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Leonids
Conferences
Fireballs
Photographic networks

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Administrative

Leonids

Ongoing meteor work

History

Front cover photo

An $m = -6$ Geminid bolide in Canis Major, near β CMa (Mirzam). Photograph by Valentin Grigore, SARM. Taken from Priboiu-Târgovişte, Romania, on 2006 Dec 13/14 at $00^{\mathrm{h}}17^{\mathrm{m}}03^{\mathrm{s}}$ UT. Camera: Canon T70 with $f = 50$ mm, $f/1.4$ Canon lens. Film: Konica VX400.

Writing for WGN This Journal welcomes papers submitted for publication. All papers are reviewed for scientific content, and edited for English and style. Instructions for authors can be found in WGN **31:4**, 124–128, and at `http://www.imo.net/articles/writingforwgn.pdf` .

Cover design Rainer Arlt

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Janus

Paul Roggemans [1]

When I started with systematically observing meteors in 1975, Dirk Artoos (IMO-member of the first hour) had gathered some experience before and taught me all about limiting magnitudes, radiants, etc. The typical beginners questions were easily answered, but more advanced questions remained without an answer as almost no information was available. The only motivation to keep my interest with meteors was the idea that I could do something useful. It was a big disappointment as 16 year old amateur astronomer, to discover that there existed no international co-ordination in this field. Looking for a good book about meteors in 1975 ended in an unsuccessful search for Lovell's 'Meteor Astronomy' published in 1954 which wasn't anywhere for sale anymore. There was almost nothing for meteor observers!

Unhappy about the poor situation of amateur meteor work worldwide, I started correspondence with meteor observers abroad. It was a real delight when I learned about circulars such as 'Meteor News', 'Meteoros', 'De Meteoor', etc.; at least something existed about meteors! The lack of co-operation and co-ordination of efforts was obvious and this inspired me to do something about the unfortunate situation of amateur meteor astronomy. My correspondence, s-mail in that time, acquired industrial proportions, keeping contact with just about anyone observing meteors and willing to answer my letters.

In 1978 there was a first attempt to negotiate co-operation on bases of national structures. This led to the creation of FEMA, the Federation of European Meteor Astronomers. A noble project, but doomed to fail as each national group focussed on the national benefit not on the overall general interest. With FEMA, first steps were made to introduce standard plotting maps and observing forms. Some correspondence about the preparation of the first 'Meteor Seminar' in Knigswinter, Germany (which evolved into the legendary IMCs) was written on letter paper with the FEMA-logo. WGN served as an economic way to re-distribute the gold-mine of meteor data that I derived from correspondence towards all correspondents, so that everyone could share the information.

The FEMA went by unnoticed about 1982, but because of very successful observing campaigns the ambition for a real international structure grew stronger. The International Halley Watch was unsuccessful as far as meteor observations are considered due to the chronic lack of any structure to co-ordinate meteor work. When at the end of 1987 the formal creation of the 'International Meteor Organization' was announced, most personalities of the meteor scene joined in as founding members. Only a few individuals were against, because they felt IMO would harm their personal prestige and a couple of national meteor groups felt their national interests endangered. However, it was time to move forward with the people of goodwill. Diplomacy turned into polemic discussions without purpose which IMO ignored in order to focus its effort on positive constructive co-operation. It is a pity that the start wasn't smooth as IMO did not damage anybody's interests whatsoever, on the contrary. It took years to convince everybody, but time meanwhile has done its work.

Today IMO makes a fabulous contrast with the situation 30 years ago. WGN grew into a real scientific reference for meteor workers and the IMC got a legendary fame with its unique mixture of science, culture and creativity. Any young amateur seriously interested in meteors now finds in IMO what they would have searched for in vain some 30 years ago. The information offered by WGN and other IMO-publications, the facilities offered at IMCs and spin-offs of the solid international co-operation, make a difference of many years for any newcomer to get started. Whereas 30 years ago we lost years in getting basic matter sorted out, time and energy of newcomers are spent in a much more efficient way now. We should pay attention to the history of meteor astronomy to understand the importance of the IMO, the challenges and the struggles it took to achieve the current comfortable facilities. IMO has marked the history of meteor astronomy in a way that situations such as in the 1960's and 1970's become most unlikely, but ... there is no absolute guarantee for the future of meteor astronomy.

Every meteor observer can contribute to help to promote meteor work, the IMCs and the IMO. You have a treasure of information available in WGN, the various IMO publications and the IMO website. Act as intermediary, translate and write for your local astronomical society about meteors and help the image of IMO. Speak about meteors, show the impressive achievements of worldwide co-operation to amateurs in your country. The future of amateur astronomy is in your hands, leave no chance unused to get the spotlight on meteors wherever you can!

Janus *was a Roman god with two faces, one looking to the past and one to the future, called upon at the beginning of any enterprise. Today he is often a symbol of re-appraisal at the start of the year.*

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Editorial — Different IMC arrangements

Chris Trayner

This year's International Meteor Conference will be held in France, but in June, not September as usual. This change was made to allow it to be held in conjunction with (actually just before) Meteoroids, one of the most important professional conferences for meteor science. The decision was not taken lightly, but after much discussion and canvassing opinion.

One effect of this is that all arrangements have to be made about three months earlier. WGN, with its two-month publishing cycle, becomes a less useful medium for distributing information. Fortunately, most or all potential participants have access to the Word-Wide Web; indeed, most IMC bookings have been made online for the last couple of years.

Anyone wishing to go to IMC 2007 — and these conferences are great experiences — should visit the organsiers' website at `http://www.imo.net/imc2007/` to find the information they need and to book. Please try to register quickly, especially if you want to travel with all the group from Bareges to Barcelona on June 10th. Questions and comments can be sent to the organisers at `imc2007@imo.net` .

For many years now, the IMO has offered a support fund for people who wish to attend IMC but find the expenses hard to afford. This fund is available this year, but again the arrangements will be made by internet to save time. Details are on the next page.

IMO bibcode WGN-351-editorial NASA-ADS bibcode 2007JIMO...35....2T

From the President

Jürgen Rendtel [1]

The year 2006 was another successful year for the IMO with numerous activities which deserve to be mentioned. Our Journal WGN is the backbone of the communication of projects and results. Here we regularly publish and learn about results from meteor observations carried out with different techniques.

Comprehensive analyses of data collected from different showers lead to a better understanding of their characteristics. Based on such investigations, a new working list of meteor showers was introduced in the middle of 2006. This topic was also presented during the very encouraging and successful IMC in September in Roden, the Netherlands. An analysis of video meteor data confirmed the data of the list which is currently in use. Furthermore, a number of additional radiants were detected from the video data. Some verification work is needed before the working list is extended. At the same time a working group on meteor shower designation was established by the IAU Commission 22, further emphasizing that the questions connected with meteor shower identification and dseignation are of great interest.

While it is known that immediate visual reports allow a fast overview over the activity of meteor showers, a new project of instantaneous ZHR analysis was introduced for the Leonids and Geminids in 2006. Using an on-line form, the observer could immediately see the ZHR graph growing. This way the number of fast reports grew and I found this a very fascinating and encouraging way to stimulate visual observations.

Another aspect is the better knowledge of things managed through the IMO Council. For this purpose we published reports about Council matters in WGN in several issues of 2006. Hopefully, this increases the interest in such items which are necessary and important for our organization.

In 2007, we have a good opportunity to increase the interaction between professional and amateur meteor workers because the IMC and the Meteoroids 2007 conferences are in close conjunction in Bareges (France) and Barcelona (Spain). I look forward to meeting many people at both occasions leading to interesting talks and joint projects.

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IMO bibcode WGN-351-rendtel-president NASA-ADS bibcode 2007JIMO...35....2R

Financial support for IMC2007 participants

Jürgen Rendtel

As last year, *IMO* is making funds available to support attendance at the *IMC* 2007. To apply for support:

1. E-mail your application to *IMO* President Jürgen Rendtel, at `president@imo.net`. Include the word 'Meteor' in the subject line to get round the anti-spam filters. *IMO* cannot be held responsible for applications which are lost or arrive late. The application must be submitted by an *IMO* member, but may also request support for other meteor workers. The proposal must state that all the candidates are committed to attend the *IMC* (except for unforeseen circumstances) if the requested support is granted in full.
2. Include an *IMC* Registration Form for everyone seeking support (unless already sent).
3. Include a brief curriculum vitae of everyone seeking support, focusing on aspects relevant to meteor work. Supported participants are expected to present either a talk or a poster at the *IMC*. (Indicate this on the Registration Form.)
4. The application must explain the motivation for attending the *IMC* and the importance of it to the person or group of persons requesting support.
5. Include a budget for travel costs and registration, and the amount of support requested. Other sources of external support, or their absence, must be mentioned. The proposal must indicate to what extent *IMO* support is essential to attend the *IMC*.
6. The applications should reach the President no later than 2007 March 31. The decision of the *IMO* Council will be made as soon as possible, probably within two weeks after this deadline. If the support is granted in full, the registration form becomes final. If the requested support is not granted, or only partially granted, the candidates should inform the President within three weeks after notification of the *IMO* Council's decision if they want to sustain or withdraw their registration. The support granted will be paid in cash at the *IMC*. Any unpaid registration fees will be deducted from the amount paid to the candidates.

Should the application be turned down, the standard conference fee (i.e. €120, without the surcharge for a late application) will still apply. We strongly encourage all meteor workers who want to attend the *IMC* 2007, but who are prevented from doing so by financial considerations, to apply for support.

IMO bibcode WGN-351-rendtel-imcsupport NASA-ADS bibcode 2007JIMO...35....3R

Solar Longitudes for 2007

Compiled by Rainer Arlt

A conversion table of dates to solar longitudes using (Steyaert, 1991) is given as every year. The longitudes are given on the next page; they are only valid for 2007. The conversion formulae for any time of the day are repeated here for your convenience.

If you want to calculate the solar longitude $\lambda_\odot$ of a specific time of the day, you may use a linear interpolation between two dates. Suppose you have a certain *Date* and the *Time* in hours (UT), you get the solar longitude by

$$\lambda_\odot = \lambda_{\odot,\mathrm{Date}} + (\lambda_{\odot,\mathrm{NextDay}} - \lambda_{\odot,\mathrm{Date}}) \times \frac{\mathrm{Time}}{24\ ^{\mathrm{h}}}.$$

Alternatively, if you want to convert a certain solar longitude $\lambda_\odot$ into a time of the day, look up the *Date* with the next-smaller solar longitude in the table and calculate

$$\mathrm{Time} = \frac{(\lambda_\odot - \lambda_{\odot,\mathrm{Date}})}{(\lambda_{\odot,\mathrm{NextDay}} - \lambda_{\odot,\mathrm{Date}})} \times 24\ ^{\mathrm{h}}.$$

The solar longitudes of 1988–2020 are given in two-hour increments and with three decimals at `http://www.imo.net/data/solar`.

