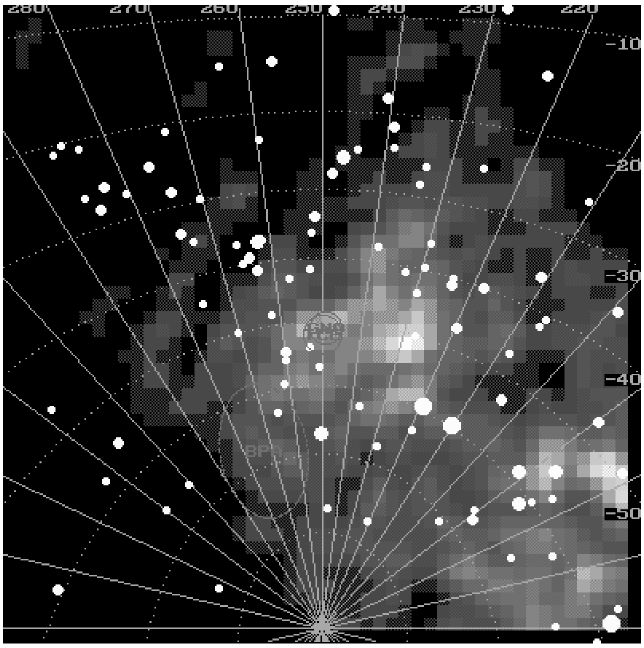

Figure 2 – Radiant area of the γ-Normids as derived from 1264 video meteor positions obtained between 2001 March 01 and 20 (swat and sso1 cameras). There is no distinct radiant at the listed position. A weak concentration can be found somewhat west near $\alpha = 230°$, $\delta = -50°$.

2.4 η-Lyrids

This shower is often referred to as the meteors from IRAS-Araki-Alcock which is a comet that passed perihelion in May 1983. We are following the usual shower naming which refers to constellations and use the abbreviation `ELY`.

Comet C/1983 H1 IRAS-Araki-Alcock is a well studied object, and meteor activity from that parent has been significant though not very high. A comprehensive set of video meteors shows the radiant very clearly (Figure 3). Since nearly all the video meteors are in the visual range of brightnesses, the radiant is also a good representation of what visual observations would obtain, less accurately though.

Ohtsuka (1991) reported about five orbits in the IAU orbital database which were associated with the Comet. These orbits give a radiant position of about $\alpha = 289°$, $\delta = +43\overset{\circ}{.}2$ centered around a solar longitude of $\lambda_\odot = 49\overset{\circ}{.}6$. The closest approach to the orbit of C/1983 H1 is $\lambda_\odot = 48\overset{\circ}{.}4$ with a theoretical radiant position of $\alpha = 288\overset{\circ}{.}0$, $\delta = 44\overset{\circ}{.}0$ and a geocentric velocity of $v_g = 43.8$ km/s. Bearing in mind that the difference in reference dates for the observational and the theoretical estimates are about one day, they agree very well. The radiant position from video data in Figure 3 refers to $\lambda_\odot = 49\overset{\circ}{.}0$.

In the new Shower List, we adopt an activity period of May 3–12 as was done by Kronk (1988). There are several methods of how to compute the possible evolution of meteoroid particles to approach Earth, without actually following the motion of individual particles. The methods compiled by Neslušan et al. (1998) yield a time of probable maximum activity at $\lambda_\odot = 48\overset{\circ}{.}4$ or

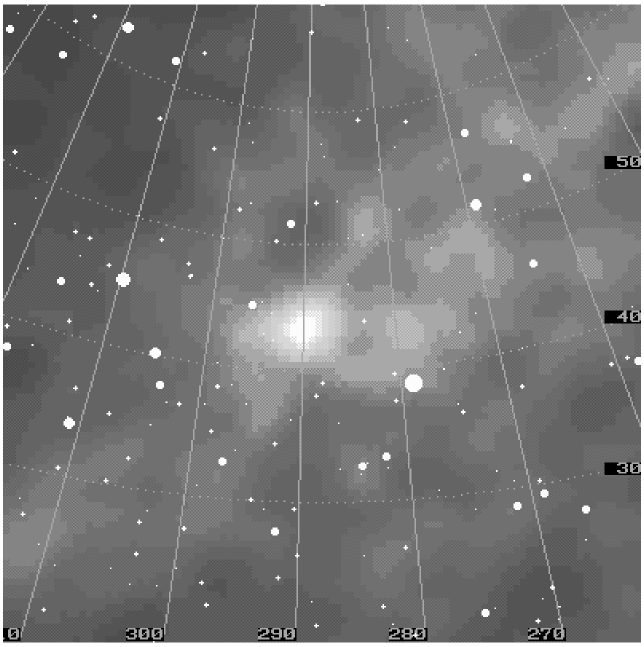

Figure 3 – Radiant plot with 684 video meteors of May 6–13 around the possible radiant of the η-Lyrids.

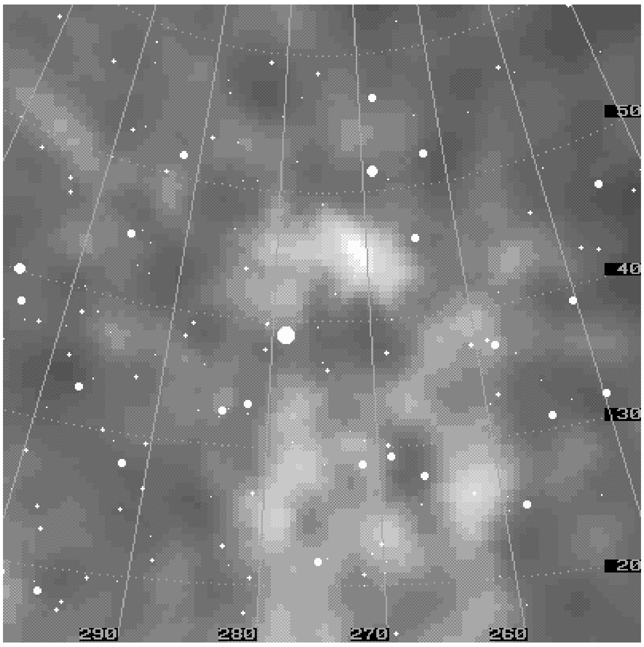

Figure 4 – Radiant plot with 679 video meteors around the possible radiants of the June Lyrids and ξ-Draconids, selected from the period June 12.0–19.0.

roughly May 9. The encounter velocity of the particles including the gravity of the Earth is 44 km/s. A daily motion of the radiant of 1° per day is assumed for the ephemeris given in Table 2.

The η-Lyrids may be an interesting source as both orbital elements and parent are available. The shower should not be confused with the τ-Herculids theoretically generated from the disintegrated Comet 73P/ Schwassmann-Wachmann 3, but not exhibiting significant meteor numbers hitherto.

2.5 June Lyrids

First observations of this shower have been reported in the 1960s. Later the shower was dropped off the working lists because its evidence was very low. A comprehensive review of observations collected between 1985 and 1997 by Kidger (2000) shows a low but significant activity around $\lambda_\odot = 86°$ with ZHRs of the order of 3. Hindley (1970) suggested a link of the stream with Comet C/1915 C1 (Mellish) which is not very evident because of the comet's near-parabolic orbit and its perihelion outside the Earth's orbit. Orbits of stream meteoroids are missing except for a single case (Sekanina, 1979) which may be a coincidence. The radiant distribution around the area of the June Lyrid radiant is shown in Figure 4. There is a slightly enhanced radiant density at the position of the June Lyrid radiant as listed in the pre-1995 shower lists. The strongest radiant areas are distributed over an area of 30° diameter, north, south, and southwest of the expected place.

This shower — or one which has its radiant nearby — may be an interesting source to be followed also in future observations, but the poor knowledge of physical parameters does not yet allow us to include the shower in the Working List.

2.6 June Boötids

The activity period is an issue with this shower, since the maximum on June 27 follows the beginning of the period, June 26, very closely. Dust trail predictions have delivered peak dates as early as June 22. That case may have been exceptional but, nevertheless, we propose to extend the activity period of the June Boötids to June 22 to July 2. Even if this activity period is overestimated, a pollution by sporadic meteors is not very likely because of the high elongation of the radiant from the apex and the peculiar velocity of the shower.

2.7 July Pegasids

The activity of this shower has been very low to nonexistent over the last two decades at least. We propose to omit the shower from the Working List, because it will not deliver any meaningful results in the long term.

2.8 July Phoenicids

Lack of data, orbital information, and parent object give little prominence to this shower, and we propose to omit it from the Working List.

2.9 Northern δ-Aquarids

It has been hard to detect this shower apart from the general ecliptical activity in July and August as an individual source. Based on the shower associations in the records of the Visual Meteor Database, a rate profile of the Northern δ-Aquarids was computed. The two-sided exponential fit yielded a maximum ZHR of 2.6 (Dubietis & Arlt, 2004). An isolated radiant would be suitable for visual observations at this level of activity, but the close vicinity of the antihelion background component makes the discrimination of Northern δ-Aquarids very unreliable. Similar findings were published by Arlt et al.

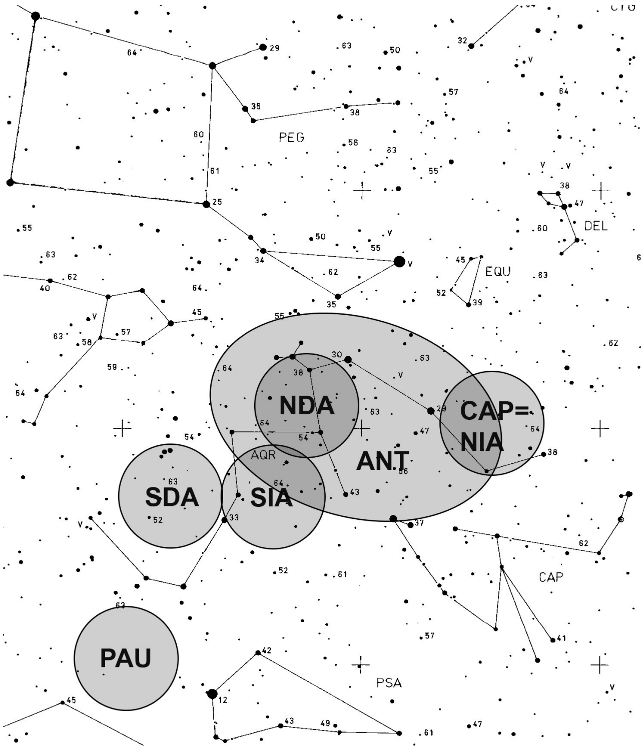

Figure 5 – Radiant positions of the Aquarid showers and the main location and area of the antihelion background activity. The radiant position of the traditional showers are taken from the 2006 Meteor Shower Calendar (McBeath 2005).

(1992) within the Aquarid project. Figure 5 shows that the radiant of `NDA` as it was listed in the old Working List actually lies within the average radiant area of the antihelion source. We suggest omitting `NDA` from the new Working List for these reasons.

2.10 Capricornids

Despite the radiant overlap with the Antihelion Source, we leave the shower in the Working List, because of the interesting connection with a comet or perhaps asteroids, the good knowledge of orbits, and the prominence in activity curves of the ecliptical activity in July–August. Observers should make a careful distinction between the Capricornids and the Antihelion Source from July 3 to August 15 considering the low velocity of the shower meteors.

2.11 Perseids

There is not much really to be changed for the Perseids. The only thing we adapted is the radiant motion which was studied by Arlt (2003). The positions of August 10 and later are taken from that paper, while earlier position have been recomputed with a larger set of video meteors and longer, overlapping intervals in order to produce a smooth ephemeris of the radiant. The positions were also compared with the photographic results by Svoreň and Kaňuchová (2005) based on the most recent version of the IAU orbital database. We found fairly good agreement, especially on the fact the radiant does not lie below $\delta = +40$ or even below $\delta = +30$ in July and early July, respectively. Radiant positions in the central part of Andromeda have often been reported from visual data, but cannot be deduced from video and photographic data.

2.12 September Perseids and δ-Aurigids

These two shower designations were combined in the shower code `DAU` in the old Working List, because a smooth radiant drift was found indicating that it could actually be one shower being active for more than a month. However, a recent activity analysis by Dubietis & Arlt (2002) shows clearly separated activity maxima, and it was concluded that the continuation of the radiant drift of one shower by the other is accidental.

The analysis showed the minimum between the two maxima near September 17. We propose an activity period of September 05–17 for the September Perseids (`SPE`) and a period of September 18–October 10 for the δ-Aurigids (`DAU`). In the stream search by Welch (2001), the September Perseids are at position 21 in the ranking of the most prominent 'orbit clusters' (note that the shower is called δ-Aurigids there but definitely refers to `SPE`).

2.13 Leo Minorids

The first mention of this shower dates back to McCrosky & Posen (1959) who found just two meteors with very similar orbits in their photographic survey. More recent compilations of photographic and video data by the Dutch Meteor Society confirmed this confined meteoroid stream (de Lignie & Betlem 1999). Visual activity of the shower is weak; Jenniskens (1994) estimated the maximum ZHR to be 2 from a two-sided exponential fit. According to his graph, we propose to set the activity period to October 19–27, but the maximum is hard to fix. We therefore propose to use the solar longitude of 211° as it was listed in the very first IMO Working List, or approximately October 24. The average of ascending nodes of the photographic orbits given by de Lignie & Betlem (1999) is near $\lambda_\odot = 209°$ though, matching the peak time of the two-sided exponential fit by Jenniskens (1994). Their results for the geocentric velocity of the meteoroids was 61.9 km/s converting to an entry velocity of 63 km/s. The average radiant position for a solar longitude of 210° is $\alpha = 160\overset{\circ}{.}2$, $\delta = 36\overset{\circ}{.}8$. Recently, Borovička (2001) reported about a spectrum of a Leo Minorid. The stream is also detected by the new search method by Welch (2001).