IMO bibcode WGN-351-arlt-solarlong
NASA-ADS bibcode 2007JIMO...35....3A

References

Steyaert C. (1991). "Calculating the solar longitude 2000.0". *WGN*, **19:2**, 31–34.

Solar longitudes 2007. Dates refer to 00^h UT.

Jan	1	280.08	Mar	1	339.92	May	1	40.16	Jul	1	98.72	Sep	1	158.10	Nov	1	218.07
Jan	2	281.10	Mar	2	340.92	May	2	41.13	Jul	2	99.67	Sep	2	159.06	Nov	2	219.08
Jan	3	282.12	Mar	3	341.92	May	3	42.10	Jul	3	100.62	Sep	3	160.03	Nov	3	220.08
Jan	4	283.13	Mar	4	342.93	May	4	43.07	Jul	4	101.58	Sep	4	161.00	Nov	4	221.08
Jan	5	284.15	Mar	5	343.93	May	5	44.04	Jul	5	102.53	Sep	5	161.97	Nov	5	222.08
Jan	6	285.17	Mar	6	344.93	May	6	45.01	Jul	6	103.48	Sep	6	162.94	Nov	6	223.08
Jan	7	286.19	Mar	7	345.93	May	7	45.98	Jul	7	104.44	Sep	7	163.91	Nov	7	224.09
Jan	8	287.21	Mar	8	346.93	May	8	46.94	Jul	8	105.39	Sep	8	164.88	Nov	8	225.09
Jan	9	288.23	Mar	9	347.93	May	9	47.91	Jul	9	106.34	Sep	9	165.85	Nov	9	226.09
Jan	10	289.25	Mar	10	348.93	May	10	48.88	Jul	10	107.30	Sep	10	166.82	Nov	10	227.10
Jan	11	290.27	Mar	11	349.93	May	11	49.85	Jul	11	108.25	Sep	11	167.79	Nov	11	228.10
Jan	12	291.29	Mar	12	350.93	May	12	50.81	Jul	12	109.20	Sep	12	168.77	Nov	12	229.11
Jan	13	292.30	Mar	13	351.93	May	13	51.78	Jul	13	110.16	Sep	13	169.74	Nov	13	230.11
Jan	14	293.32	Mar	14	352.93	May	14	52.74	Jul	14	111.11	Sep	14	170.71	Nov	14	231.12
Jan	15	294.34	Mar	15	353.92	May	15	53.71	Jul	15	112.07	Sep	15	171.69	Nov	15	232.13
Jan	16	295.36	Mar	16	354.92	May	16	54.67	Jul	16	113.02	Sep	16	172.66	Nov	16	233.14
Jan	17	296.38	Mar	17	355.92	May	17	55.64	Jul	17	113.97	Sep	17	173.64	Nov	17	234.14
Jan	18	297.40	Mar	18	356.91	May	18	56.60	Jul	18	114.93	Sep	18	174.61	Nov	18	235.15
Jan	19	298.42	Mar	19	357.91	May	19	57.57	Jul	19	115.88	Sep	19	175.59	Nov	19	236.16
Jan	20	299.44	Mar	20	358.90	May	20	58.53	Jul	20	116.84	Sep	20	176.57	Nov	20	237.17
Jan	21	300.45	Mar	21	359.90	May	21	59.49	Jul	21	117.79	Sep	21	177.54	Nov	21	238.18
Jan	22	301.47	Mar	22	0.89	May	22	60.45	Jul	22	118.75	Sep	22	178.52	Nov	22	239.19
Jan	23	302.49	Mar	23	1.88	May	23	61.42	Jul	23	119.70	Sep	23	179.50	Nov	23	240.20
Jan	24	303.51	Mar	24	2.87	May	24	62.38	Jul	24	120.66	Sep	24	180.48	Nov	24	241.21
Jan	25	304.52	Mar	25	3.87	May	25	63.34	Jul	25	121.61	Sep	25	181.45	Nov	25	242.22
Jan	26	305.54	Mar	26	4.86	May	26	64.30	Jul	26	122.57	Sep	26	182.43	Nov	26	243.23
Jan	27	306.56	Mar	27	5.85	May	27	65.26	Jul	27	123.52	Sep	27	183.41	Nov	27	244.24
Jan	28	307.57	Mar	28	6.84	May	28	66.22	Jul	28	124.48	Sep	28	184.39	Nov	28	245.25
Jan	29	308.59	Mar	29	7.83	May	29	67.18	Jul	29	125.43	Sep	29	185.38	Nov	29	246.26
Jan	30	309.60	Mar	30	8.82	May	30	68.14	Jul	30	126.39	Sep	30	186.36	Nov	30	247.28
Jan	31	310.62	Mar	31	9.80	May	31	69.10	Jul	31	127.34						
Feb	1	311.63	Apr	1	10.79	Jun	1	70.06	Aug	1	128.30	Oct	1	187.34	Dec	1	248.29
Feb	2	312.65	Apr	2	11.78	Jun	2	71.01	Aug	2	129.26	Oct	2	188.32	Dec	2	249.30
Feb	3	313.66	Apr	3	12.76	Jun	3	71.97	Aug	3	130.21	Oct	3	189.31	Dec	3	250.32
Feb	4	314.68	Apr	4	13.75	Jun	4	72.93	Aug	4	131.17	Oct	4	190.29	Dec	4	251.33
Feb	5	315.69	Apr	5	14.73	Jun	5	73.89	Aug	5	132.13	Oct	5	191.27	Dec	5	252.35
Feb	6	316.70	Apr	6	15.72	Jun	6	74.84	Aug	6	133.08	Oct	6	192.26	Dec	6	253.36
Feb	7	317.72	Apr	7	16.70	Jun	7	75.80	Aug	7	134.04	Oct	7	193.25	Dec	7	254.38
Feb	8	318.73	Apr	8	17.69	Jun	8	76.76	Aug	8	135.00	Oct	8	194.23	Dec	8	255.39
Feb	9	319.74	Apr	9	18.67	Jun	9	77.71	Aug	9	135.96	Oct	9	195.22	Dec	9	256.41
Feb	10	320.76	Apr	10	19.65	Jun	10	78.67	Aug	10	136.92	Oct	10	196.21	Dec	10	257.42
Feb	11	321.77	Apr	11	20.63	Jun	11	79.63	Aug	11	137.88	Oct	11	197.20	Dec	11	258.44
Feb	12	322.78	Apr	12	21.61	Jun	12	80.58	Aug	12	138.84	Oct	12	198.19	Dec	12	259.46
Feb	13	323.79	Apr	13	22.60	Jun	13	81.54	Aug	13	139.80	Oct	13	199.17	Dec	13	260.47
Feb	14	324.80	Apr	14	23.58	Jun	14	82.49	Aug	14	140.76	Oct	14	200.16	Dec	14	261.49
Feb	15	325.81	Apr	15	24.56	Jun	15	83.45	Aug	15	141.72	Oct	15	201.16	Dec	15	262.51
Feb	16	326.82	Apr	16	25.54	Jun	16	84.41	Aug	16	142.68	Oct	16	202.15	Dec	16	263.53
Feb	17	327.83	Apr	17	26.51	Jun	17	85.36	Aug	17	143.64	Oct	17	203.14	Dec	17	264.54
Feb	18	328.84	Apr	18	27.49	Jun	18	86.32	Aug	18	144.60	Oct	18	204.13	Dec	18	265.56
Feb	19	329.85	Apr	19	28.47	Jun	19	87.27	Aug	19	145.56	Oct	19	205.12	Dec	19	266.58
Feb	20	330.86	Apr	20	29.45	Jun	20	88.23	Aug	20	146.52	Oct	20	206.12	Dec	20	267.60
Feb	21	331.87	Apr	21	30.43	Jun	21	89.18	Aug	21	147.49	Oct	21	207.11	Dec	21	268.61
Feb	22	332.88	Apr	22	31.40	Jun	22	90.14	Aug	22	148.45	Oct	22	208.10	Dec	22	269.63
Feb	23	333.89	Apr	23	32.38	Jun	23	91.09	Aug	23	149.41	Oct	23	209.10	Dec	23	270.65
Feb	24	334.89	Apr	24	33.35	Jun	24	92.04	Aug	24	150.38	Oct	24	210.09	Dec	24	271.67
Feb	25	335.90	Apr	25	34.33	Jun	25	93.00	Aug	25	151.34	Oct	25	211.09	Dec	25	272.69
Feb	26	336.90	Apr	26	35.30	Jun	26	93.95	Aug	26	152.30	Oct	26	212.09	Dec	26	273.71
Feb	27	337.91	Apr	27	36.27	Jun	27	94.90	Aug	27	153.27	Oct	27	213.08	Dec	27	274.72
Feb	28	338.91	Apr	28	37.25	Jun	28	95.86	Aug	28	154.23	Oct	28	214.08	Dec	28	275.74
			Apr	29	38.22	Jun	29	96.81	Aug	29	155.20	Oct	29	215.08	Dec	29	276.76
			Apr	30	39.19	Jun	30	97.76	Aug	30	156.16	Oct	30	216.08	Dec	30	277.78
									Aug	31	157.13	Oct	31	217.08	Dec	31	278.80

Leonids

Leonid predictions for the period 2001–2100

Mikhail Maslov [1]

This article provides a set of summaries of what to expect from the Leonid meteor shower for each year of the period 2001–2100. Each summary contains the moments of maximum/maxima, their expected intensity and some comments about average meteor brightness during them. Special attention was paid to background (traditional) maxima, which are characterized with their expected times and intensities.[1]

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1 Introduction

Today meteor shower activity remains one of the most unpredictable astronomical phenomena. Scientists have learned how to make very detailed predictions of such events as solar and lunar eclipses and planetary transits across the Sun. Evolution of the main bodies in the Solar system can be computed for many thousands of years into the past and future; for asteroids such computations are made for at least hundreds of years (the most important purpose being to search for those of them which can collide with the Earth). At the same time, meteor showers, whose activity in astronomical terms occurs literally next to the Earth, continue to surprise us.

During many decades meteor astronomers tried to predict meteor activity using various criteria. But it was a form of guessing. In some cases their expectations were realized, although often meteor activity anyway caused surprise in some aspects (for example, occurring at unexpected times or giving strong fireball activity). Sometimes such forecasts proved to be completely wrong.

The method of meteor activity prediction by computing meteor particle orbital evolution after ejection by a comet become more widespread in the 1990s. Earlier its use was restricted by the low computing abilities of computers. But such Russian forecasters as V.V. Reznikov and E.A. Emel'yanenko had already issued their computations for the Leonids, Draconids, Bielids and some other showers. By the end of the 1990s, when computers became powerful enough, several researchers — Robert MacNaught, David Asher and Esko Lyytinen — published their predictions of Leonid activity for several years nearest to the date of publication.