The data from the IMO video network also exhibit a weak but well confined radiant area (Figure 7) very close to the photographic position of the Leo Minorid radiant. If the radiant were closer to the radiant of ε-Geminids and Orionids, it would probably be hardly detectable in such a radiant plot. However, the well separated position and the clear evidence in orbital data makes the shower an interesting target for future observations. The IMO code will be `LMI`.

2.14 Taurids

As was discussed already in Section 2.1, the Taurids are a very prominent part of ecliptical activity which will certainly provide new insights in the dynamics of mete-

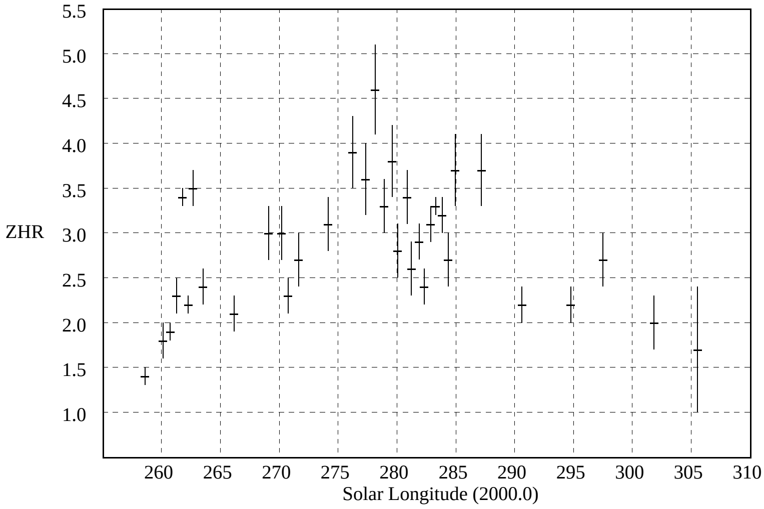

Figure 6 – Average activity profile of the Coma Berenicids derived from 5700 visual observations of 1986–2005.

oroid streams of short-period comets. According to the study by Triglav-Čekada & Arlt (2005), we propose the activity period of the Northern and Southern Taurids to be September 25 to November 25. This is the period in which a consistent radiant drift was found for both branches.

2.15 Leonids

Stream modelling of the Leonids led to various activity peaks which occurred outside the activity period of the shower in the previous Working List. Observers not being aware of the predictions will fail to associate the meteors seen with the Leonids on such occasions. Also automated video systems will ignore possible activity.

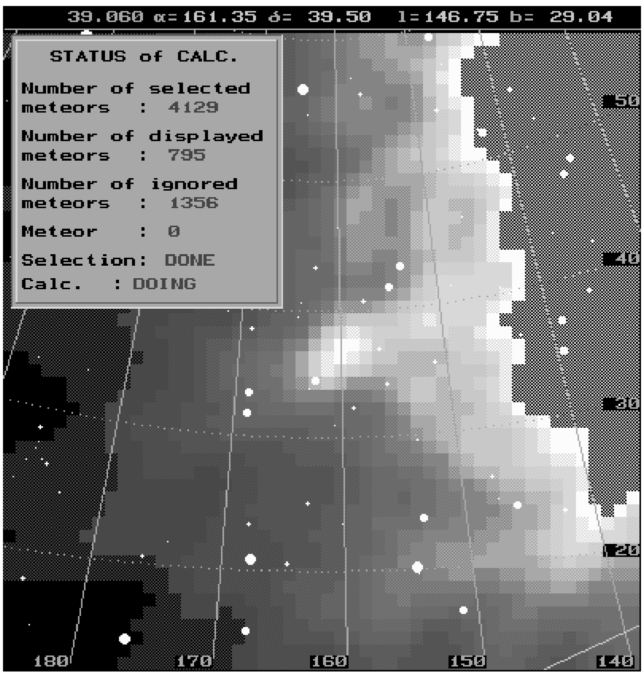

Figure 7 – Radiant plot from 795 video meteors showing the radiant of the Leo Minorids. The huge area of radiants of various sources, such as the Orionids, ε-Geminids and ecliptical background meteors had to be suppressed to make the `LMI` radiant visible.

We propose to extend the activity period to November 10–23. The Leonid radiant is sufficiently isolated from other sources. Their very high speed make the Leonids well distinguishable from the sporadic meteors. A severe contamination from sporadic meteors at the far ends of the activity period does not seem harmful. On the other hand, we may obtain information about possible activity caused by meteoroids on orbits far from the main stream.

2.16 December Phoenicids

Lack of data, orbital information, and parent object gave little prominence to this shower, and the original proposal was to omit it from the Working List. Recent observations of the planet-crossing minor planet 2003 WY_{25} indicate a cometary nature of the object and support its identification with the lost comet D/1819 W1 (Blanpain) (Jewitt, 2006). Perhaps the comet split and the breakup accounts for the 1956 activity (Jenniskens & Lyytinen, 2005). Although there are still open questions, we suggest to leave the shower in our Working List. Otherwise there is a chance of missing data if we were omitting the entry now.

2.17 Coma Berenicids

This shower with an assumed activity period for about 1.5 months has not been associated successfully with a parent object. An activity profile of the shower was constructed using 5700 observations of the Visual Meteor Database. The result is shown in Figure 6 and indicates that there is indeed significant activity over the entire proposed activity period. Since the radiant position of the Coma Berenicids is also quite isolated, we propose to keep the long activity period of the shower as was in the previous Working List.

3 More showers?

In an attempt to add potentially interesting meteor showers to the list which were not included in the old version, we evaluated the showers of other compilations. The radiant list given by Jenniskens (1994), contains

Table 1 – New Working List of Meteor Showers to be adopted starting in 2007. The solar longitude $\lambda_\odot$ refers to equinox J2000.0. The date of maximum has to be computed for each individual year. The dates given here are only approximate and may vary by ± 1 day. The entry-velocity V_∞ is the geocentric encounter velocity plus acceleration by the gravity of the Earth. The radiant positions can be taken from Table 2. Radiants for the time of maximum are not given, because of the risk of being used for the entire activity period by less involved observers. The same holds for the population index which varies during the activity periods of each shower. Meteor showers typically exhibit a population index of $r = 2.0$ to 2.5 during their maximum. Values in this range should be used for tentative analyses; otherwise r must be determined as a function of time before any activity computation of a meteor shower. The ZHR of the Antihelion Source is not a maximum ZHR but an average value throughout the year.

Shower	Code	Activity period –	$\lambda_\odot$ of maximum J2000.0	Approx. date of maximum	V_∞ km/s	ZHR
Antihelion source	ANT	Jan 01–Dec 31	–	–	30	~ 3
		ANT not observable during NTA/STA				
Quadrantids	QUA	Jan 01–Jan 05	283°.16	Jan 03	41	120
α-Centaurids	ACE	Jan 28–Feb 21	319°.2	Feb 07	56	5
δ-Leonids	DLE	Feb 15–Mar 10	336°	Feb 24	23	2
γ-Normids	GNO	Feb 25–Mar 22	353°	Mar 13	56	4
Lyrids	LYR	Apr 16–Apr 25	32°.32	Apr 22	49	18
π-Puppids	PPU	Apr 15–Apr 28	33°.5	Apr 24	18	var
η-Aquarids	ETA	Apr 19–May 28	45°.5	May 05	66	60
η-Lyrids	ELY	May 03–May 12	48°.4	May 09	44	3
June Bootids	JBO	Jun 22–Jul 02	95°.7	Jun 27	18	var
Piscis Austrinids	PAU	Jul 15–Aug 10	125°	Jul 28	35	5
Southern δ-Aquarids	SDA	Jul 12–Aug 19	125°	Jul 28	41	20
α-Capricornids	CAP	Jul 03–Aug 15	127°	Jul 30	23	4
Perseids	PER	Jul 17–Aug 24	140°.0	Aug 12	59	100
κ-Cygnids	KCY	Aug 03–Aug 25	145°	Aug 17	25	3
α-Aurigids	AUR	Aug 25–Sep 08	158°.6	Sep 01	66	7
September Perseids	SPE	Sep 05–Sep 17	166°.7	Sep 09	64	5
δ-Aurigids	DAU	Sep 18–Oct 10	191°	Oct 04	64	2
Draconids	GIA	Oct 06–Oct 10	195°.4	Oct 08	20	var
ε-Geminids	EGE	Oct 14–Oct 27	205°	Oct 18	70	2
Orionids	ORI	Oct 02–Nov 07	208°	Oct 21	66	23
Leo Minorids	LMI	Oct 19–Oct 27	211°	Oct 24	62	2
Southern Taurids	STA	Sep 25–Nov 25	223°	Nov 05	27	5
Northern Taurids	NTA	Sep 25–Nov 25	230°	Nov 12	29	5
Leonids	LEO	Nov 10–Nov 23	235°.27	Nov 17	71	var
α-Monocerotids	AMO	Nov 15–Nov 25	239°.32	Nov 21	65	var
December Phoenicids	PHO	Nov 28–Dec 09	254°.25	Dec 06	18	var
Puppid/Velids	PUP	Dec 01–Dec 15	255°	Dec 07	40	10
Monocerotids	MON	Nov 27–Dec 17	257°	Dec 09	42	2
σ-Hydrids	HYD	Dec 03–Dec 15	260°	Dec 12	58	3
Geminids	GEM	Dec 07–Dec 17	262°.2	Dec 14	35	120
Coma Berenicids	COM	Dec 12–Jan 23	268°	Dec 19	65	5
Ursids	URS	Dec 17–Dec 26	270°.7	Dec 22	33	10

Table 2 – Radiant ephemeris of the showers in the new Working List in Table 1. Positions (RA & Dec) refer to eq. J2000.0.

Date		**ANT**		**QUA**		**COM**									
Dec	31	112°	+21°	228°	+50°	186°	+20°								
Jan	5	117°	+20°	231°	+49°	190°	+18°								
Jan	10	122°	+19°			194°	+17°								
Jan	15	127°	+17°			198°	+15°								
Jan	20	132°	+16°			202°	+13°								
Jan	25	138°	+15°					**ACE**							
Jan	30	143°	+13°					200°	−57°						
Feb	5	149°	+11°					208°	−59°						
Feb	10	154°	+9°					214°	−60°	**DLE**					
Feb	15	159°	+7°					220°	−62°	159°	+19°				
Feb	20	164°	+5°	**GNO**				225°	−63°	164°	+18°				
Feb	28	172°	+2°	225°	-51°					171°	+15°				
Mar	5	177°	0°	230°	-50°					176°	+13°				
Mar	10	182°	−2°	235°	-50°					180°	+12°				
Mar	15	187°	−4°	240°	-50°										
Mar	20	192°	−6°	245°	-49°										
Mar	25	197°	−7°												
Mar	30	202°	−9°												
Apr	5	208°	−11°												
Apr	10	213°	−13°	**LYR**		**PPU**									
Apr	15	218°	−15°	263°	+34°	106°	−44°	**ETA**							
Apr	20	222°	−16°	269°	+34°	109°	−45°	323°	−7°						
Apr	25	227°	−18°	274°	+34°	111°	−45°	328°	−5°						
Apr	30	232°	−19°					332°	−3°	**ELY**					
May	05	237°	−20°					337°	−1°	283°	+44°				
May	10	242°	−21°					341°	0°	288°	+44°				
May	15	247°	−22°					345°	+3°	293°	+45°				
May	20	252°	−22°					349°	+5°						
May	25	256°	−23°												
May	30	262°	−23°												
Jun	5	267°	−23°												
Jun	10	272°	−23°												
Jun	15	276°	−23°												
Jun	20	281°	−23°	**JBO**											
Jun	25	286°	−22°	223°	+48°										
Jun	30	291°	−21°	225°	+47°	**CAP**									
Jul	5	296°	−20°			285°	−16°	**SDA**							
Jul	10	300°	−19°	**PER**		289°	−15°	325°	−19°	**PAU**					
Jul	15	305°	−18°	6°	+50°	294°	−14°	329°	−19°	330°	−34				
Jul	20	310°	−17°	11°	+52°	299°	−12°	333°	−18°	334°	−33				
Jul	25	315°	−15°	22°	+53°	303°	−11°	337°	−17°	338°	−31				
Jul	30	319°	−14°	29°	+54°	308°	−10°	340°	−16°	343°	−29	**KCG**			
Aug	5	325°	−12°	37°	+56°	313°	−8°	345°	−14°	348°	−27	283°	+58°		
Aug	10	330°	−10°	45°	+57°	318°	−6°	349°	−13°	352°	−26	284°	+58°		
Aug	15	335°	−8°	51°	+58°			352°	−12°			285°	+59°		
Aug	20	340°	−7°	57°	+58°	**AUR**		356°	−11°			286°	+59°		
Aug	25	344°	−5°	63°	+58°	76°	+42°					288°	+60°		
Aug	30	349°	−3°			82°	+42°	**SPE**				289°	+60°		
Sep	5	355°	−1°			88°	+42°	55°	+46°						
Sep	10	0°	+1°			92°	+42°	60°	+47°						
Sep	15	5°	+3°					66°	+48°	**DAU**					
Sep	20	10°	+5°	**NTA**		**STA**		71°	+48°	71°	+48°				
Sep	25	14°	+7°	19°	+11°	21°	+6°			77°	+49°				
Sep	30			22°	+12°	25°	+7°	**ORI**		83°	+49°				
Oct	5			26°	+14°	28°	+8°	85°	+14°	89°	+49°			**GIA**	
Oct	10	**EGE**		30°	+15°	32°	+9°	88°	+15°	92°	+42°			262°	+54°
Oct	15	99°	+27°	34°	+16°	36°	+11°	91°	+15°			**LMI**			
Oct	20	104°	+27°	38°	+18°	40°	+12°	94°	+16°			158°	+39°		
Oct	25	109°	+27°	43°	+19°	43°	+13°	98°	+16°			163°	+37°		
Oct	30			47°	+20°	47°	+14°	101°	+16°			168°	+35°		
Nov	5			52°	+21°	52°	+15°	105°	+17°	**LEO**					
Nov	10			56°	+22°	56°	+15°			147°	+24°			**AMO**	
Nov	15			61°	+23°	60°	+16°			150°	+23°			112°	+2°
Nov	20	**ANT**		65°	+24°	64°	+16°			153°	+21°			116°	+1°
Nov	25	75°	+23°	70°	+24°	72°	+17°	**MON**		**PHO**		**PUP**		120°	0°
Nov	30	80°	+23°	**GEM**				91°	+8°	14°	−52°	120°	−45°	**HYD**	
Dec	5	85°	+23°	103°	+33°	**COM**		96°	+8°	18°	−53°	122°	−45°	122°	+3°
Dec	10	90°	+23°	108°	+33°	169°	+27°	100°	+8°	22°	−53°	125°	−45°	126°	+2°
Dec	15	96°	+23°	113°	+33°	173°	+26°	104°	+8°	**URS**		128°	−45°	130°	+1°
Dec	20	101°	+23°	118°	+32°	177°	+24°			217°	+76°				
Dec	25	106°	+22°			181°	+23°			217°	+74°				
Dec	30	111°	+21°			185°	+21°								