Of course, mainly due to the lack or inaccuracy of initial orbital elements of parent comets, as well as probable imperfections in the method itself, its reliability is still lower than desired. Serious faults in the accuracy of the time of maximum and especially the intensity of outbursts are still typical for meteor predictions, as well as cases of their failure (the last such situation was with predicting the activity of the Draconids for 2005). Nevertheless, it is obvious that this method is a large step forward compared to predictions based on the distances between the Earth's orbit and the orbital nodes of parent comets and times of their passage by the Earth.

Observational data allowed a model to be built for the calculation of the expected ZHR of meteor outbursts. Such a model, created by E. Lyytinen and T. van Flandern, was taken by us as the base for the computation of the expected intensity of Leonid outbursts.

The results of other researchers in the field of Leonid activity prediction (as well as many other showers) should not be ignored. The author is familiar with predictions by E. Lyytinen and T. van Flandern for a number of years after the comet 55P perihelion in 1998, excellent graphic predictions by J. Vaubaillon (for many Leonid returns in the 19th to 21st centuries, but mainly for around the 1998 and 2031 returns), predictions by D. Asher and R. McNaught (in particular, they were the first who pointed out the probable Leonid enhancements in 2006 and 2007), computations by M. Sato (who helped the author in coordination and refinement of some predictions), and results by I. Sato for a large number of years in the 19th to 21st centuries. This list is far from full, and we apologize to those, who were omitted due to our ignorance. We hope that these prepared predictions will be a good addition to the results of these authors, and the reader will expand his/her knowledge about such a great shower as the Leonids.

2 The Leonid shower

The Leonids are a meteor shower known for its variable activity. The years around parent comet 55P Tempel-Tuttle's returns gave considerable activity enhancements, sometimes up to storm levels. The latest perihelion of 55P was in 1998 and now it is moving to the outer areas of Solar system — its aphelion lies beyond the orbit of Saturn. Significant enhancements in Leonid activity were recorded during the period 1994–2003. In 1999, 2001 and 2002 the shower gave several storms, when the ZHR reached 3000–4000 (ZHR — zenithal hourly rate — the average number of shower meteors an observer can see during one hour when its radiant is directly overhead and stars to 6.5 mag. are visible). In 2003 and 2004 activity was slightly above

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[1] This is a shortened version of Leonid predictions. Full information is available on the author's Web page: http://feraj.narod.ru/Radiants/Predictions/predicteng.html .

the background level with ZHRs of 60 and 28, respectively (background activity is shown by the Leonids in their 'quiet' years, it usually reaches ZHR=10–20).

All main peaks of Leonid activity are traced very well with the use of meteor particle evolution modeling. Particles ejected by the comet form lengthy trails. One of the reasons is the radiation pressure force, which acts along with gravitational forces. Gravitational force depends on a particle's mass, i.e. it is proportional to the third power of the particle's radius. The radiation pressure varies as the second power of particle radius. So the influence of radiation pressure is relatively large for smaller particles. Its action is equivalent to a reduction of the gravitational constant G. So it increases the orbital period of particles, and the tinier a particle is, the more it is continuously retarded from larger particles after their ejection by the parent comet. This process therefore leads to the formation of lengthy comet trails.

Meteor modeling is done through computation of the orbital evolution of particles ejected by a comet with different velocities in directions tangential to the comet trajectory at the moment of perihelion. In reality, of course, particles are ejected not only at the point of perihelion, but also during several months around it. However, comets are in the perihelion part of their orbits for quite a short time compared to their overall orbital period and the main perturbations happen around their aphelia; so when comets are close to the Sun, newly ejected particles move very close to them in a compact dust cloud. This is the reason the cloud can be considered as being completely ejected at the point of perihelion, with virtually no influence on the results of computations.

Speaking of the directions in which particles are ejected, it should be underlined that, again, in reality they are ejected not only in tangential directions but in all possible ones. However, ejection velocities (from 0 to 100 m/s, and the overwhelming majority of real ejections are from 0 to 20 m/s (Lyytinen & van Flandern, 1998)) are negligibly small compared to the comet's own velocity (from 30 to 40 km/s near the Earth's orbit), ejected particles have only slightly changed orbits and do not 'fly away in all directions'. The radial part of ejection velocity defines only the thickness of a trail, which usually reaches several hundred thousand kilometers. The shape of the trail is defined by the tangential part of ejection velocity.

Finally, non-gravitational forces are often not taken into consideration in meteor calculations, as in our case. However some of them, say, radiation pressure, can be considered indirectly. As far as this kind of force works as a diminishing of the gravitational constant G, this is equivalent to an increase of ejection velocity which could be easily incorporated in the model. So this non-gravitational force like many others does not change the configuration of the trails, but leads to a shifting of particles with different masses along these trails.

As already stated, Leonid trail modeling has allowed the preparation of very good predictions of shower activity around the latest comet perihelion. Real maxima differed from the predicted ones mostly by no more than 10–15 minutes — not very much considering that computations are made for several hundreds years of particle movement. Also successful post-predictions were done for Leonid outbursts in the past, for example, for the famous storm in 1966. A more serious problem is the prediction of outburst intensity — how strong the maximum could be. For such predictions special empirical models were elaborated (the only way in this case) but as before for their improvement new observations are necessary.

The results the author obtained for predicted past and future Leonid showers during the period 2001–2100 are presented in this paper. Predictions were done for each year in the period mentioned, and, as this work is finished in 2006, it contains 'real' predictions for the years 2006–2100, while for the years 2001–2005 'post-predictions' were compiled. Also, although the models used in computations are based after all on meteor observations of real activity in the past, no comparisons for each year between the elaborated predictions and respective real Leonid activity are made.

3 Computation characteristics

This paper presents the results of the Leonid meteor stream simulation aimed at predicting its meteor activity in 2001–2100. The simulation was made for the trails of 30 past revolutions and 2 future ones, i.e. beginning from the 1001 trail, and partially for three earlier ones, i.e. the 901, 935 and 967 trails. The two future trails are the 2031 and 2065 ones. The author used the program COMET'S DUST 2.0 created by S. Shanov and S. Dubrovsky to calculate orbital elements of ejected meteor particles. To estimate expected ZHRs for different encounters the model built by E. Lyytinen and T. van Flandern was used with some author's alterations made in order to adopt the model for ejection velocity (Vej) instead of da0 (difference in a, the major semiaxis) as well as to correct the fn function to consider factual Leonids activity during recent storms and outbursts. The computation considered only gravitational forces, but the results are on the whole in good accordance with those of other researchers. The prediction includes all encounters found within the range ± 0.007 AU. The following parts of trails were computed: the first 5 rev. trails for ejection velocities [-50;100] m/s, 6–10 rev. trails for [-30;50] m/s, 10–20 rev. trails for [-20;30], older than 20 rev. trails for [-10;20] m/s.

4 Leonids 2001–2101

In 2001 a strong background maximum is expected. At 08^{h} UT 17 November activity will rise to 40–50 meteors on the ZHR scale. Also, a number of outbursts from trails are expected. The first will be a small increase from the 1965 trail. It will happen at $12^{h}49^{m}$ UT 17 November, the ZHR will rise to 30–40 meteors with a lowering of their average brightness. The next strong outburst will occur at $10^{h}25^{m}$ UT 18 November. It will be caused by the 1767 trail, its intensity will be 550–600 meteors on the ZHR scale, and brightness will be on the average level or slightly above it. After that a

Table 1 – Orbit of the comet 55P in 1901–2100.

Time of perihelion	q AU	e	AOP	Node	i	Min. dist. AU	$\lambda_\odot$
1932.07.12.7024	0.9785688	0.9051097	172°.68761	235°.06108	162°.70792	−0.0061323	234°.86925
1965.04.30.0078	0.9816245	0.9044541	172°.56352	235°.11505	162°.70653	−0.0030093	235°.02198
1998.02.28.0970	0.9765868	0.9055202	172°.49739	235°.25826	162°.48612	−0.0079092	235°.00813
2031.05.24.1519	0.9644153	0.9077893	172°.86186	235°.60482	162°.57237	−0.0202647	234°.95046
2065.03.19.6790	0.9677816	0.9072625	173°.83873	236°.74127	162°.52970	−0.0176772	236°.27196
2098.06.03.6488	0.9790155	0.9052530	174°.02966	236°.95791	162°.50368	−0.0066467	236°.80005

Initial orbital elements of 55P, starting from perihelion of 901 and up to 1998 are taken from Nakano's site (Nakano, 1999). Orbital elements for perihelia in 2031, 2065 and 2098 are generated by the program Comet's Dust 2.0 (by S. Shanov and S. Dubrovsky). Orbital elements of 55P in the period 1901–2100, as well as values of minimal distances to the Earth orbit for these elements and relative solar longitudes are given.
Orbital elements are given for the Epoch J2000. The symbols are: q: perihelion distance; e eccentricity; AOP: argument of the perihelion; Node: longitude of the ascending node; i: inclination. A positive value of minimal distance means that point of such minimum lies outside the Earth's orbit, and a negative value means that this point is inside the Earth's orbit. $\lambda_\odot$: solar longitude.

strong storm will take place. It will be produced by the 1699 and 1866 trails which will be partly superimposed. From $17^{h}33^{m}$ to $18^{h}18^{m}$ UT 18 November quite a long peak is expected, during this period activity will vary between 4400–5200 meteors on the ZHR scale. The first part of the storm will be characterized by bright meteors, then their brightness will decline to a little lower that average level.

In 2002 two storms will happen, but the first peak will be the traditional maximum. Considering the proximity of comet 55P, activity at 14^{h} UT 17 November will rise to 20–30 meteors on the ZHR scale. Then a small enhancement from the 1965 trail will follow. At 19^{h} UT 17 November activity will rise to 30–40 meteors on the ZHR scale, meteor brightness will be very low. For radio meteors a much stronger outburst is likely. After that at $04^{h}09^{m}$ UT 18 November the first storm caused by the 1767 trail will occur. Activity will rise to 1300 meteors on the ZHR scale and brightness close to the average level. The second storm will be much stronger. At $10^{h}44^{m}$ UT 18 November the 1866 trail will give activity up to 4300 meteors on the ZHR scale and brightness will be noticeably lower than average.

In 2003 several comparatively small enhancements are expected. The first one will be an outburst from the 1499 trail at 14^{h}–15^{h} UT 13 November. Activity will rise to 30 meteors on the ZHR scale and brightness will be considerably lower than average. The next peak, again from the 1499 trail will happen at 21^{h} UT 13 November. Activity will reach 20–25 meteors on the ZHR scale, and brightness will be considerably below average. Then at 14^{h} UT 14 November, the 1433 trail will give the next enhancement. Activity will rise to 50 meteors on the ZHR scale and brightness considerably below average. Then a traditional maximum will follow. Considering the proximity of comet 55P, activity at 20^{h} UT 17 November will reach 20–30 meteors on ZHR scale. After that a small increase from the 1733 trail will occur. At $18^{h}44^{m}$ UT 19 November, activity will rise to 15–20 meteors on the ZHR scale and brightness will be considerably lower than average. The final enhancement will happen at $18^{h}54^{m}$ UT 20 November. It will be produced by the 1866 trail, activity will reach 15–20 meteors on the ZHR scale. Brightness will be considerably lower than average level.