five showers which were not listed in the previous IMO list, have known orbital parameters, and do not belong to the ecliptical source near the antihelion point. These are the γ-Velids, α-Hydrusids, δ-Pavonids, κ-Aquarids, and Leo Minorids. We were unable to detect the first three in a radiant search with video meteors, but the amount of data from the southern hemisphere is inferior to that from the northern hemisphere. The κ-Aquarids deliver a very weak radiant signal, and may be an interesting target for future updates of the Working List.

The new stream search method by Welch (2001) delivered 29 most prominent 'orbit clusters'. It is interesting to note that there is only a single stream among these 29 which has not yet been in the old Working List; this is the Leo Minorids which we have now included.

4 Conclusions

The new Working List of Meteor Showers is given in Table 1. We remind the reader that the list contains visually observable and scientifically interesting showers. The radiant motion of each of these showers is given in 5-day steps in Table 2. Some of the ephemerides are based on recent research, others are taken from the previous version of the Working List; we refer to the above sections for corresponding notes.

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This work could not have evolved without the comments by numerous people. We would like to thank Peter Brown, Tim Cooper, Audrius Dubietis, Peter Jenniskens, Robert Lunsford, Alastair McBeath, Sirko Molau, and Mihaela Triglav-Čekada for their comments and suggestions.

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Precise photographic orbit of a 2005 October Camelopardalid meteor

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Regular photographic observations in the scope of the European Fireball Network provided a reliable atmospheric trajectory and heliocentric orbit of one meteor from the unexpected meteor outburst on 2005 October 5. We confirm that the meteors, named October Camelopardalids, were on a long period orbit. The lower limit for the semimajor axis is 41 AU. The perihelion distance was 0.991 AU and the inclination was $77\overset{\circ}{.}7$. The meteoroid behavior in the atmosphere was consistent with its cometary origin.

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1 Introduction

An unexpected meteor outburst was observed on 2005 October 5. The outburst was first reported by E. Lyytinen (e-mail to the IMO-News mailing list, 2005 October 6) on the basis of video data obtained by J. Moilanen in Finland and confirmed immediately by S. Molau from Germany (e-mail to the IMO-News mailing list, 2005 October 6). All available video and radar data have been analyzed by Jenniskens et al. (2005). The maximum of the outburst occurred on 2005 October 5, 19.7 UT and the duration (FWHM) was about 3.6 hours. The shower was rich in bright meteors, the brightest recorded fireball being of magnitude −6. Only one meteor was observed from two stations. Unfavorable geometric configuration, however, prevented reliable radiant determination for this meteor. The best radiant solution was therefore obtained by intersecting single station trajectories. The geocentric radiant was found to lie at RA = 166°, Dec = $+79\overset{\circ}{.}1$ (J2000.0). There was an indication that some meteors had different radiants. The shower was named October Camelopardalids. The geocentric velocity was found to be 46.6 ± 0.5 km/s, giving a nearly parabolic orbit with perihelion at 0.993 AU and inclination of $78\overset{\circ}{.}6$.

2 Photographic observations

We have carefully examined photographic films obtained by the cameras of the Czech part of the European Fireball Network. The network is aimed at studying bright (mostly sporadic) fireballs. It is operated every clear night. Usually, one exposure per night is obtained at each station. The Czech and Slovak parts of the network contain the most precise and most sensitive cameras equipped with Zeiss Distagon fish-eye objectives. The limiting magnitude is about −4, depending on meteor angular velocity. Six stations have already been equipped with new autonomous cameras (Spurný & Borovička, 2002) which also contain all-sky photoelectric detectors. The detectors measure sky brightness 500 times per second, providing timing and light curves of fireballs.

On the night of 2005 October 5/6, nine of the ten Czech stations were working, though the sky was partly cloudy at some stations. One October Camelopardalid meteor was found on the photographic negatives. The meteor was clearly visible on the image from station 11 (Přimda), where it was 63° above horizon (Figure 1). At stations 3 (Růžová) and 20 (Ondřejov), the meteor was near detection limit but measurable without problems. Having records from three stations, the meteor atmospheric trajectory and heliocentric orbit could be determined reliably and precisely. The mutual convergence angles were between 26° and 84°. The photoelectric detectors of autonomous cameras at stations 20 (Ondřejov) and 2 (Kunžak) recorded the meteor signal. The duration of the signal was 0.6 seconds and the maximum occurred at $19^{\mathrm{h}}19^{\mathrm{m}}55\overset{\mathrm{m}}{.}6$ UT (Figure 2). The signal intensity was 4% of the total brightness of all the sky. The correspondence of the signal with the Camelopardalid meteor was confirmed by an image from the guided camera still operated at the Ondřejov Observatory (in the past, guided cameras were the only means of determining fireball time of appearance).

3 Results

The resulting trajectory and orbit are given in Table 1. The right ascension of the radiant is 4 degrees larger east of that given by Jenniskens et al. (2005). Nevertheless, owing to the high declination, the difference in sky position is less than one degree. We can confirm that the orbit is of long period. Since no sign of meteoroid deceleration was apparent in the data, the velocity averaged along the whole trajectory was taken to be equal to the preatmospheric velocity. The orbital period was certainly larger than 260 years. The nom-

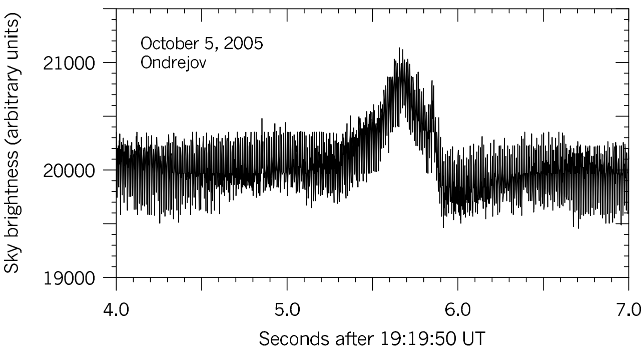

Figure 2 – The record of all-sky brightness from the photoelectric detector of the Autonomous Fireball Observatory at station Ondřejov. These data provided the most precise timing of the EN 051005B fireball.

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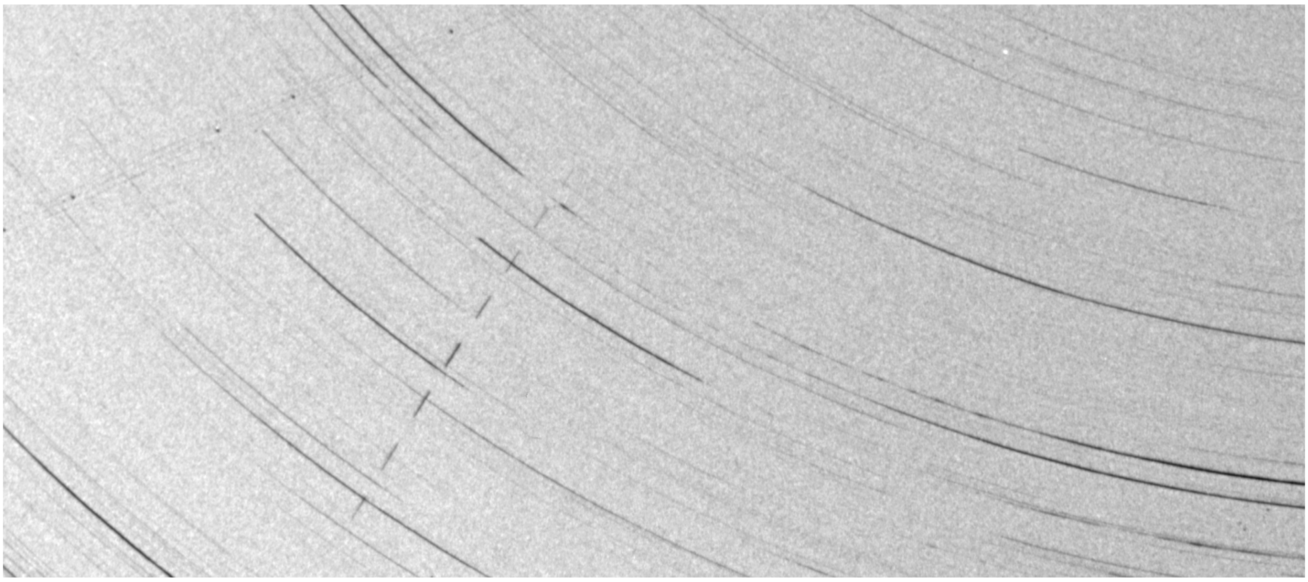

Figure 1 – Part of the all-sky photograph from the station Přimda showing the EN 051005B fireball crossing star trails in Cassiopeia. The meteor flew from top to bottom. The meteor image has been interrupted by the rotating shutter 15 times per second. The star trails have been interrupted by passing clouds. The photo was taken with a Zeiss Distagon 3.5/30 mm fish-eye lens using 9 × 12 cm sheet film. The film was exposed from $19^h18^m15^s$ to $03^h54^m22^s$ UT. Photo J. Macura. This photograph is reproduced at greater enlargement on the back cover.

inal value is 4500 years. Strictly speaking, we cannot exclude hyperbolic orbit, although this is very unlikely.

Table 1 – Data on trajectory and orbit of the EN051005B October Camelopardalid meteor.

Atmospheric trajectory

	Beginning	End
Longitude, East (deg)	13.1950 ±.0003	13.2327 ±.0002
Latitude, North (deg)	50.0089 ±.0002	49.8217 ±.0001
Height (km)	106.10 ±.02	87.63 ±.01

Radiant (J2000.0)

	R.A. (deg)	Declination (deg)	Velocity (km/s)
Apparent	170.45 ±.12	79.66 ±.11	47.44 ±.27
Geocentric	170.30 ±.12	78.80 ±.11	46.16 ±.28
	Longitude	Latitude	Velocity
Heliocentric	259.0 ±0.6	76.6 ±0.2	42.1 ±0.2

Heliocentric orbit (J2000.0)

Perihelion (AU)		0.9912	±.0004
Eccentricity		0.996	±.020
Semimajor axis (AU)		> 41 (nominally 270)	
Reciprocal semimajor axis (AU^{-1})		0.0037	±.0208
Longitude of perihelion (deg)		169.4	±0.3
Ascending node (deg)		192.5736	
Inclination (deg)		77.7	±0.2
Perihelion passage	2005	Sep 28.2	±0.2

The meteor end height of 88 km and its nearly symmetrical light curve are consistent with weak cometary structure of the meteoroid. The maximal absolute magnitude of the meteor was −5 mag. The meteoroid mass was of the order of 0.01 kg.

4 Conclusions

After the successful observation of 1998 June Bootid meteor (Spurný & Borovička, 1998) the European Fireball Network confirmed again that it is capable of providing orbits of unexpected meteor outbursts, although this is not its primary goal. The 2005 October Camelopardalids have been proven to be caused by meteoroids on long period orbits. Perihelion distance, inclination, and angular orbital elements were determined with good precision.

Acknowledgements

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A numerical method to aid in the combined determination of stream activity and Observability Function

Christian Steyaert [1], Jeffrey Brower [2], and Felix Verbelen [3]

A method to separate stream and sporadic activity of forward scatter meteor counts is applied to two widely different station set-ups: one had a long baseline and uses scatter from a high power TV video carrier, whilst the other had a much shorter baseline and records echoes from a low powered beacon. The method was applied to the 2005 Geminids data sets from each station and the results obtained were very promising. This opens possibilities for the method's use on data from other forward scatter observers as well as on other streams.