In 2004 a weak background maximum is expected, but considering the proximity of comet 55P activity at 02^{h} UT 17 November will rise to 15–20 meteors. Also, an enhancement from the 1733 trail is expected. At $20^{h}37^{m}$ UT 19 November activity will rise to 25–30 meteors on the ZHR scale with brightness notably lower than average level.

In 2005 a traditional maximum weaker than average level is expected. At 08^{h} UT 17 November activity will rise to 10 meteors on the ZHR scale. Also, at 00^{h}–02^{h} UT 21 November an enhancement from the 1167 trail is possible. Its intensity will reach 15–20 meteors on the ZHR scale, and brightness will be somewhat lower than the average level.

In 2006 a weak traditional maximum is expected. At 15^{h} UT 17 November activity will rise to 10–15 meteors on the ZHR scale. Besides that at $04^{h}55^{m}$ UT 19 November an outburst from the 1932 trail will follow. Its intensity will reach 35–40 meteors on the ZHR scale, meteor brightness will be very low, but for radio meteors a much higher activity is likely.

In 2007 a traditional maximum weaker than average is expected. At 21^{h} UT 17 November activity will rise to 15 meteors on the ZHR scale. Besides that at $23^{h}05^{m}$ UT 18 November an outburst from the 1932 trail will follow. Its intensity will reach about 30 meteors on the ZHR scale, meteor brightness will be very low, but for radio meteors a much higher activity is likely.

In 2008 a traditional maximum somewhat higher than average level is expected, and it will almost coincide with considerable outburst from the 1466 trail. At $00^{h}22^{m}$ UT 17 November activity should rise to 130 meteors on the ZHR scale. Meteor brightness will be somewhat higher than average.

In 2009 a very strong traditional maximum is expected. At 09^{h} UT 17 November activity should rise to 25–30 meteors on the ZHR scale. Also, at 21^{h}–22^{h} UT 17

November a considerable outburst from the 1466 and 1533 trails is likely. Activity will reach 130–140 meteors on the ZHR scale and a number of submaxima are likely. Meteor brightness will be about average level. Another small enhancement can be produced by the 1201 trail. At $19^{\rm h}$ UT 18 November activity will rise to 10–15 meteors on the ZHR scale and meteor brightness will be a little lower than average level.

In 2010 a quite strong traditional maximum is expected. At $15^{\rm h}$ UT 17 November activity will rise to about 20 meteors on the ZHR scale. No other outbursts are found.

In 2011 a weak background maximum is expected. At $21^{\rm h}$ UT 17 November activity will rise to 5–10 meteors on the ZHR scale. Also, at $23^{\rm h}$ UT 18 November, the 1567 trail should give a small enhancement. Activity will reach about 10 meteors on the ZHR scale and brightness will be a little below average level.

In 2012 a weak background maximum is expected. At $03^{\rm h}$ UT 17 November activity will rise to 5–10 meteors on the ZHR scale. Also, at $06^{\rm h}$ UT 20 November, the 1400 trail can give a small increase. Activity will rise to 10–15 meteors on the ZHR scale and brightness will be somewhat lower than the average level.

In 2013 quite a strong traditional maximum is expected. At $10^{\rm h}$ UT 17 November activity will rise to 15–20 meteors on the ZHR scale. No other outbursts are found.

In 2014 a moderate traditional maximum is expected. At $16^{\rm h}$ UT 17 November activity will rise to 10–15 meteors on the ZHR scale. No other outbursts are found.

In 2015 a strong traditional maximum is expected. At $21^{\rm h}$ UT 17 November activity will rise to 20 meteors on the ZHR scale. No other outbursts are found.

In 2016 quite a weak traditional maximum is expected. At $04^{\rm h}$ UT 17 November activity will rise to 10 meteors on the ZHR scale. No other outbursts are found.

In 2017 quite a weak traditional maximum is expected. At $10^{\rm h}$ UT 17 November activity will rise to 10 meteors on the ZHR scale. No other significant outbursts are found.

In 2018 a very strong traditional maximum is expected. At $16^{\rm h}$ UT 17 November activity will rise to 25 meteors on the ZHR scale. Also, at $09^{\rm h}$ UT 20 November average meteor brightness can increase due to the 1466 trail.

In 2019 an average traditional maximum is expected. At $23^{\rm h}$ UT 17 November activity will rise to 15–20 meteors on the ZHR scale. Also, at $02^{\rm h}$ UT 16 November a small increase from the 1400 trail is possible. Activity will reach 15–20 meteors on the ZHR scale and brightness will be considerably above average. Activity from another, the 1800 trail, can appear at $05^{\rm h}$ UT 19 November as an increase in the number of bright meteors.

In 2020 a traditional maximum somewhat lower than average level is expected. At $03^{\rm h}$ UT 17 November activity will rise to 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2021 a weak traditional maximum is expected. At $09^{\rm h}$ UT 17 November activity will rise to 10 meteors on the ZHR scale. No other outbursts are found.

In 2022 a moderate traditional maximum is expected. At $16^{\rm h}$ UT 17 November activity will rise to 10–15 meteors on the ZHR scale. Also, a strong outburst from the 1733 trail is possible. At $06^{\rm h}$ UT 19 November activity can reach 250–300 meteors on the ZHR scale and brightness will be much higher than the average level. Another small enhancement to 5–10 meteors on the ZHR can occur at $15^{\rm h}$ UT 21 November due to the 1800 trail. Meteor brightness will be again much higher than average level.

In 2023 a moderate background maximum is expected. At $22^{\rm h}$ UT 17 November activity will rise to 15 meteors on the ZHR scale. Also, at $12^{\rm h}$ UT 21 November a little increase from the 1767 trail is possible. Activity will rise to 10–15 meteors on the ZHR scale. Brightness will be much higher than the average level.

In 2024 a quite strong traditional maximum is expected. At $04^{\rm h}$ UT 17 November activity will rise to 15–20 meteors on the ZHR scale. No other significant outbursts are found.

In 2025 a quite weak traditional maximum is expected. At $10^{\rm h}$ UT 17 November activity will rise to 10–15 meteors on the ZHR scale. Also, from $19^{\rm h}$ to $23^{\rm h}$ UT 17 November an outburst from the 1699 trail is possible. Activity will reach 60–90 meteors on the ZHR scale and brightness will be much higher than the average level.

In 2026 a moderate traditional maximum is expected. At $16^{\rm h}$ UT 17 November activity will rise to 15 meteors on the ZHR scale. No other significant outbursts are found.

In 2027 a strong background maximum is expected and due to the proximity of comet 55P and activity will rise to 40–50 meteors on the ZHR scale at $22^{\rm h}$ UT 17 November. Also, at $04^{\rm h}$ UT 20 November an outburst from the 1167 trail is possible. Activity will rise to 40–50 meteors on the ZHR scale and brightness will be notably above average.

In 2028 a moderate background maximum is expected, but considering the proximity of comet 55P, activity at $05^{\rm h}$ UT 17 November can rise to 30–40 meteors on the ZHR scale. No other outbursts are found.

In 2029 a background maximum somewhat lower than usual is expected, but considering the proximity of comet 55P, activity at $11^{\rm h}$ UT 17 November can rise to 30–40 meteors on the ZHR scale. No other outbursts are found.

In 2030 a very weak traditional maximum is expected. Only due to the proximity of comet 55P an optimistic estimation of maximum activity would be 15–20 meteors on the ZHR scale, the peak is to occur at $17^{\rm h}$ UT 17 November. But it is not impossible that the traditional maximum will be very weak even by the standards of usual years, lower than 10 meteors on the ZHR scale. Outbursts from trails are not found.

In 2031, as in the previous year, a very weak traditional maximum is expected, despite the perihelion passage of comet 55P. An optimistic estimation of maximum activity would be 15–20 meteors on the ZHR scale, the peak is to occur at $23^{\rm h}$ UT 17 November. But it is not impossible that the traditional maximum will be very weak even by the standards of usual years, lower than 10 meteors on the ZHR scale. Outbursts from trails are not found.

In 2032, as in the previous year, a very weak traditional maximum is expected, despite the proximity of comet 55P. An optimistic estimation of maximum activity would be 15 meteors on the ZHR scale, the peak is to occur at 05^h UT 17 November. But it is not impossible that the traditional maximum will be very weak even by the standards of usual years, lower than 10 meteors on the ZHR scale. Outbursts from trails are not found.

In 2033 a quite weak background maximum is expected, but considering the proximity of comet 55P, activity at 11^h UT 17 November will rise to 25–35 meteors on the ZHR scale. After that a small enhancement from the 1932 trail will occur. At 17^h UT 17 November activity will reach about 30 meteors on the ZHR scale and their brightness will be below average. Finally, the last will be a strong outburst from the 1899 trail. At 20^h53^m UT 17 November activity will rise to 300–400 meteors on the ZHR scale and brightness will be somewhat lower than average.

In 2034 a number of outbursts are expected. The first will be the traditional maximum. It will be quite strong, and considering the proximity of comet 55P, activity at 18^h UT 17 November will reach 40–50 meteors on the ZHR scale. After that a strong outburst from the 1932 trail will happen. At 03^h04^m UT 18 November activity will rise to 400–500 meteors on the ZHR scale, brightness will be significantly lower than average, for radio meteors activity should be stronger. Then a small enhancement from the 1899 trail will occur. At 09^h02^m UT 18 November activity will rise to 30–40 meteors on the ZHR scale and brightness will be somewhat lower than average. Then the next significant outburst from the 1767 trail will follow. At 22^h04^m UT 18 November activity will reach 150–250 meteors on the ZHR scale and brightness will be close to the average level. Another strong outburst will be produced by the 1699 and 1866 trails, which will be partially superimposed. At 05^h–06^h UT 19 November activity will reach 300–400 meteors on the ZHR scale, a number of submaxima are possible. At 05^h UT 19 November the rate will be somewhat lower than average, but closer to 06^h UT it should increase considerably.

In 2035 again a number of outbursts is expected. The first will be a quite strong traditional maximum. At 00^h UT 18 November activity will rise to 30–40 meteors on the ZHR scale. The next increase will be a rather weak enhancement from the 1800 and 1833 trails. At 15^h24^m UT 19 November activity will reach 50–60 meteors on the ZHR scale and brightness will be close to average level. After that a weak enhancement from the 1866 trail will follow. At 20^h10^m UT 19 November activity will rise to 30 meteors on the ZHR scale and brightness will be a little lower than average. Finally, at 06^h06^m UT 20 November, the 1633 trail will give a strong outburst to 300–350 meteors on the ZHR scale and brightness will be significantly above average level.

In 2036 a quite weak traditional maximum is expected, but considering the proximity of comet 55P activity will reach 20–30 meteors on the ZHR scale at 06^h UT 17 November. A number of weak enhancements is also expected. At 16^h01^m UT 17 November, the 1965 trail will give an increase to 30–40 meteors on the ZHR scale and brightness will be significantly lower than average, for radio meteors a much stronger peak is likely. The next one will be outburst from the 1466 trail at 21^h49^m UT 18 November. Activity will reach 15–25 meteors on the ZHR scale and brightness will be considerably lower than average. Another enhancement from the 1800 and 1833 trails will occur at 08^h–11^h UT 19 November. Activity will rise to 20–30 meteors on the ZHR scale, a number of submaxima is possible and brightness will be a little lower than average level.

In 2037 a quite weak traditional maximum is expected, but considering the proximity of comet 55P and maximum from the 1499 trail, activity will reach 40–50 meteors on the ZHR scale at 02^h UT 17 November. Some other outbursts will also occur. At 22^h58^m UT

17 November, the 1965 trail will give a peak of 30–40 meteors on the ZHR scale. For radio meteors activity should be much stronger. Finally, at 20^h15^m UT 19 November and at 01^h21^m UT 20 November a double maximum from the 1800 and 1833 trails is expected. The first peak will reach 250–350 meteors on the ZHR scale, and the second one 200–300 meteors on the ZHR scale. Brightness will be a little lower than the average level.

In 2038 a moderate traditional maximum is expected. At 18^h UT 17 November activity will reach 15 meteors on the ZHR scale. Also a number of outbursts from trails will occur. All before, at 05^h21^m UT 18 November a radio outburst from the 1965 trail is expected. Then at 08^h48^m UT 20 November 1767 trail will give an outburst to 60–70 meteors on the ZHR scale and brightness will be somewhat lower than average. The next outburst from the 1800 trail will happen at 14^h23^m UT 20 November. Its intensity will reach about 20 meteors on the ZHR scale. Then at 21^h18^m UT 20 November, the 1833 trail will also give an enhancement to 20 meteors on ZHE scale, brightness a little lower than average. Finally at 10^h32^m UT 21 November, the 1866 trail will produce a peak of 70–90 meteors on the ZHR scale and brightness will be significantly lower than average.

In 2039 a quite strong background maximum is expected. At 00^h UT 18 November activity will reach 10–15 meteors on the ZHR scale. Also, at 09^h UT 20 November, the 1333 trail can give a small enhancement to about 10 meteors on the ZHR scale and brightness will be close to the average level. Another small increase will be produced by the 1767 trail at 02^h08^m UT 21 November. Activity will reach 10–20 meteors on the ZHR scale, brightness will be notably lower than average.

In 2040 a moderate background maximum is expected. At 06^h UT 17 November activity will reach 15–20 meteors on the ZHR scale. Also, at 00^h UT 19 November an enhancement from the 1366 trail is possible. Activity will reach 25–35 meteors on the ZHR scale, brightness close to average level.

In 2041 a moderate traditional maximum is expected. At $13^{\rm h}$ UT 17 November activity will reach about 15 meteors on the ZHR scale. No other outbursts are found.

In 2042 a quite weak traditional maximum is expected. At $19^{\rm h}$ UT 17 November activity will reach about 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2043 a strong background maximum is expected. At $01^{\rm h}$ UT 18 November activity will rise to 25 meteors on the ZHR scale. Also, at $18^{\rm h}$ UT 19 November an enhancement from the 1400 trail is likely. Activity will reach 50–60 meteors on the ZHR scale, a number of submaxima are possible. Meteor brightness will be a little lower than average level. Then at $13^{\rm h}45^{\rm m}$ UT 20 November, the 1932 trail can give a significant radio outburst.

In 2044 a moderate background maximum is expected. At $07^{\rm h}$ UT 17 November activity will reach about 15 meteors on the ZHR scale. Also, at $16^{\rm h}43^{\rm m}$ UT 19 November 1932 trail can give a significant radio outburst.

In 2045 a quite strong traditional maximum is expected. At $13^{\rm h}$ UT 17 November activity will reach about 20 meteors on the ZHR scale. No other significant outbursts are found.

In 2046 a quite strong traditional maximum is expected. At $19^{\rm h}$ UT 17 November activity will reach about 15–20 meteors on the ZHR scale. No other significant outbursts are found.

In 2047 a weak traditional maximum is expected. At $02^{\rm h}$ UT 18 November activity will reach about 10 meteors on the ZHR scale. No other significant outbursts are found.

In 2048 a moderate traditional maximum is expected. At $08^{\rm h}$ UT 17 November activity will reach about 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2049 a very weak traditional maximum is expected. At $14^{\rm h}$ UT 17 November activity will reach about 5–10 meteors on the ZHR scale. No other significant outbursts are found.

In 2050 a quite weak traditional maximum is expected. At $20^{\rm h}$ UT 17 November activity will reach about 10–15 meteors on the ZHR scale. Also, at $08^{\rm h}$ UT 18 November an outburst from the 1234 trail is possible. Activity will rise to 15–20 meteors on the ZHR scale and brightness will be much higher than average level.

In 2051 a quite strong traditional maximum is expected. At $02^{\rm h}$ UT 18 November activity will rise to about 20 meteors on the ZHR scale. Also, at $09^{\rm h}$ UT 20 November average meteor brightness can increase due to the 1466 trail. It is not impossible that activity would rise to 10 meteors on the ZHR scale.

In 2052 a quite weak background maximum is expected. At $08^{\rm h}$ UT 17 November activity will rise to 10–15 meteors on the ZHR scale. Also at $14^{\rm h}32^{\rm m}$ UT 17 November 1866 trail can give a radio outburst.

In 2053 a quite weak traditional maximum is expected. At $14^{\rm h}$ UT 17 November activity will rise to 10–15 meteors. Also, at $01^{\rm h}$ UT 17 November, the 1433 trail can give an enhancement to 20 meteors on the ZHR scale and brightness will be much higher than average level. After that at $09^{\rm h}49^{\rm m}$ UT 22 November meteor brightness can increase due to the 1800 trail.

In 2054 a very weak traditional maximum is expected. At $04^{\rm h}$ UT 19 November activity will reach about 5–10 meteors on the ZHR scale. No other outbursts are found.

In 2055 a weak traditional maximum is expected. At $10^{\rm h}$ UT 19 November activity will reach about 10 meteors on the ZHR scale. No other significant outbursts are found.

In 2056 a quite weak traditional maximum is expected. At $17^{\rm h}$ UT 19 November activity will reach about 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2057 a quite weak traditional maximum is expected. It will partially coincide with the 1866 trail. Maximum will occur at $01^{\rm h}38^{\rm m}$ UT 19 November, its intensity will reach 25–30 meteors on the ZHR scale and brightness will be much higher than average.

In 2058 a weak traditional maximum is expected. At $05^{\rm h}$ UT 19 November activity will reach about 10 meteors on the ZHR scale. No other significant outbursts are found.

In 2059 a moderate traditional maximum is expected. At $11^{\rm h}$ UT 19 November activity will reach about 15 meteors on the ZHR scale. Also, at $21^{\rm h}54^{\rm m}$ UT 18 November average meteor brightness can increase due to the 1998 trail.

In 2060 a moderate traditional maximum is expected. At $17^{\rm h}$ UT 18 November activity will reach about 15 meteors on the ZHR scale. Also, at $05^{\rm h}45^{\rm m}$ UT 18 November an outburst from the 1965 trail is likely. Activity will rise to about 25 meteors on the ZHR scale and brightness will be much higher than average. After that at $12^{\rm h}$ UT 19 November average meteor brightness can increase due to the 1600 trail.

In 2061 a strong traditional maximum is expected, and considering the proximity of comet 55P, at $23^{\rm h}$ UT 18 November activity will rise to 40–50 meteors on the ZHR scale. A number of outbursts from trails will also occur. At $01^{\rm h}56^{\rm m}$ UT 19 November, the 1965 trail can increase activity to 60 meteors on the ZHR scale and brightness will be much higher than average level. Another strong outburst, from the 1998 trail, should happen at $15^{\rm h}51^{\rm m}$ UT 19 November. Activity will rise to about 300 meteors on the ZHR scale and brightness will be much higher than average.

In 2062 a quite strong traditional maximum is expected, and considering the proximity of comet 55P, at $06^{\rm h}$ UT 19 November activity will rise to about 30–40 meteors on the ZHR scale. No other significant outbursts are expected.

In 2063 a moderate traditional maximum is expected, and considering the proximity of comet 55P, at $11^{\rm h}$ UT 19 November activity will rise to about 30–40 meteors on the ZHR scale. No other significant outbursts are expected.

In 2064 a weak traditional maximum is expected, and considering the proximity of comet 55P, at $18^{\rm h}$ UT 18 November activity (in optimistic expectations) will rise to about 20–30 meteors on the ZHR scale. It is possible that activity will not surpass 10–15 meteors on the ZHR scale. No other outbursts are found.

In 2065 a very weak traditional maximum is expected. Despite the perihelion passage of comet 55P, at 00^h UT 19 November, an optimistic estimate suggests that activity will rise to about 15–20 meteors on the ZHR scale. It is possible that activity will not surpass 5–10 meteors on the ZHR scale. No other outbursts are found.

In 2066 again a very weak traditional maximum is expected. Despite the perihelion passage of comet 55P, at 06^h UT 19 November an optimistic estimate suggests that activity will rise to about 15–20 meteors on the ZHR scale. It is possible that activity will not surpass 5–10 meteors on the ZHR scale. No other outbursts are found.

In 2067 a quite weak traditional maximum is expected. Considering the proximity of comet 55P, at 12^h UT 18 November activity will rise to about 25–35 meteors on the ZHR scale. No other outbursts are found.

In 2068 a quite strong traditional maximum is expected, considering the proximity of comet 55P activity will rise to 40–50 meteors on the ZHR scale at 18^h UT 18 November. Also, at 00^h48^m UT 19 November, the 1866 trail will give an outburst to 50 meteors on the ZHR scale. Brightness will be a little lower than the average level.

In 2069 a moderate background maximum is expected, but considering the proximity of comet 55P, activity at 00^h UT 19 November will rise to about 30–40 meteors on the ZHR scale. Also, a number of outbursts from trails are expected. The first (earlier than the traditional maximum) will be an outburst from the 1932 trail. At 05^h35^m UT 18 November activity will rise to 100 meteors on the ZHR scale, meteor brightness will be significantly lower than average, and for radio meteors a much stronger activity is expected. Then, after the traditional maximum an outburst from the 1433 trail will follow. At 09^h UT 19 November activity will rise to 70–80 meteors on the ZHR scale, brightness will be considerably lower than average. After that a small enhancement from the 1800 and 1833 trails will occur. Activity will rise to 30–40 meteors on the ZHR scale and brightness will be close to the average level. Finally, the last outburst will be produced by the 1699 trail. At 10^h21^m UT 20 November activity will reach 300–350 meteors on the ZHR scale and brightness will be above average.