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1 Introduction

Radio observations of meteors are complementary to optical observations. Unlike the optical counterparts, radio observations have an additional benefit of being able to continue observing during periods of daylight and during clouded periods. As a result, radio observations can provide a continuous record of stream activity.

The data obtained from individual observers has been widely variable making comparisons and modeling difficult. This lack of standardization of the radio observational data has been a major deterrent to researchers trying to employ the data in their analyses.

The radio observers' derivation of a term equivalent to the visual observers' ZHR is dependent on many instrumental variables, which has not yet been defined successfully. Yet several radio observers have succeeded in obtaining consistent measures of both sporadic activity and total activity in the presence of a known stream. This raises the expectation that a quantitative function, that takes in such factors as the radio set-up and system characteristics, can be identified and applied to each observer's data. The method described below is the first step to achieving that goal.

Felix Verbelen (Kampenhout, Belgium, 4°36′ E, 50°57′ N) registers the reflected signals generated by the VVS (Vereniging Voor Sterrenkunde) beacon near Ypres (2°55′ East, 50°49′ North), at a distance of 119 km. The beacon (Steyaert, 2005) runs 40 watts with vertical incidence. His antenna is a 2 elements HB9CV Yagi with an elevation of 52° and an azimuth of 250° (almost west), placed 2 meters above ground level.

The radio signal is conveyed by a RG-213 line to an unmodified IC R-7100 receiver tuned to 49.990 MHz, USB mode. The station has been operating continuously since May 2005. The audio signal is fed directly into the sound card of an Intel Pentium II PC 233 MHz and analysed using DL4YHF's Spectrum Lab (Buescher 2006), a FFT audio signal analyser.

The resulting graphics, a 150 Hz wide frequency window, and sound (digitised at 5512 Hz) were stored at 5 minute intervals on hard disks and then visually inspected at a later time.

Manual counts were done by placing echoes into three categories: reflections lasting at least 2 seconds, 10 seconds, and 1 minute; thus long reflections are counted in more than one category. Reflections shorter than 2 seconds are not counted. This highly favoured overdense echoes.

Brower's station is located west of Kelowna, British Columbia, Canada (49°51′ N, 119°34′ W). His station recorded reflected signals from the 58.9 kW video carrier (61.260 MHz) of KOAB (TV-3) located near Bend, Oregon, U.S.A. (44°4′ N, 121°20′ W). The transmitter site is at a bearing of 193° (SSW) from the receiver's site and at distance of 655 km, making the path a moderately long baseline.

His station consisted of a software controlled Icom PCR-1000 receiver that was connected to a less than ideal, temporary HF antenna by six meters of RG-9913 coax cable. The antenna was a delta loop tuned by an automatic antenna tuner to resonate at 61.260 MHz. The null of his antenna was in the direction of the transmitter station. No pre-amplifier was used. The receiver was in the CW (continuous wave) detection mode and had a bandpass width of 2.2 kHz. Audio from the PCR-1000 was sent to sound card of a 1.4 GHz computer.

The computer utilized a fast Fourier transform (FFT) program, mAnalyzer-A V 0.94, which was designed by Esko and Olli Lyytinen (Lyytinen & Lyytinen 2001). The program listens to a 100 Hz bandwidth to detect the presence of meteor echo signatures. It also compared the meteor channel to a noise channel before it validated the signal as being a true echo and not due to noise or other interference. Three data files were produced: a spectrogram image, an hourly text file, and a ten minute period text file. The data files recorded echo counts along with echo strengths and duration of echoes at four power levels. FTP software routed the data to various archives and web sites. The output data text files were parsed and statistics performed by software written by Brower.

2 The proposed numerical method

Steyaert introduced the proposed numerical method for data reduction at the 2005 International Meteor Conference in Oostmalle, Belgium (Steyaert, 2006a). The

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NASA-ADS bibcode 2006JIMO...34...87S

method assumes that the observed activity, O, at time t, is the sum of a fixed sporadic term $S(T)$ and a term which can be attributed to the stream. The term for the stream is the product of the 'true' stream activity $Z(t)$ and the observability function, OF(T). (Although sporadics have their own observability function, this is unknown and thus subsumed in S(t).) The value of the observability function is dependent on many factors, such as the geometry of the transmitter-receiver, the characteristics of the receiving and antenna systems, the radiant height and velocity of the stream's members, as well as other variables (Steyaert, 1987). Conceptually, the observability function is an analog to the visual observers' ZHR correction factor.

The S and OF terms are periodic in that they have the same value at the same time of the day during consecutive days.

$$O(t) = S(T) + Z(t)OF(T) \tag{1}$$

Where T is derived by applying equation (2).

$$T = \frac{t - t_0}{D} \tag{2}$$

Where t_0 is an arbitrary starting point in time and D is the length of the day in hours (i.e. 24).

We assume a double asymmetric exponential function for the stream:

$$Z(t) = e^{-(t_{\mathrm{M}}-t)/a} \tag{3}$$

for $t < t_{\mathrm{M}}$, where t_{M} is the time of the maximum and a and b are time constants. Note that this is normalised so that $Z(t_{\mathrm{M}}) = 1$. The intensity is $1/e$ at a hours before or b hours after the maximum:

$$Z(t) = e^{-(t-t_{\mathrm{M}})/b} \tag{4}$$

for $t > t_{\mathrm{M}}$

In practice we have counts, or other measures, that cover a time interval that is typically of one hour duration.

We replace the continuous model of equation (1) with its discrete counterpart. The index refers to the time interval; typically (as below), interval 1 is from $00^{\mathrm{h}}00^{\mathrm{m}}00^{\mathrm{s}}$ to $00^{\mathrm{h}}59^{\mathrm{m}}59^{\mathrm{s}}$.

The equation for the first hour of the first day is:

$$O_1 = S_1 + Z_1 OF_1 \tag{5}$$

The equation for the last hour of the first day is:

$$O_{24} = S_{24} + Z_{24} OF_{24} \tag{6}$$

The equation for first hour of the second day is:

$$O_{25} = S_1 + Z_{25} OF_1 \tag{7}$$

The equation for the last hour of the second day is:

$$O_{48} = S_{24} + Z_{48} OF_{24} \tag{8}$$

The general equation for hour j of day k:

$$O_{j+24(k-1)} = S_j + Z_{j+24(k-1)} OF_j \tag{9}$$

Next the $24n$ equations (n days) for 24 unknowns S, and the 24 unknowns OF were solved. We then determined the three stream parameters t_{M}, a and b. The equations are linear for S and O, but non-linear for the stream parameters. A practical minimum duration of observation is 3 days, whilst 5 days will generally capture the maxima of most annual streams.

It is obvious that an exact solution is not possible. However, if the stream parameters are known, we can find the least square solutions for S and O. We use equation (10) to minimize the quadratic criterion J (defining, for convenience, m to be $j + 24(k-1)$):

$$J = \frac{1}{2} \sum_k \sum_j (O_m - S_j - Z_m OF_j)^2 \tag{10}$$

For S_j, $j = 1$ to 24 and OF$_j$, $j = 1$ to 24

$$\frac{\partial J}{\partial S_j} = 0 \tag{11}$$

$$\frac{\partial J}{\partial OF_j} = 0 \tag{12}$$

The solutions for this form of linear regression are:

$$OF_j = \frac{n \sum O_m Z_m - \sum O_m \sum Z_m}{n \sum Z_m^2 - (\sum Z_m)^2} \tag{13}$$

$$S_j = \frac{\sum O_m - OF_j \sum Z_m}{n} \tag{14}$$

Not unexpectedly, the OF$_j$ and S_j values remain constant for the given time interval j for all days being calculated.

Although we know that OF$_j$ has to be zero when the radiant is below the horizon during the whole one hour interval, we can still apply equation (13). This should result in a small positive or negative value, the latter having no physical meaning.

If on the other hand we force OF$_j$ to zero, then formula (14) simplifies to:

$$S_j = \frac{\sum_k O_m}{n} \tag{15}$$

Or, the average of the observed values for the hourly interval j.

Up to this point we have worked with known, or rather assumed, stream parameters t_{M}, a and b. The function J is non-linear for the stream criterion.

$$J(t_{\mathrm{M}}, a, b) \tag{16}$$

We minimize $J(t_{\mathrm{M}}, a, b)$ by means of the downhill simplex numerical method (Vetterling et al., 1992), for

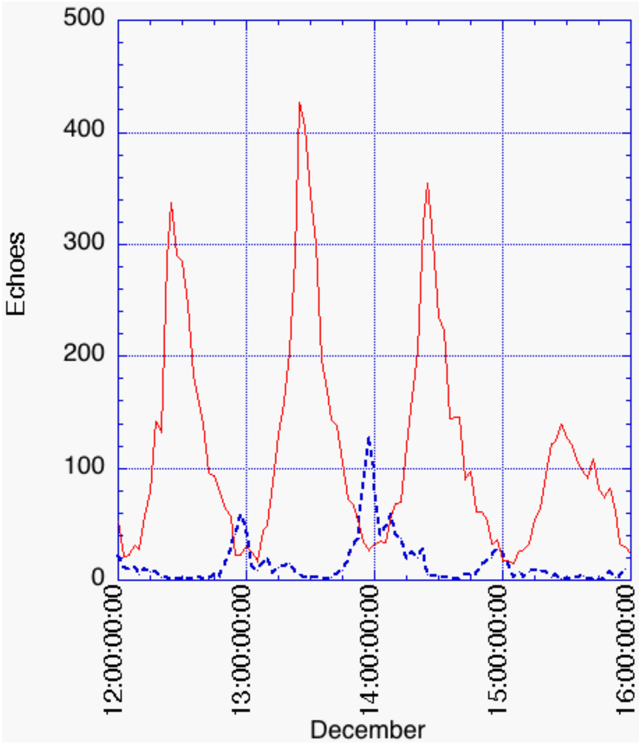

Figure 1 – Observed number of reflections by Brower (solid line) and Verbelen (dotted line) for 2005 December 12–15.

the three stream parameters. There are some limits involved in using this numerical method. The initial t_M should fall somewhere within the observation period (unless only the ascending or descending branch of the stream activity was observed, in which case the downhill simplex method is not recommended). Initial values for a and b can be taken from the literature. If no such information is available, then start with very high values of a and b, or put b always equal to a if there is no reason to expect an asymmetrical stream.

3 Applying the proposed method to the 2005 Geminids

The method was tested on the observational data of Brower for December 12–16, and of Verbelen for December 11–15, which was published in the Radio Meteor Observation Bulletin (Steyaert, 2006b). Figure 1 shows the observed counts of both Brower and Verbelen. The activity curves are very different regarding the time of the *observed* maxima.

Note: Verbelen observes only the larger particles that produce overdense echoes, whilst Brower records both overdense echoes and the shorter underdense reflections as well. The maximum for the larger particles occurred later in time according to the results presented in Figure 1, which was in agreement with the literature

Table 1 – Stream parameters for Brower and Verbelen.

Derived stream parameters			
Observer	t_M	a	b
Brower	Dec 14 at 4.7^hUT	77.7	13.5
Verbelen	Dec 14 at 9.5^hUT	25.0	6.1

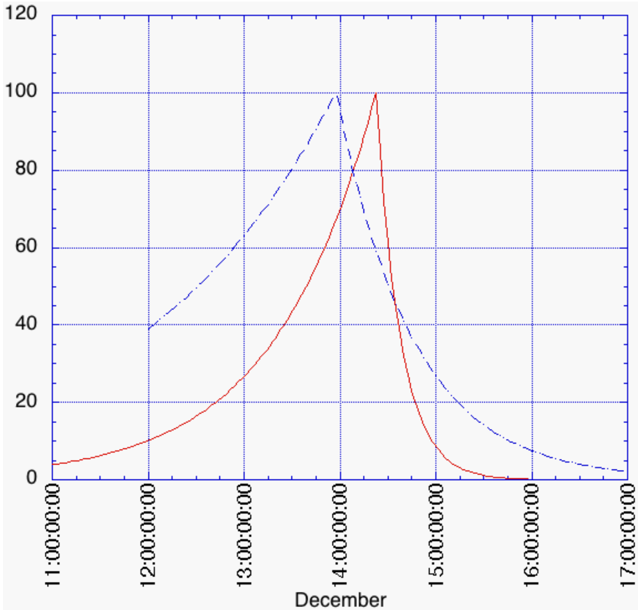

Figure 2 – The normalized Geminids activity curves for Verbelen (solid line) and Brower (dotted line)

for this stream. Figure 2 shows Verbelen's activity curve is narrower and steeper than that of Brower's, which was also as expected with the mass sorting of particles seen in the Geminid stream.

We derived the stream parameters as given in Table 1.

There were very few visual observations of the 2005 Geminids and therefore the IMO did not issue a Shower Circular for it. However it was known the maximum was predicted to occur on December 14, at 04^h30^m UT $\pm 2^h.5$.

Obtaining an error margin on the stream parameters requires running a series of Monte Carlo simulations, which has not yet been done. For those not familiar with this type of simulation the number of events, in this case echo counts per period, is the parameter, μ, of a Poisson distribution. A random number between 0 and 1 serves as a look up in the cumulative Poisson distribution table. The corresponding look up x-value replaces the observed value. This is repeated for all the observed values, and the new stream parameters are found. After a sufficient number of simulations are performed the spread on the parameters can be established.