In 2070 a moderate traditional maximum is expected. Considering the proximity of comet 55P, at 06^h UT 19 November activity will rise to about 20–30 meteors on the ZHR scale. No other significant outbursts are found.

In 2071 a traditional maximum a little weaker than usual is expected, but considering the proximity of comet 55P, at 13^h UT 19 November activity will rise to about 20–25 meteors on the ZHR scale. No other significant outbursts are found.

In 2072 a moderate traditional maximum is expected. At 19^h UT 18 November activity will rise to 15 meteors on the ZHR scale. Also, at 16^h UT 19 November, the 1499 trail will give a small outburst to 10–15 meteors on the ZHR scale and brightness will be somewhat lower than average.

In 2073 a quite weak traditional maximum is expected. At 19^h UT 18 November activity will rise to 10–15 meteors on the ZHR scale. Also, at 12^h29^m UT 18 November 1998 trail will give an outburst to 35–40 meteors on the ZHR scale. Brightness will be much lower than average level, for radio meteors activity should be much higher.

In 2074 a quite strong traditional maximum is expected. At 07^h UT 19 November activity will rise to 15–20 meteors on the ZHR scale. Also, at 05^h26^m UT 23 November, the 1800 trail will give an outburst to 25–30 meteors on the ZHR scale. Brightness will be a little lower than average.

In 2075 a strong traditional maximum is expected. At 13^h UT 19 November activity will rise to 20 meteors on the ZHR scale. Also, at 13^h–14^h UT 21 November, the 1533 trail will give a small enhancement to 5–10 meteors on the ZHR scale and brightness will be close to the average level.

In 2076 a weak traditional maximum is expected. At 19^h UT 18 November activity will rise to about 10 meteors on the ZHR scale. No other outbursts are found.

In 2077 a moderate traditional maximum is expected. At 02^h UT 19 November activity will rise to 15 meteors on the ZHR scale. Also, at 02^h UT 20 November, the 1400 trail will give an outburst to 15–20 meteors on the ZHR scale and brightness will be a little lower than average.

In 2078 a quite weak traditional maximum is expected. At 08^h UT 19 November activity will rise to 10–15 meteors on the ZHR scale. No other outbursts are found.

In 2079 a quite weak traditional maximum is expected. At 14^h UT 19 November activity will rise to 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2080 a moderate traditional maximum is expected. At 20^h UT 18 November activity will rise to 15 meteors on the ZHR scale. No other outbursts are found.

In 2081 a quite faint traditional maximum is expected. At 02^h UT 19 November activity will rise to 10–15 meteors on the ZHR scale. No other outbursts are found.

In 2082 a quite faint traditional maximum is expected. At 08^h UT 19 November activity will rise to 10–15 meteors on the ZHR scale. No other significant outbursts are found.

In 2083 a quite faint traditional maximum is expected. At 14^h UT 19 November activity will rise to 10–15 meteors on the ZHR scale. No other outbursts are found.

In 2084 a moderate traditional maximum is expected. At 21^h UT 18 November activity will rise to 15 meteors on the ZHR scale. No other outbursts are found.

In 2085 a moderate traditional maximum is expected. At 03^h UT 19 November activity will rise to 15 meteors on the ZHR scale. No other significant outbursts are found.

In 2086 a quite strong traditional maximum is expected. At 03^h UT 19 November activity will rise to 15–20 meteors on the ZHR scale. No other significant outbursts are found.

In 2087 a strong traditional maximum is expected. At 04^h UT 20 November activity will rise to about 20–25 meteors on the ZHR scale. Also, at 09^h–11^h UT 19 November it is not impossible that the 1567 trail will give some bright meteors.

In 2088 a weak traditional maximum is expected. At 10^h UT 19 November activity will rise to 10 meteors on the ZHR scale. No other significant outbursts are found.

In 2089 a very weak traditional maximum is expected. At 16^h UT 20 November activity will rise to about 5–10 meteors on the ZHR scale. Also, at 08^h UT 21 November it is not excluded, that the 1567 trail will give some bright meteors.

In 2090 a very weak traditional maximum is expected. At 22^h UT 19 November activity will rise to 5–10 meteors on the ZHR scale. Also, at 20^h24^m UT 20 November the 1800 trail can give a small enhancement to 10 meteors on the ZHR scale and brightness will be much higher than average.

In 2091 a weak traditional maximum is expected. At 04^h UT 20 November activity will rise to 5–10 meteors on the ZHR scale. No other outbursts are found.

In 2092 a moderate traditional maximum is expected. It will coincide with possible activity from the 1998 trail. At 09^h11^m UT 19 November activity will rise to 50–60 meteors on the ZHR scale and brightness will be much higher than average. Also, at 13^h UT 18 November, the 1965 trail can give a number of bright meteors.

In 2093 a number of outbursts is expected. The first one will be a peak from the 1965 trail which will partially coincide with a strong background maximum. Activity will rise to 25–35 meteors on the ZHR scale and brightness will be much higher than average. After that at 03^h27^m UT 20 November, the 1998 trail will give an enhancement to 15–20 meteors and brightness will be much higher than average. Finally, another small increase is possible at 15^h UT 20 November due to the 1600 trail. Activity will rise to 20–25 meteors on the ZHR scale and brightness will be much higher than average.

In 2094, as in the previous year, a number of outbursts are expected, but they will be considerably stronger. First of all, a number of bright meteors can come from the 1466 trail at 11^h UT 19 November. After that a strong outburst from the 1899 trail will follow, partially coinciding with a strong traditional maximum. At 00^h47^m UT 20 November activity will rise to about 800–900 meteors on the ZHR scale and brightness will be much higher than average. The next, less intensive outburst will be produced by the 1932 trail at 07^h07^m UT 20 November. Activity will reach 100–150 meteors on the ZHR scale and brightness will be much higher than average. Then a potentially stormy outburst from the 1965 trail will follow. At 11^h43^m UT 20 November activity will rise to 1300–1400 meteors on the ZHR scale, brightness will be much higher than average. It is very likely that 2094 will give the first Leonid storm return since 2002.

In 2095 a quite strong traditional maximum is expected, and considering the proximity of comet 55P, at 05^h UT 20 November activity will rise to 40–50 meteors on the ZHR scale. No other significant outbursts are found.

In 2096 a quite strong traditional maximum is expected, and considering the proximity of comet 55P, at 11^h UT 20 November activity will rise to 40–50 meteors on the ZHR scale. No other significant outbursts are found.

In 2097 a quite strong traditional maximum is expected, and considering the proximity of comet 55P, at 17^h UT 20 November activity will rise to 30–40 meteors on the ZHR scale. No other significant outbursts are found.

In 2098 a very powerful traditional maximum is expected, and considering the perihelion passage of comet 55P, at 23^h UT 19 November activity will rise to 100–150 meteors on the ZHR scale. Also, at 06^h UT 20 November, the 1499 trail will give an outburst to 80–100 meteors on the ZHR scale and brightness will be much higher than average.

In 2099 a quite strong background maximum is expected, and considering the proximity of comet 55P, at 06^h UT 20 November activity will rise to about 40–50 meteors on the ZHR scale. Also, the 1633 and 1699 trails should give two small enhancements at 01^h UT 16 November and at 18^h UT 17 November, respectively. Activity will reach 15–20 meteors on the ZHR scale in the first case, and about 25–30 meteors on the ZHR scale in the second one. Brightness will be both times considerably lower than average level.

In 2100 a very weak traditional maximum is expected. Considering the proximity of comet 55P, at 12^h UT 20 November activity can reach to 15–20 meteors on the ZHR scale, but it is possible that activity will not exceed 10 meteors on the ZHR scale. No other outbursts are found.

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Ongoing meteor work

Spanish Meteor Network: 2006 continuous monitoring results

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Initial results from the first year of continuous CCD low-scan-rate all-sky and video monitoring by the SPanish Meteor Network (SPMN) are presented. Under extraordinary weather conditions, the SPMN recorded almost 40 bright (over $m = -6$) fireballs, some of which were observed simultaneously from several stations. Daily observations of meteor activity have helped to increase our knowledge on cometary and asteroidal-origin meteoroid streams. The focus herein will be on the overall description of the fireballs recorded, first estimations of the measured spatial fluxes of selected streams, and information on unexpected activity from poorly-known meteoroid streams.

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1 Introduction

We previously reported on the first steps in the development of the SPanish Meteor Network (SPMN) by using innovative low-scan-rate all-sky CCD cameras that achieve +2/+3 meteor limiting magnitude (Trigo-Rodríguez et al., 2004). The year 2006 was extraordinary for the SPMN network, especially due to the excellent weather conditions during autumn and winter that guaranteed almost a continuous record of meteor activity from the different SPMN stations. During 2006 new progress has been made by having set up two additional all-sky CCD stations in Catalonia and three video stations in Andalusia with the main goal to increase our atmospheric coverage of meteor and fireball activity (Trigo-Rodríguez et al., 2006b). Since the two already active cores of the network (Andalusia and Catalonia) are separated by 1000 km, it minimizes the chance that adverse weather affects both sites and that meteor activity is recorded almost every night. During 2006, the SPMN built their first cameras with an internal rotating shutter to obtain measurements of meteor velocities (Figure 2). The shutter is located nearby the focal plane, between the lens and the chip, and more details will be given during the next Meteoroids 2007 meeting. First results are consistent with a velocity uncertainty of the order of 0.2–0.3 km/s, similar to photographic or video systems (Trigo-Rodríguez et al., 2007b). Additionally, for those all-sky CCD cameras still operating without rotating shutters we have performed common field monitoring with video cameras to provide meteor velocities. The different stations and imaging systems are listed in Table 1 (Figure 1). As a consequence of all this effort, reliable trajectory and orbital data of both meteors and fireballs are being obtained.

Figure 1 – Location of the SPMN all-sky stations. For image simplicity, only the names of the main stations are shown. The circles around the operative all-sky stations are the optimal range for bright fireball detection (350–400 km) although from some of the stations larger detection distances have been achieved (see e.g. Trigo-Rodríguez et al., 2003).