The observed and fitted activity for Verbelen is seen in Figure 3, and for Brower in Figure 4.

In general the fits are remarkably good, giving credibility to the model. The remaining differences between the observations and the calculated values are due to:

- true deviations of the stream activity from the model;
- the measurements are counts following the Poisson distribution, not an 'exact' measurement;
- errors, e.g. overlapping reflections (saturation), interference counted as meteors.

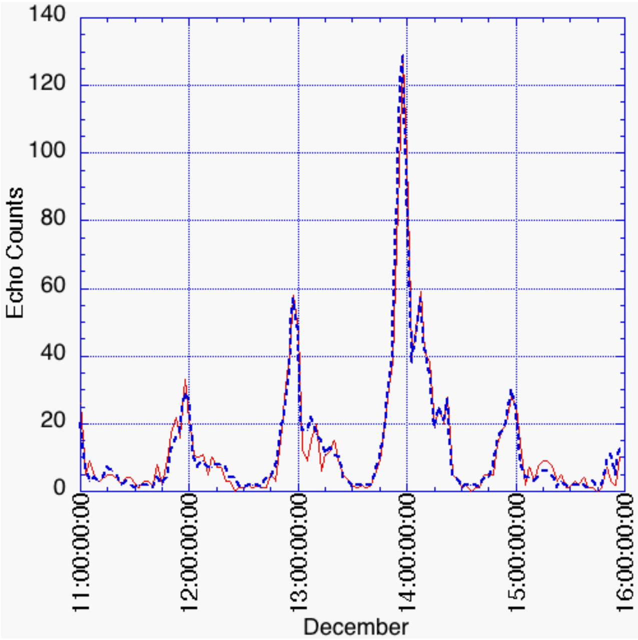

Figure 3 – Observed (solid line) versus fitted activity (dotted line) for Verbelen.

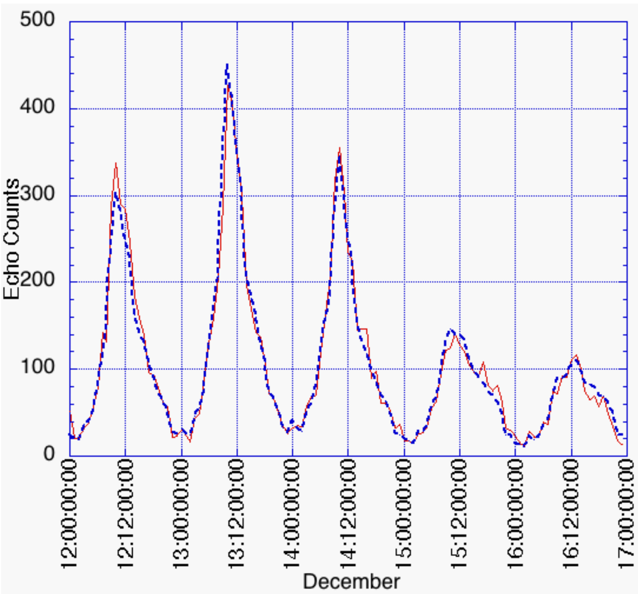

Figure 4 – Observed activity (solid line) versus fitted activity (dotted line) for Brower.

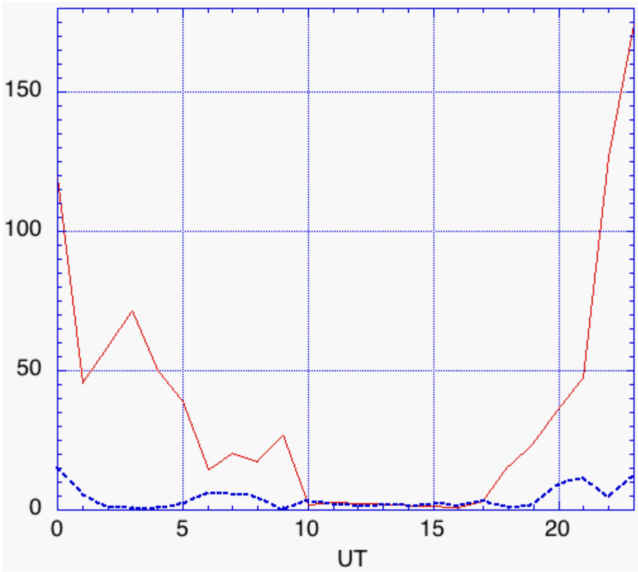

Figure 5 – The sporadic activity S (dotted line) and the observability function OF (solid line) values for Verbelen.

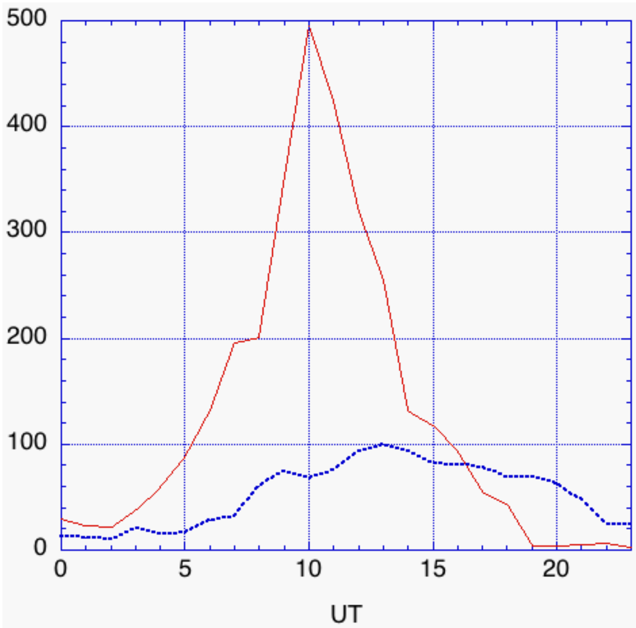

Figure 6 – The sporadic activity S (dotted line) and the observability function OF (solid line) values for Brower.

Verbelen's setup is insensitive to the Geminids between 10^{h} and 17^{h} UT. The radiant is below the horizon for him for part of the hours between 12^{h} and 15^{h} UT; thus the values of OF were set to zero. Note the corresponding sporadic echo values, S, also remain low during this period. On the other hand, his setup is most efficient between 22^{h} and 01^{h} UT. The highest observed counts occur during this interval, although the actual maximum stream activity was found to peak on December 14 at $09\overset{\mathrm{h}}{.}5$ UT. The non Geminid, sporadic, activity is low throughout the day. The S values between 20^{h} and 01^{h} UT might even be overstated, and the corresponding OF values underestimated.

For Brower the Geminids radiant is below the horizon a portion of the time between the hours of 19^{h} through 00^{h} UT. The sporadic echo activity, S, contributes significantly more to the total counts for Brower than they did for Verbelen. The maximum in the sporadics takes place around 05^{h} local time, while the minimum occurs around 18^{h} local time, which is in good agreement with the normal diurnal curves found in the literature. Each of the S and OF values are determined independently from the adjacent ones, yet good continuity is obtained.

4 Predictions

Assuming the radio observing set-up, stream activity, and solar longitude of the maximum remain unchanged the next few years, we can make predictions of the number of reflections that should be recorded by the two observers. The time of the maximum increases 6 hours

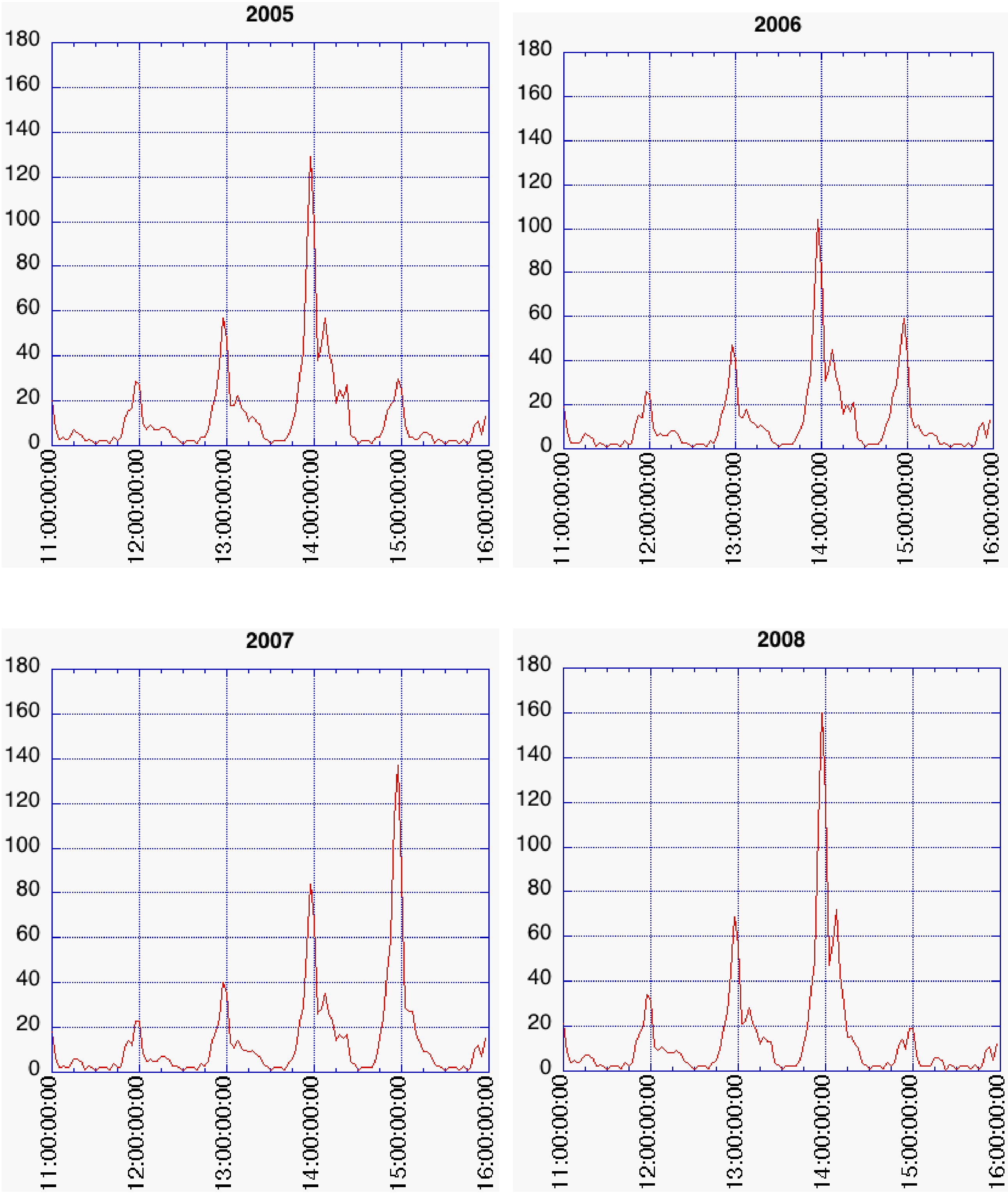

Figure 7 – Predicted Geminid echo counts for Verbelen 2005 to 2008.

in 2006 and 2007. It occurs another 6 hours later in 2008, but one day earlier due to the leap day.

Figure 7 shows the predictions for Verbelen. The predicted highest rates are as low as 105 in 2006, and as high as 165 in 2008.

Figure 8 gives the predictions for Brower. For him the lowest maximum of 430 is predicted for 2005, the highest is 500 in 2006.

5 Conclusions

A promising numerical method, which is easily incorporated in a spreadsheet, has demonstrated data reduction from two widely different stations is possible. It can also be employed as a predictive tool in future showers.

The efficacy of the method depends on two assumptions: 1) that each station maintains a fixed receiver-antenna system over time, and 2) the data produced is of research quality, i.e., it is not statistically under-sampled and demonstrates proper daily diurnal curves. Stations not yet meeting these criteria are urged to meet these requirements so appropriate data comparisons can be made.

This method applies a correction factor, referred to as the observability function. The correction factor accounts for variables such as transmitter power, baseline lengths, unknown path geometry, and equipment variables. By use of the correction factor the data can be reduced, individual's radio ZHR predicted, and stream trends discovered, on a per stream and per station basis.

It is also hoped that this new method will encourage greater professional-amateur co-operation. High quality radio observations should be seen as being relevant and be viewed as complementary to visual observations, especially when there are large gaps in visual observations due to bad weather or lack of observers as occurred during the 2005 Geminids. With an increase in such co-operation, the amateur observers will be more motivated to improve and maintain the quality of their data an continue their around the clock recording of echoes. The data archives will continue to grow and be more useful to researchers in the future.

The model presented is the first step in data reduction between widely varying forward scatter data. The next logical step will be to employ Monte Carlo simulations in parallel with the model to further refine the modeling and increase the method's effectiveness. At that point the experimentally derived OF function (Steyaert, 1987) can be evaluated against Hines and Pugh's (Hines & Pugh 1956) theoretical model of stream structures.

6 Acknowledgements

We are deeply indebted to Pierre Terrier (Terrier, 2006) for creating and managing the Radio Observatories On Line web page, which enables radio observers to post their results in real time.

And our thanks to Gaspard De Wilde who built the VVS meteor beacon, as well as to the Astrolab IRIS, which is hosted on the beacon at Ypres, Belgium. Felix Verbelen's results would not have been possible without this beacon. The beacon has also stimulated new interest in radio forward scatter observations in general. And thanks to the many forward scatter observers who faithfully send their data in to the RMOB archives.

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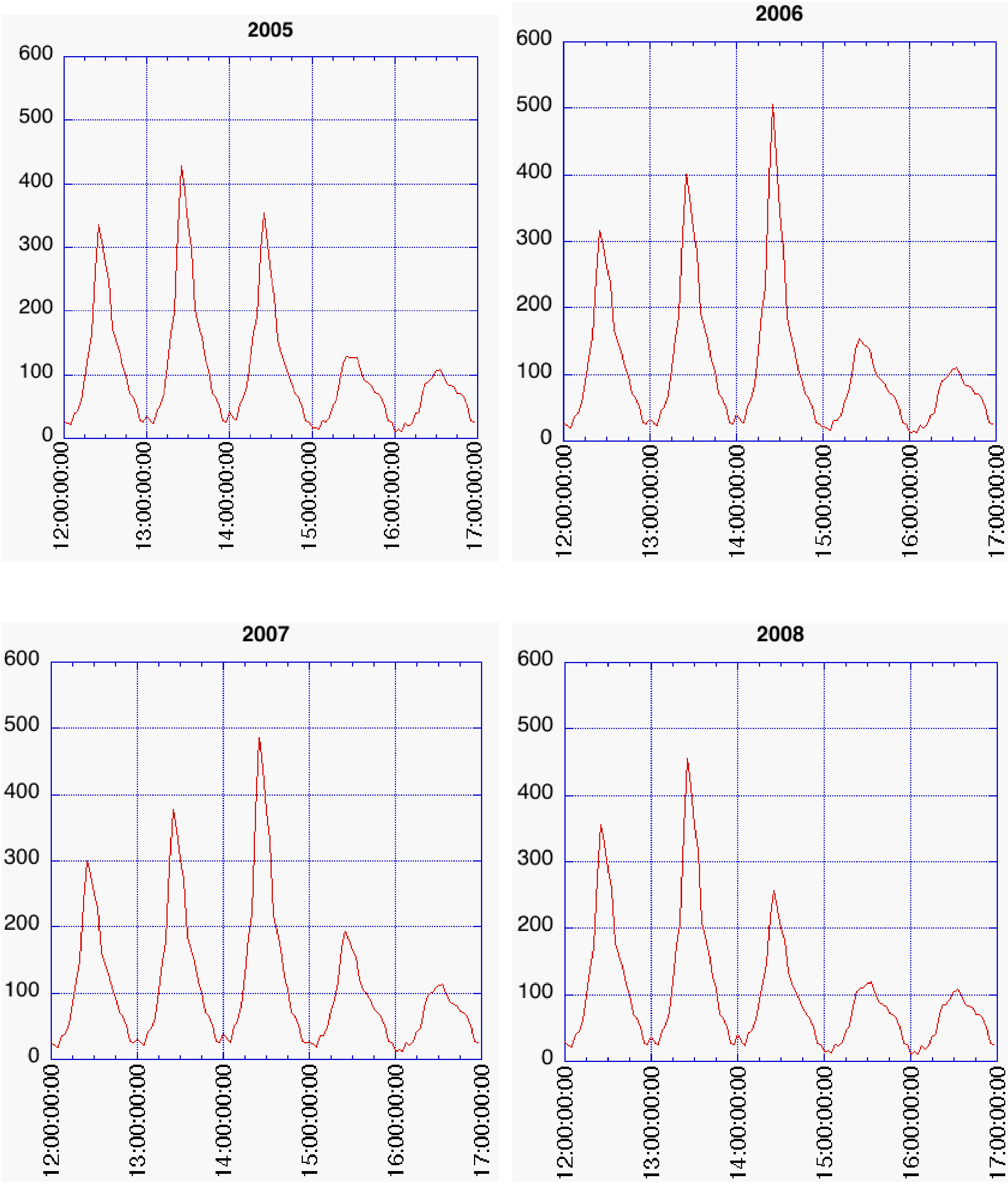

Figure 8 – Predicted Geminid echo counts for Brower 2005 to 2008.

History

Meteor Beliefs Project: Meteoric portents from Livy and Julius Obsequens

Andrei Dorian Gheorghe[1] *Alastair McBeath*[2]

An annotated catalogue of meteoric, meteoritic and possibly allied events, extracted from texts by Livy and Julius Obsequens, is presented, covering the period 671–17 BC. Brief biographical notes on both authors are given, with some discussion of ancient Roman beliefs about portents and prodigies.

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1 Introduction

Titus Livius, more commonly known modernly as Livy, was born in Patavia (modern Padua) in 59 BC, where he also died, in 17 AD. He was a well-educated philosopher and writer who spent much of his adult life in Rome, where he enjoyed a long, close friendship with the Emperor Augustus, dying only three years after the Emperor. His masterwork was his *Ab Urbe Condita*, 'From the Founding of the City'. This was a monumental history of Rome (**the** City) and its Empire from the legendary foundation of Rome by Aeneas (whom we have met several times previously during this Project), to the death of Drusus, and possibly the death of Quintilius Varus, in 9 BC. Aside from the fascinating history, Livy frequently recorded lists of portents, including the meteoric and possibly meteoritic events which we shall examine here.

Unfortunately, of the original 142 books, only about a quarter survive mostly intact — Books I–X and XXI–XLV. An 'Epitome' of the history, possibly compiled by Livy's son, is also lost, but various extracts and summaries of this summary have survived, to hint at what we lack. These are far from satisfactory however, as they have often been reworked through other lost versions before coming down to today.

From these secondary compendia, that of greatest interest to us here is the *Prodigiorum Liber*, 'Book of Prodigies', of Julius Obsequens. He gave a chronological series of portent lists from 190 to 12 BC (not entirely complete in the form we have it, sadly), extracted from Livy's work. In his original, it probably began in 249 BC. Obsequens is a wholly obscure character. His text has been suggested as dating to the 4th century AD, or a little before, and from his writings, he clearly believed in prodigies, thus cannot have been a Christian, but all other details about him are lacking.

The biographical notes above were largely taken from the Introductions to Foster (1919) and Schlesinger (1967).

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NASA-ADS bibcode 2006JIMO...34...94G

2 Portents and prodigies

We have already touched on meteoric portents and prodigies earlier in this series, for instance the spoof list of portents from 'Bored of the Rings' in (Gheorghe & McBeath, 2004), or the ancient portents mentioned in regard to meteorite worship (McBeath & Gheorghe, 2005). To give a better idea of what a complete list might historically have contained, the following example came from Livy XXX.II.9–13, for 203 BC (Moore, 1949, pp. 372–373):

'And new religious fears were aroused in men's minds by portents reported from a number of places. On the Capitol ravens were believed not only to have torn away gilding with their beaks but even to have eaten it. At Antium mice gnawed a golden wreath. The whole region around Capua was covered by an immense number of locusts, while there was no agreement as to whence they had come. At Reate a colt with five feet was foaled. At Anagnia there were at first shooting-stars at intervals and then a great meteor blazed out. At Frusino a halo encircled the sun with its slender circumference, and then the ring itself had a greater circle bright as the sun circumscribed about it. At Arpinum in an open meadow the earth settled into a huge depression. One of the consuls on sacrificing his first victim found the 'head' of the liver lacking. These prodigies were expiated by full-grown victims; the gods to whom the sacrifices should be offered were announced by the college of the pontiffs.'

Such a list seems to have been collected annually — or at least was announced so — as this was the typical way in which Livy presented them. As we can see, meteoric events formed only a small fraction of the whole, but things like aurorae or atmospheric halo effects were featured too, together with human and animal oddities. Animal sacrifices, as noted above, were the normal way to offset the ill-fortune portended by such occurrences. The liver's 'head' incidentally, was a notable protuberance on a variably-shaped organ. A large 'head' was considered very favourable, a small or misshapen one very unfavourable, while a liver with no 'head' was considered singularly disastrous.

Whether the ancient Romans really believed in these omens is open to debate. For instance, Livy XXVIII. XXVII.16 (op. cit., pp. 114–115) cited the following as part of a long speech by the military commander Publius Scipio at Sucro in Spain in 206 BC, after he had quelled a mutiny among his troops begun while he was ill:

'Showers of stones and thunderbolts hurled from the sky and animals bringing forth strange offspring you reckon portents; here we have a portent which cannot be expiated by any victims, by any set days of prayer, without the blood of those who have dared so great a crime.'

The 'portent' and 'crime' Scipio referred to was of course the mutiny.

Other authors occasionally implied that such prodigies were treated rather like modern newspaper horoscopes - some people believed them, most were sceptically ambivalent, and some were entirely sceptical. Livy obviously felt the need to justify including them, perhaps in response to criticism of earlier volumes of his work, as in his discussion for 169 BC, he wrote (XLIII.XIII.1–2; (Schlesinger, 1951, pp. 44–45)):

'I am not unaware that, as a result of the same disregard that leads men generally to suppose nowadays that the gods foretell nothing, no portents at all are reported officially, or recorded in our histories. However, not only does my own mind, as I write of old-time matters, become in some way or other old-fashioned, but also a certain conscientious scruple keeps me from regarding what those very sagacious men of former times thought worthy of public concern as something unworthy to be reported in my history.'

We are thankful he did record such matters, since whatever the beliefs or supposed contemporary relevance attributed to them, they provide a reassuring insight that unusual events of similar character to today, were also present more than 2000 years ago.

Taking the portent-lists from Livy and Obsequens, we have extracted what we think to be the more likely meteoric and meteoritic candidates, or which indicated the beliefs people held about things that could fall from the sky, which we would modernly view in such a possible way. We present these in the chronological catalogue below, with annotations or explanations where necessary. The events selected were dated to between 672 and 17 BC, though most were recorded from 218 (when Livy's extant text resumed after a ten-book gap) to 87 BC.

In using this catalogue, it is important to have in mind the selection effects employed. Livy (and as a result, Obsequens) did not record everything in this regard. Not all years had portents listed for them, perhaps because Livy's sources were lacking them. Some lists were very substantially shorter than others, and Livy occasionally noted he had omitted prodigies he did not consider relevant or credible. These choices did not seem to have affected his recording of plausibly meteoric events, but we cannot be certain of this.

Then too, there is our selectivity in picking the items we have. Some 'meteors' or 'lights in the sky' seemed to be more auroral than modernly meteoric, and most of these we excluded. In doing so, it is possible we have omitted some which may have been more relevant than we realised, but we hope these would be very few. Conversely, we have included some events which may not seem especially meteoric, a few of which seem incapable of a modernly-scientific explanation as written. As usual within this Project, we are as interested in what people believed as what may be scientifically accurate, and we are reasonably convinced there may be meteoric events behind the vast majority of those we have given, however garbled the accounts may seem.

3 Catalogue of events

For each entry in this catalogue, we have given the date, the relevant place, details of what occurred (including quotations from the text), the source reference, and any additional comments of ours. For the few items featured jointly by Livy and Obsequens, we have given information on variations between the sources, since this helps give a rough idea of Obsequens' general accuracy. Figure 1 provides a map to help with orientation.

Regarding the dating of events, Livy used a system of 'A.U.C' ('Ab Urbe Condita') dates, from the legendary founding of Rome, from which base his modern editors have generated dates BC. However, as the ancient Roman year began and ended in March, there is an uncertainty as to which year by the modern calendar a given prodigy occurred in, particularly as there is only the assumption they were from just the year immediately passed. Regrettably, no better dating than this can be achieved.

672–640 BC: On Mount Alban, '...it was reported to the king and senators that there had been a rain of stones' ... 'As this could scarce be credited, envoys were dispatched to examine the prodigy, and in their sight there fell from the sky, like hail-stones which the wind piles in drifts upon the ground, a shower of pebbles. They thought too that they heard a mighty voice issuing from the grove on the mountain-top...' This voice commanded the Albans to celebrate the sacrifices their forefathers had made, which they had either forgotten, or abandoned in favour of the Roman rites. 'The Romans also, in consequence of the same portent, undertook an official nine days' celebration', either commanded by the mysterious voice from the mountain, or on the advice of the soothsayers. 'At all events, it remained a regular custom that whenever the same prodigy was reported there should be a nine days' observance.'

'Not very long after this Rome was afflicted with a pestilence.' When King Tullus Hostilius, legendary third king of Rome, contracted the illness, he became obsessed by superstitions and religious observances. In performing one of these rites in secret, the ceremony was incorrectly done, so it was said, as no divine guidance was sent to the king, who in fact, 'was struck by a thunderbolt and consumed in the flames of his house.' Livy I.XXXI.1–8 (Foster, 1919, pp. 110–113).