2 General overview of bright bolides recorded

Since the number of recorded fireball events were quite high, this section was restricted to placing special emphasis in the description of the brightest fireballs (over −6 absolute magnitude), and especially to those meteorite-dropping events that we are currently studying in more detail. Table 4 provides a preliminary list of such events giving clues on their origin. Due to the incomplete development status of the network, we are still not covering certain areas completely, and thus many

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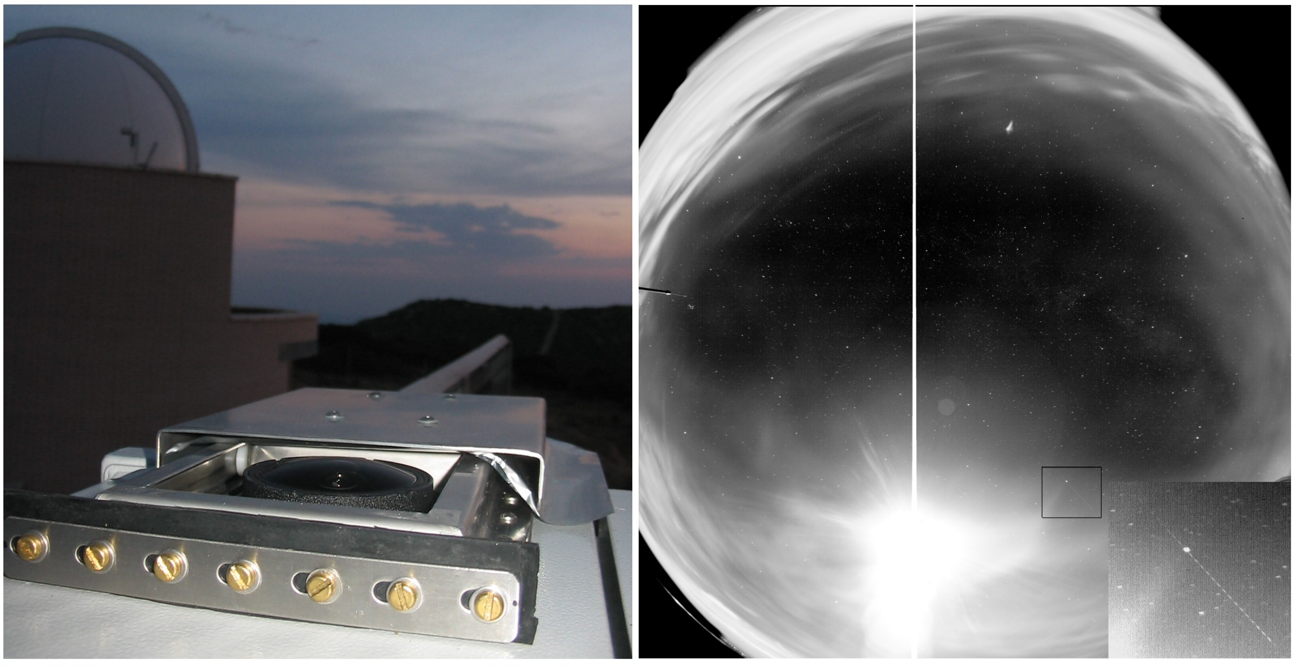


Figure 2 – An example of the excellent camera performance even under unfavourable conditions (partially cloudy skies with disturbing Moon). a) All-sky CCD camera of Montsec (SPMN station #3, OAdM). b) All sky-image taken by the camera shown in a). The black square nearby the full Moon includes an $m = -2$ Perseid imaged on 2006 August 12.

Table 1 – Current list of CCD all-sky and video stations in operation by the SPMN. Under the column labeled "imaging system" the meaning for the different acronyms are: AS (low-scan-rate CCD all-sky camera), WF (low-scan-rate wide-field CCD camera), WFV (Wide field video cameras) and MS (low-scan rate CCD wide field camera). The location of the currently operative all-sky stations are shown in Figure 1.

Station number	Station location (Province)	Longitude	Latitude (N)	Alt. (m)	Imaging system
1	El Arenosillo, BOOTES-1 (Huelva)	06°43′58″ W	37°06′16″	40	AS+WFV
2	La Mayora, BOOTES-2 (Málaga)	04°02′40″ W	36°45′35″	60	AS
3	Montsec, OAdM (Lleida)	00°43′46″ E	42°03′05″	1570	AS
4	Montseny (Girona)	02°31′14″ E	41°43′17″	300	AS
5	Sevilla (Sevilla)	05°58′50″ W	37°20′46″	28	WFV
6	Cerro Negro (Sevilla)	06°19′35″ W	37°40′19″	470	WFV
7	Torremolinos (Málaga)	04°31′11″ W	36°36′34″	10	MS
8	Folgueroles (Barcelona)	02°19′33″ E	41°56′31″	580	MS
9	Aras de los Olmos, UVAO (Valencia)	01°06′01″ W	39°56′46″	1300	AS

Table 2 – Averaged orbital elements of two ν Aurigids imaged by SPMN video cameras. All elements given for Equinox (2000.00). For comparison the averaged orbital elements of ν Aurigids (stream #229, Table 7, (Jenniskens, 2006) are shown. Full trajectory details and individual orbits are given in (Trigo-Rodríguez et al., 2007b).

Reference	q	a	e	i	ω	Ω
This work average (N=2)	0.225	1.97	0.886	$123.^{\circ}9$	$310.^{\circ}6$	—
#229	0.267	1.298	—	$134.^{\circ}3$	$311.^{\circ}0$	$208.^{\circ}0$

fireball records are from only a single station. In such a case, the meteoroid source (given in Table 4 between parentheses) was deduced by taking into account the criteria of the meteor's path intersection with the radiant, apparent trajectory length and apparent angular velocity. Of course, fireball association is unequivocal only in those cases when two or more stations recorded the fireball, and when consequently the geocentric radiant is accurately determined. The planned future deployment of additional SPMN stations will allow an increase in the number of double or multiple-station fireballs. Another important aspect we are currently working on is the fireball's timing. Our idea is to develop additional video stations surrounding the all-sky network "cores". This is already achieved in western Andalusia where three video stations with 3–4 cameras each are covering common fields with all-sky CCD cameras. However, we don't have a complete coverage at this point all around the network, being the reason of time uncertainties of several seconds (given in first column of Table 4). This is an important aspect to solve in the future with simultaneous video observations.

By examining Table 4, it can be deduced that the most important sources of fireballs encountering the Earth during 2006, were the meteoroid streams associated with comets 1P/Halley, 4P/Tempel, 8P/Tuttle, 7D/Pons-Winnecke, 45P/Honda-Mrkos-Pajdusáková, 55P/Tempel-Tuttle, and 109P/Swift-Tuttle. It deserves to be mentioned that less fireballs were recorded from the Taurid complex (associated with 2P/Encke) compared to the level exhibited and recorded by our cameras in 2005. In the opposite way, particularly remarkable was the completely unexpected fireball activity associated with 1P/Halley, and 7D/Pons-Winnecke. Fireball rates for the streams associated with these comets are usually low. Consequently both detections are a significant success for the network and were possible mainly because of its continuous monitoring efforts.

3 Continuous follow up of annual streams: the unexpected Orionid outburst

We focus here on an overall description of the recorded activity of cometary meteor showers. From precise velocity determinations, we obtained orbital data from both major meteor showers, and also from poorly-known meteoroid streams. Several low-velocity cometary showers were active during 2006. For example, between June 27 and July 1 we imaged four June Bootid fireballs associated with comet 7 P/Pons-Winnecke. With an unexpected outburst observed in 1998, this stream with a geocentric velocity of only 14.1 km/s, is a likely source of Interplanetary Dust Particles (IDPs). Despite that, the June Bootids exhibited in 2006 a low level of visual activity but with a background of bright fireballs that was remarkable. During July and August our cameras also recorded several α Capricornid fireballs that are typically associated with 45P/Honda-Mrkos-Pajdusáková, although other cometary sources have been suggested. The brightest one occurred on

Table 3 – Orbital elements of the Doñana bolide.

a (AU)	2.62	± 0.09
e	0.798	± 0.007
q(AU)	0.5273	± 0.0026
ω	$274\overset{\circ}{.}77$	$\pm 0\overset{\circ}{.}28$
Ω	$117\overset{\circ}{.}97678$	$\pm 0\overset{\circ}{.}00021$
i	$4\overset{\circ}{.}96$	$\pm 0\overset{\circ}{.}12$

2006 July 20 at $22^{h}24^{m}41\overset{s}{.}5 \pm 0.1^{s}$ UTC over Doñana Natural Park, reaching absolute magnitude -12 ± 2. This interesting event is one of the brightest members of this stream ever recorded, with an estimated photometric mass of 500±200 kg. Fortunately, it was imaged from one all-sky CCD camera and one video camera that were monitoring the sky from La Mayora (Málaga) and Sevilla (Figure 5). From the astrometric reduction of the double station images of the bolide, we have estimated a geocentric radiant of RA $= 300.95 \pm 0.14°$ and Dec $= -14.44 \pm 0.12°$ and a V_{∞}=27.0±0.3km/s. The computed orbital elements confirm its association with the α Capricornid stream (Table 3 from (Trigo-Rodríguez et al., 2007a).

A good example of the excellent performance of our all-sky cameras to record visual meteors was the detection of an unexpected outburst in the Orionid activity during 2006. As the limiting magnitude of the meteors recorded by the all-sky CCDs is +3 for this meteor shower (Trigo-Rodríguez et al., 2004) we recorded an important part of the display, rich in bright meteors and fireballs. Despite very bad weather in Andalusia, two stations in Catalonia (#4 and 8) recorded the outburst on Oct. 21 under excellent conditions, and several orbits were obtained (Trigo-Rodríguez et al., 2007a). While the typical Zenithal Hourly Rate (ZHR) of this meteor shower is 20 meteors/hour, the activity imaged during October 20/21 was three times higher (Trigo-Rodríguez et al., 2006a). This was confirmed by using the count rates obtained from the all-sky systems that had been corrected through a high fidelity meteor simulation. The simulation provides a means to account for sensor sensitivity characteristics, geometric loss terms, radiant position changes, and the meteor stream's particle distribution, as well as convert to a ZHR measure using a standard human observer's perception. The corrected SPMN counts were found to be 2.8 times stronger during the outburst than four hours later when the Orionid activity returned to normal yearly levels. Note also that a background of unusually bright Orionid fireballs was detected from Oct. 15–25 supporting the idea that meteoroids trapped in a resonance played a role in the unusual display. In fact, since the parent body (1P/ Halley) was far away when the activity increase occurred, the outburst meteoroids may have been trapped in a Jovian resonance (Trigo-Rodríguez et al., 2007b) to produce such a display. In the literature we found only one previous reported case, the 1993 Orionid outburst observed from Holland by the Dutch Meteor Society (Jenniskens, 2006). It is important to note that the

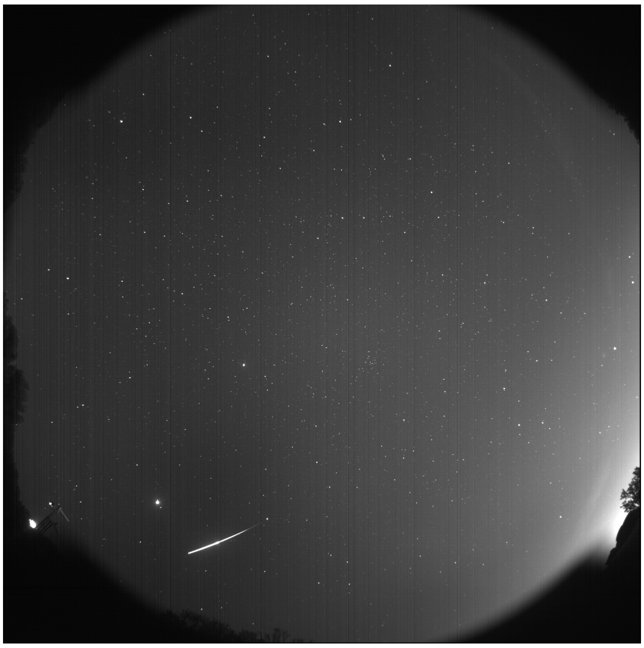


Figure 3 – A likely σ Leonid fireball of magnitude -9 ± 1 recorded on April 20, 2006 at $23^{\rm h}40^{\rm m}15^{\rm s} \pm 15^{\rm s}$ from the all-sky CCD camera located in La Mayora (BOOTES-2, Málaga).