We have provided so much detail from this report, as it was a particularly important one, giving more discussion of the 'fall of stones' than most of the rest. It also stressed the importance of the nine days of rites, which was frequently prescribed subsequently, as Livy noted. Whether the stones were meteoritic, meteorological, or geological, is unknown. This instance suggested

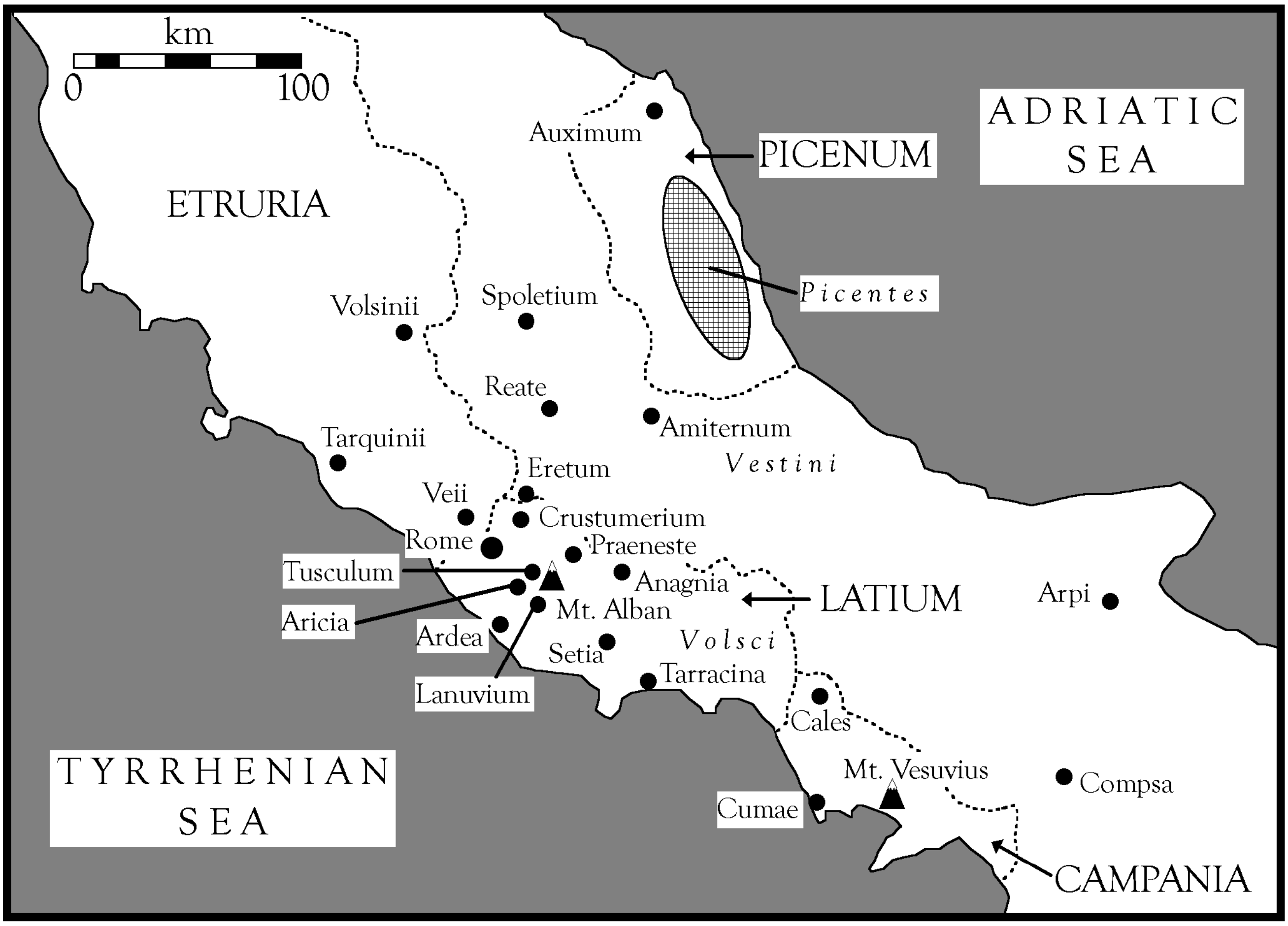

Figure 1 – A sketch-map of central Italy showing the named ancient towns and the city of Rome (filled circles), mountains (triangular symbols), regions (bounded by dashed lines and identified using capital letters), or tribal areas (in italics; the caption or shaded area approximately defines the area they were most active in), mentioned in the catalogue entries or otherwise relevant to this article. Sources included maps in the various Livy translations referred to below, plus (Treharne & Fullard, 1963, pp. 10–13) and (Scarre, 1991, pp. 168 and 172–173).

a meteorological explanation was unlikely here, given the clear negative comparison with normal hailstones, though other later stone-falls were not so straightforward. If hailstones, they may have been unusually large, as can rarely happen in a severe storm. A volcanic explanation was unlikely for Mount Alban, $\sim$ 160 km from the nearest known major volcano, Vesuvius. A shower of stones thrown by an unseen group on the mountain might be a more possible origin, especially given the political agenda of the 'mighty voice'. Stones were thrown as weapons by the Roman army, often ones rounded for the purpose, and Roman military annals did mention thrown weapons of various kinds — darts, longer spears, arrows, stones or sling-shots — falling in showers.

Whatever the case, the two events recorded in this instance, including one perfectly-timed for the arrival of witnesses, suggested a meteoritic solution for both would be highly unlikely. The belief that stones could fall from the sky in showers, and the powerful effect this might have on witnesses and those to whom the event was reported, was certainly well demonstrated, so much so that an entirely new method of expiation for this one specific class of event only, which continued for centuries afterwards, was generated as a result. The dates were those traditionally assigned to the reign of King Tullus, incidentally.

345–343 BC: On the Capitoline Hill, Rome. The dedication of the Temple to Juno Moneta 'was immediately followed by a prodigy like the one which had happened long before on the Alban Mount; for a shower of stones fell, and a curtain of night seemed to stretch across the sky'. The Sibylline Books were consulted, and sacrifices performed to avert these prodigies by the Romans and the people in the country round about. Livy VII.XXVIII.6–8 (Foster, 1924, pp. 452–455).

The shower and 'curtain of night' might suggest a stormy explanation as most plausible, with heavy, dark clouds, but the 'curtain' effect might also have been the dark dust trail from a meteoritic fireball, which may perhaps explain what the 'seemed to stretch across the sky' comment was trying to encapsulate. Oddly, no nine-day observance afterwards was mentioned, despite the explicit link with the original stone-fall on Mount Alban.

295 BC: Many places. Showers of earth fell, in a year with both a pestilence and a successful war. Livy X.XXXI.8 (Foster, 1926, pp. 478–479). If we allow that some ancient falls of stones might be meteoritic, then earth-falls, where 'earth' meant simply finely-powdered rock, could also be connected, albeit perhaps rather less likely.

218 BC: In the country of the Picentes. A shower of pebbles fell, for which a nine-day sacrifice was proclaimed. Livy XXI.LXII.5–6 (Foster, 1929, pp. 184–187).

217 BC: At Praeneste, 'glowing stones had fallen from the sky'. At Arpi, 'bucklers had appeared in the sky and the sun had seemed to be fighting with the moon'. Livy XXII.I.9–10 (op. cit., pp. 200–201). No nine-day rite was held for the fall of the glowing stones. A 'buckler' was a small, round shield, and some descriptions suggested this was used as a term for a very bright meteor on occasion. The odd context here may indicate a halo explanation, however. These two portents were part of a very long list in Livy XXII.I.8–13, with an equally long list of expiations in lines 14–20.

216 BC: On the Aventine Hill, Rome, and at Aricia, showers of stones were reported, at about the same time. Livy XXII.XXXVI.7 (op. cit., pp. 320–321). Possibly from a single meteorite shower?

215 BC: At the Temple of Juno Sospita, Lanuvium, 'images of the gods dripped blood, and it rained stones around the temple - a shower on account of which there were ceremonies, as usual, for nine days.' Livy XXIII. XXXI.15 (Moore, 1940, pp. 108–109).

214 BC: At Cales, a rain of chalk was reported. Livy XXIV.X.7 (op. cit., pp. 206–207). Chalk might be any other light coloured stone, even if the report was apparently too geologically-specific to be meteoritic.

212 BC: 'There were terrible storms; on the Alban Mount it rained stones steadily for two days.' ... 'At Reate a huge stone seemed to fly', while the Sun there seemed an unusually blood-red colour. Livy XXV.VII. 7–8 (op. cit., pp. 364–365). The stone-rain was most plausibly meteorological here. A nine-days' observance was held afterwards. The Reate flying stone was unique in Livy.

211 BC: At Eretum, a shower of stones was reported, followed by a nine-days' observance. Livy XXVI.XXIII. 5–6 (Moore, 1950, pp. 88–91).

207 BC: At Veii, and in the Armilustrum on the Aventine Hill at Rome, rains of stones were reported, expiated by two nine-day ceremonies. Livy XXVII.XXXVII. 1 & 4 (op. cit., pp. 356–359).

205 BC: Frequent showers of stones were reported from unstated locations, prompting the transfer of the Magna Mater stone from Pessinus in Phrygia to Rome. Livy XXIX.X.4–5 (Moore, 1949, pp. 244–245). We discussed these events in relation to the Magna Mater stone previously (McBeath & Gheorghe, 2005).

204 BC: At Setia, a meteor was seen 'shooting from east to west'. At an unstated location, a shower of stones was reported, following which nine days of rites were observed. Livy XXIX.XIV.2–4 (Moore, 1949, pp. 256–259).

203 BC: As cited in Section 2 above, shooting stars followed by a great meteor were seen at Anagnia. Livy XXX.II.11.

202 BC: 'At Cumae the sun was partially eclipsed and it rained stones'. On the Palatine Hill in Rome, there was also a shower of stones, after which a nine-day ceremony was held. Livy XXX.XXXVIII.8–9 (op. cit., pp. 510–511).

194 BC: At Rome, several showers of earth were reported, plus a shower of stones in the Hadriani country (location unknown). Livy XXXIV.XLV.6–8 (Sage, 1936a, pp. 534–535).

193 BC: Showers of stones were reported at Aricia, Lanuvium and on the Aventine Hill in Rome. A single nine-day sacrifice was performed as a result. Livy XXXV.IX.4–5 (Sage, 1935, pp. 24–25).

192 BC: At Amiternum, there was a shower of earth. Livy XXXV.XXI.4 (op. cit., pp. 60–61).

191 BC: At Tarracina and Amiternum several showers of stones were reported. Livy XXXVI.XXXVII.3 (op. cit., pp. 262–263). A nine-day festival to expiate these showers was held. In the same year, the new Temple to the Magna Mater was dedicated on the Palatine Hill in Rome.

190 BC: Near Tusculum, the people reported a shower of earth. Livy XXXVII.III.3 (op. cit., pp. 298–299). This featured in the first report in Obsequens too, although he had the shower fall *at* Tusculum, not simply nearby. Obsequens 1 (Schlesinger, 1967, pp. 238–239).

188 BC: On the Aventine Hill at Rome, it was said there had been a shower of stones, following which a nine-day sacrifice was held. This was recorded after the report of an eclipse, modernly dated to 188 BC July 17. Livy XXXVIII.XXXVI.4 (Sage, 1936b, pp. 118–119). Obsequens 2 pluralized the shower (Schlesinger, 1967, loc. cit.).

186 BC: '...a nine-day feast took place because in Picenum through three days there had been showers of stones, and especially because flames shining in the sky in many places were said to have set fire to the garments of many when a light breeze blew upon them.' Livy XXXIX.XXII.3 (Sage, 1936b, pp. 280–281). The description might suggest severe hail storms with much lightning. This was reinforced by Obsequens 3 (Schlesinger, 1967, pp. 238–241), who mentioned just a single stone-shower, but also that lightning bolts in many places had lightly scorched people's clothing. However, very rare reports from other, somewhat later, sources mentioned 'flames in the sky' in association with severe earthquakes, possibly due to burning material cast into the air during such an event, and although apparently unlikely, we should not ignore the possibility that this may have been a garbled account of strong meteor activity, or maybe an aurora, perhaps associated with an exaggerated meteorite shower report.

177 BC: '...a stone fell from the sky into the grove of Mars in the territory of Crustumerium'. Livy XLI.IX.5 (Sage & Schlesinger, 1938, pp. 210–211). No nine-day observance was recorded for this, most plausibly meteoritic, event.

176 BC: '...at Tusculum, a firebrand was seen in the sky'. Livy XLI.XVI.6 (op. cit., pp. 232–233). A probable bright meteor report, similar to the next entry.

174 BC: At Rome, 'a rainbow by day in a clear sky was seen extending over the temple of Saturn in the Forum Romanum, and three suns shone at once, and that same night numerous firebrands glided through the sky'. Livy XLI.XXI.12–13 (op. cit., pp. 254–255). An interesting day of bright haloes and a night of strong meteor activity, much as might appeal to many IMO members today, we felt.

173 BC: Near Veii (called by its alternate name of Remens in the text), a shower of stones was reported. Livy XLII.II.4 (op. cit., pp. 296–297). No nine-day observance was mentioned.

172 BC: At Auximum, it was reported that a shower of earth had fallen. Livy XLII.XX.6 (op. cit., pp. 348–349).

169 BC: At Anagnia, a fiery meteor was seen in the sky. At Reate, a rain of stones was reported. Livy XLIII.XIII.3–4 (Schlesinger, 1951, pp. 44–47). Near the end of the year, two showers of stones were reported, one near Rome, the other near Veii, and for both, separate nine-day rites were carried out (though apparently not for that at Reate earlier). Livy XLIV.XVIII.6 (op. cit., pp. 148–149). The late-year Veii and Roman events might have been parts of a single meteorite shower.

167 BC: At Anagnia, a rain of earth was reported. At Lanuvium, a meteor was seen in the sky. Livy XLV.XVI.5 (op. cit., pp. 296–297). Obsequens 11 (Schlesinger, 1967, pp. 244–245) called the Lanuvium event 'a blazing meteor' (*fax ardens* in the Latin text).

166 BC: At many places in Campania there was a shower of earth. At Lanuvium, a meteor was seen in the night sky. Obsequens 12 (op. cit., pp. 244–247).

163 BC: 'In Cephallenia a trumpet seemed to sound from the sky. There was a rain of earth.' Obsequens 14 (op. cit., pp. 248–249). 'Cephallenia' was probably modern Cephalonia, one of the islands west of the Greek mainland. The rain of earth probably did not occur there too, judging by other entries in Obsequens. The sound in the sky might have been due to a large meteoric event.

154 BC: 'At Compsa weapons appeared to fly through the sky.' Obsequens 17 (op. cit., pp. 250–251). Similar descriptions sometimes seemed to refer elsewhere to meteors.

152 BC: At Aricia, a rain of stones was reported. A single day of prayer was performed because of it. Obsequens 18 (op. cit., pp. 252–253). Curiously, not the usual nine-day ritual.

140 BC: 'At Praeneste and in Cephallenia it seemed that images had fallen from the sky.' Obsequens 23 (op. cit., pp. 254–255). Cephallenia was again presumably the same Greek island as mentioned in Obsequens 14, for 163 BC above. Perhaps meteoritic, or due to unusually shaped hail, or an aurora?

137 BC: 'At Praeneste a blazing meteor appeared in the sky, and there was thunder from cloudless heavens.' Obsequens 24 (op. cit., pp. 256–257). While tempting to assume the two events were related, this need not have been the case.

133 BC: At Ardea, a rain of earth was reported. Obsequens 27a (op. cit., pp. 260–261).

125 BC: 'At Arpi there was a rain of stones for three days...' Obsequens 30 (op. cit., pp. 264–265). The lacuna in the text immediately after this item was unfortunate, as it might have shed more light on a, possibly meteorological, event.

108 BC: At Rome, a firebird and an owl were seen. Obsequens 40 (op. cit., pp. 272–273). We have included this item, as some modern commentators have suggested 'firebird' (Latin *avis incendiaris*) might have been a euphemism for 'meteor'. Pliny (*Natural History* X.XVI.36; (Rackham, 1983, pp. 314–315)) discussed the firebird, but gave 107 BC as the year it and an eagle-owl appeared at Rome, necessitating the city's ritual purification. Pliny noted the bird as one of ill-omen, but he continued, 'What this bird was I cannot discover, and it is not recorded.' He reported the opinions of others that it might have been any bird seen taking a coal from a fire-altar, or it might have been a 'spinturnix', but no one could say what such a name meant or referred to. Overall, Pliny's commentary did not support a meteoric view, but we should perhaps not dismiss the possibility entirely.

106 BC: At an unspecified location, 'An uproar in the sky was heard, and javelins seemed to fall from heaven.' At Rome, a meteor was seen flying over in daylight. Obsequens 41 (Schlesinger, 1967, pp. 272–274). Meteors and comets were sometimes described as weapons of various kinds, but whether this was what 'javelins' here meant is unknown. Perhaps a large, fragmenting fireball, through to something entirely non-meteoric?

104 BC: At an unstated place, 'Weapons in the sky seemed to join in battle at both times of day from east and west; those from the west appeared to suffer defeat.' The soothsayers advised this portent be averted by a collection of gifts, brought by twenty-seven maidens to the goddesses Ceres and Proserpina. Obsequens 43 (op. cit., pp. 274–277). This event might have been meteoric, or auroral, or something else entirely. As the modern footnotes identified, the odd 'both times of day' phrasing might have meant 'by day and night' or 'night and morning'. The number of virgins had great mystical significance, being 3^3, while the two goddesses were both associated with the cyclical growth of agricultural crops.

102 BC: In Etruria, a rain of stones was reported, and a nine-day ceremony was held afterwards to purify the city: 'The ashes of the victims were scattered in the sea by the Board of Ten, and for nine days a procession of suppliants was led by magistrates about all the temples and the outlying towns.' Obsequens 44 (op. cit., pp. 276–277). An interesting, rare, sketch of one of the nine-day ceremonies. The 'victims' were animals sacrificed to one or other deity, and burnt, while the 'Board of Ten', or *decemviri*, was the college of Roman priests who guarded and consulted the Sibylline Books, as we described in (McBeath & Gheorghe, 2005). It is interesting too that although the portent occurred in Etruria, it was necessary to ritually cleanse the city of Rome and its nearby towns.

101 BC: In Rome: 'The sacred shields rattled and moved of their own accord. A slave of Quintus Servilius Caepio emasculated himself in devotion to the Great Mother, and was shipped across the sea, that he might never return to Rome. The city was purified.' Obsequens 44a (Schlesinger, 1967, pp. 278–279). While not meteoric directly, we have included these two items as they provided some follow-up to items we discussed previously, in (McBeath & Gheorghe, 2005): the ancilia, based on the original sky-fallen sacred shield, the Ancile; and the potentially meteoritic stone of the Magna Mater, or Great Mother.

100 BC: 'A blazing meteor was seen far and wide at Tarquinii, falling in a sudden plunge. At sunset a circular object like a shield was seen to sweep across from west to east.' Obsequens 45 (Schlesinger, 1967, pp. 278–281). 'Shield' was sometimes used to describe apparently very bright meteoric objects elsewhere. The location of this event was not stated.

98 BC: At Rome, 'During a festival it rained white chalk in the theatre; this foretold good crops and good weather. There was thunder from a clear sky.' Obsequens 47 (op. cit., pp. 282–283). Theatres were open to the sky in Roman times. Whether the chalk-fall and the thunder were related is unknown.

94 BC: Among the Volsci, a rain of stones was reported. A nine-day ceremony was held as a result. Elsewhere, a firebird was seen and killed. Among the Vestini, stones rained down inside a villa. Somewhere else, a meteor was seen, 'and the whole sky appeared to be on fire.' Obsequens 51 (op. cit., pp. 286–287). The firebird here seemed decidedly non-meteoric, while the lone 'meteor' might have been used in its earlier sense of anything in the sky, with the event actually an auroral display.

93 BC: A nine-day ceremony was mentioned at an unspecified place, but no fall of stones was listed. 'At Volsinii flame was seen to flash from the sky at dawn; after it had gathered together, the flame displayed a dark grey opening, and the sky seemed to divide; in the gap tongues of flame appeared.' Obsequens 52 (op. cit., pp. 288–289). While the Volsinii event at first resembled a meteor's description, the rest was much more auroral in character.

92 BC: A meteor was reported in the sky at an unstated place. Obsequens 53 (loc. cit.).

91 BC: Probably at Rome, 'About sunrise a ball of fire flashed forth from the northern heavens with a great noise in the sky.' ... 'Among the Vestini there was a rain of stones and sherds for seven days.' No nine-day ritual was reported. 'Near Spoletium a gold-coloured fireball rolled down to the ground; increased in size, it seemed to move off the ground towards the east, and was big enough to blot out the sun.' Obsequens 54 (op. cit., pp. 290–291). The Spoletium event was probably ball-lightning, although it may have been a garbled version of a meteoric fireball instead. The seven-day stone-and-sherd rain, if not simply an exaggeration, would have been a most unlikely meteoritic happening. It might be that the usual nine-day rites were shifted in an abbreviated form to the duration of the event in error.

88 BC: 'From cloudless air and a wide expanse of clear sky, the blast of a trumpet was heard, uttering a shrill and lamentable sound. Those who heard it were one and all beside themselves with fear. But the Etruscan soothsayers pronounced that the portent indicated a change of the race and a new era.' Livy, fragment 15a from Book LXXVII (op. cit., pp. 184–187). This was not repeated by Obsequens. No location for it was stated, but it was associated with the outbreak of the Roman civil war, so was most likely at Rome. Obsequens instead reported that in this year at 'stratopedon' (an unknown place(?)-name, but probably from the island of Rhodes, off south-west modern Turkey), 'a huge star fell from the sky.' Obsequens 56 (op. cit., pp. 292–295).

87 BC: During the civil war, at Rome, 'the sky seemed to fall' on the camp of Gnaeus Pompeius, and he himself 'perished by the blast of a heavenly body.' Obsequens 56a (op. cit., pp. 294–295). While floridly vague here, other authors suggested the camp and Pompeius were struck by lightning.

44 BC: At an unstated site, a meteor was seen to travel westwards in the sky. Obsequens 68 (op. cit., pp. 308–313). This reference included a long list of the portents recorded following Caesar's death, including the famous comet said to have been Caesar's soul ascending to heaven by some (see for instance (Gheorghe & McBeath, 2003)). Obsequens said only that the comet was dedicated to the deified Julius.

43 BC: At an unspecified location, 'A vision of armour and weapons seemed to rise with a crash from earth to heaven.' Obsequens 69 (Schlesinger, 1967, pp. 312–313). But for the sound, more like the description of a potential aurora, although meteors as weapons might have been an alternative possibility.

17 BC: At an unnoted site, 'A meteor reaching from south to north made night as bright as the light of day.' Obsequens 71 (op. cit., pp. 318–319).

4 Conclusion

The reports of events presented here from Livy and Obsequens were not always readily identifiable, and their number is difficult to visualise spatially and temporally. Consequently, a follow-up article will give an analysis to assist in this, with some further discussion.

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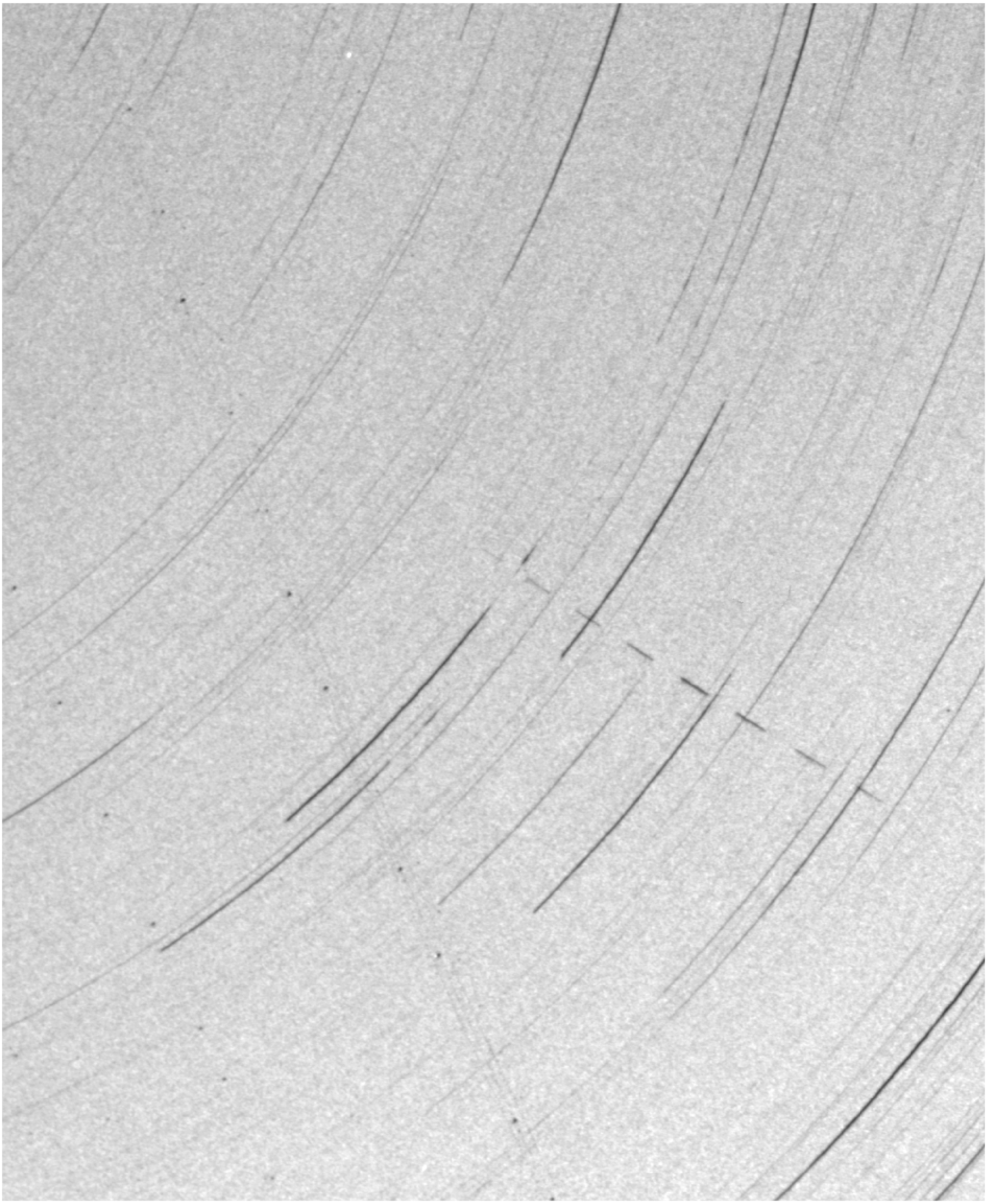

Part of an all-sky photograph from the Přimda station of the Czech fireball network, showing the EN 051005B fireball. The meteor flew from bottom-right to top-left. The meteor image has been interrupted by the rotating shutter 15 times per second. The star trails have been interrupted by passing clouds. The photo was taken with a Zeiss Distagon 3.5/30 mm fish-eye lens using 9×12 cm sheet film. The film was exposed on 2005 October 5/6, from $19^h18^m15^s$ to $03^h54^m22^s$ UT. Photo J. Macura. For further details, see the paper on page 85.