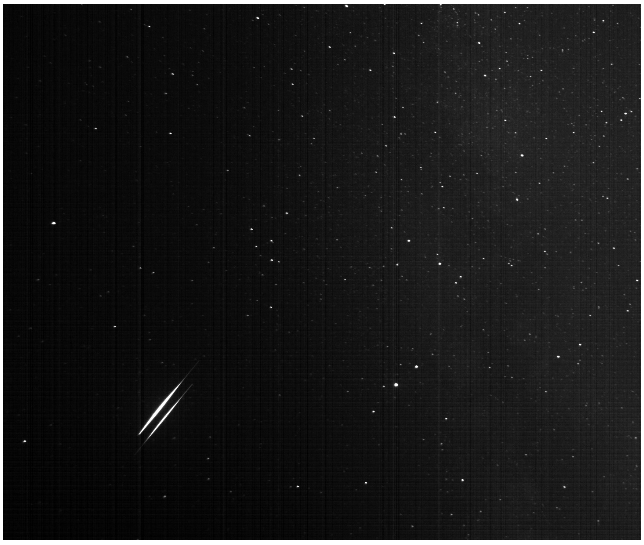


Figure 4 – Unusual twin of fireballs appeared on 2006 June 6 in the interval $03^{\rm h}08^{\rm m}15^{\rm s}{\pm}15^{\rm s}$ UTC. Part of an all-sky image obtained from La Mayora (BOOTES-2) all-sky station. Unfortunately, no velocity measurements were made, but a possible link with the τ Herculids (comet 73P/Schwassmann-Wachmann 3) can be inferred from the paths length and alignment.

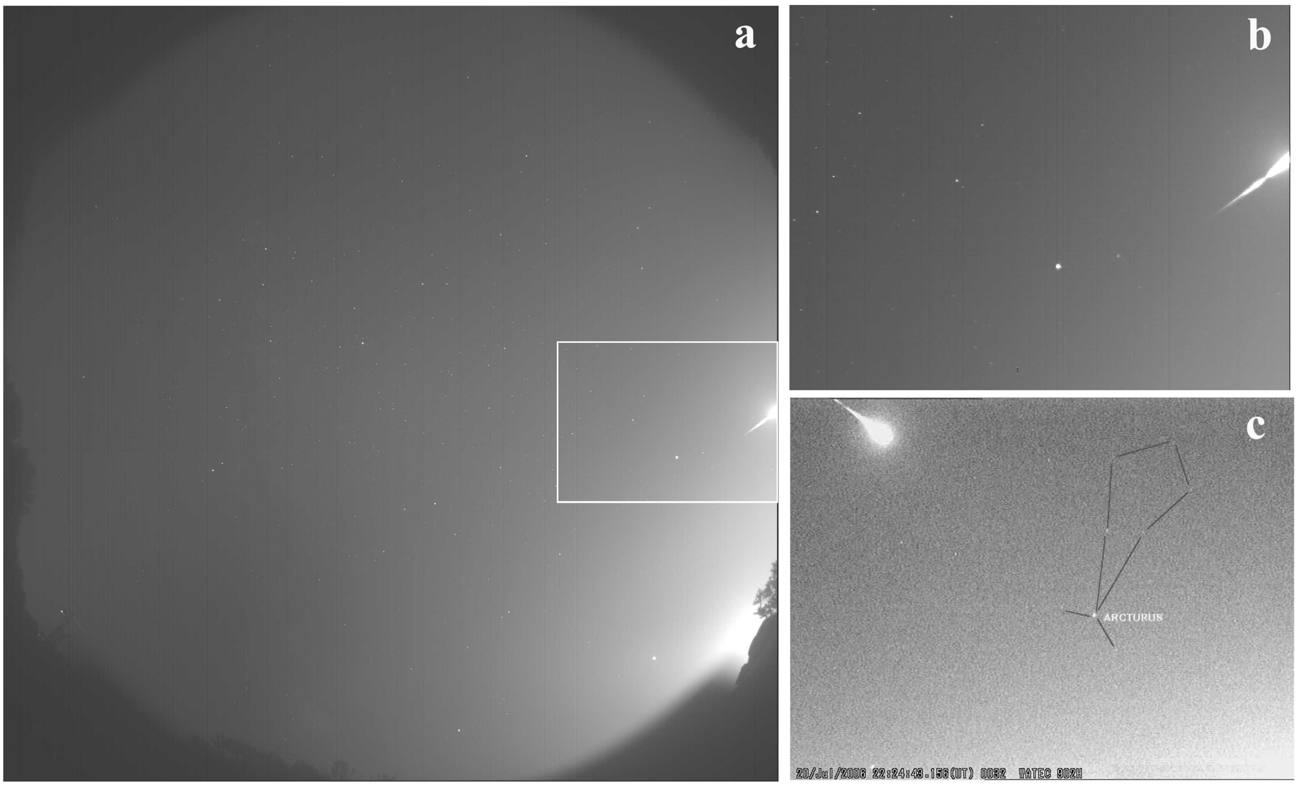


Figure 5 – The SPMN010706 (Doñana) bolide imaged from La Mayora (Málaga) and Sevilla. a) Full all-sky image showing the ending flares illuminating the western horizon. b) Magnified apparent trajectory from La Mayora. c) Last frame recorded by the video system from Sevilla.

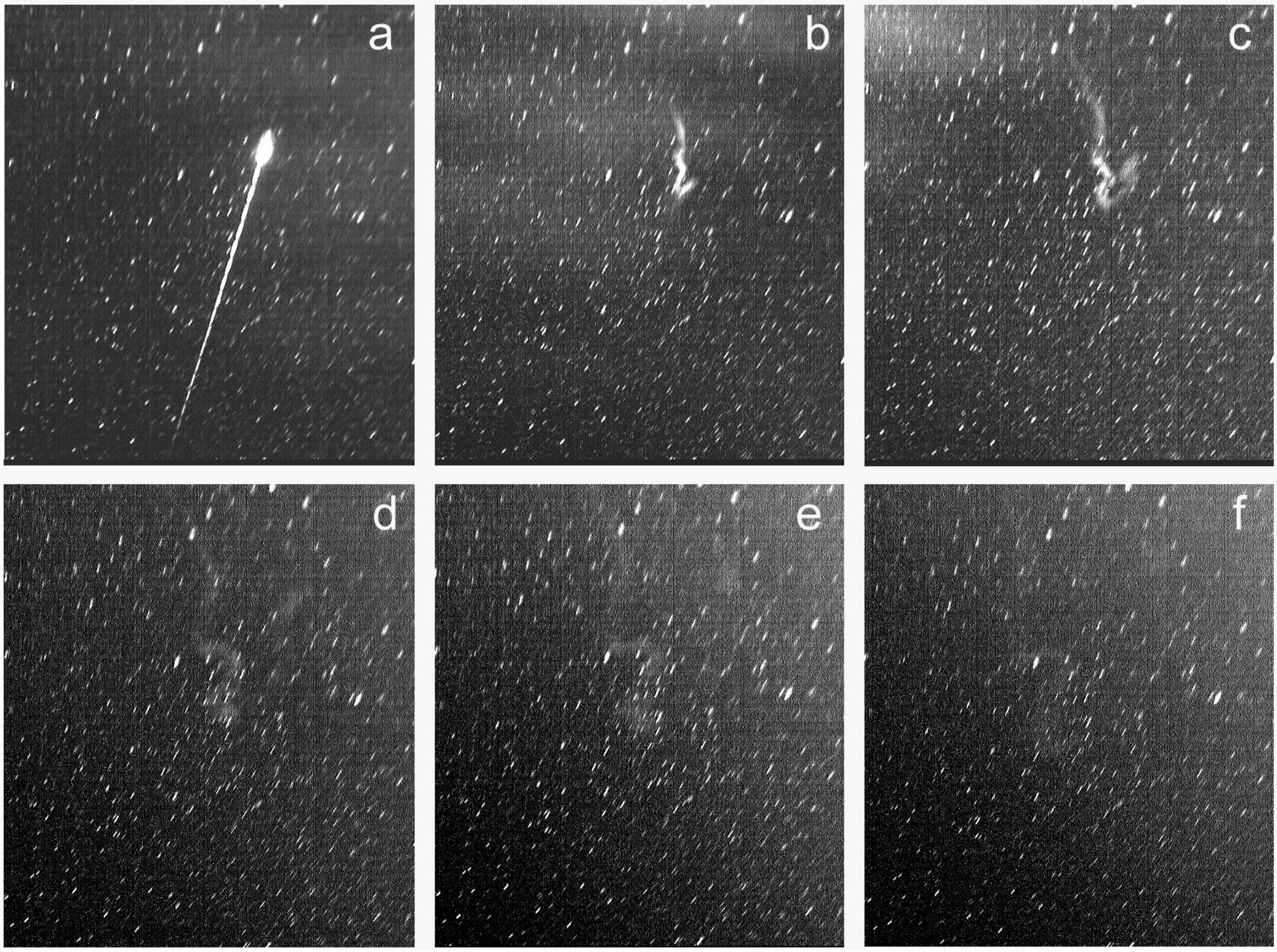


Figure 6 – a) An $m = -9$ Leonid appeared on 2006 Nov. 18 at $05^h33^m12^s \pm 45^s$ UTC. Part of an all-sky CCD image taken from Montseny (Girona). b) to f) Evolution of the persistent train in consecutive images taken every 90 seconds (for 10 minutes after the fireball's appearance). The train was visible for a total of 15 minutes.

activity was not restricted to the night of 20/21 Oct. since a background of bright fireballs persisted for several days around that date. Reduction of the images and magnitude data has provided information on these unusually large 1P/Halley meteoroids, and the origin of the outburst.

The Earth marginally crossed the two-revolution dust trail of 55P/Tempel-Tuttle on the morning of 2006 Nov. 19. Our video cameras noticed an increase in the number of +1 to +3 meteors at $04^h45^m \pm 10^m$ UTC, just as theoretically predicted (McNaught & Asher, 1999). Several impressive fireballs producing long-lasting (5–15 min.) trains were also imaged by SPMN all-sky cameras from Nov. 15–25 (see e.g. Figure 6).

Finally, in December 2006 we recorded the display of the Geminid shower associated with 3200 Phaethon, see for instance Figure 9. Tens of multiple-station Geminid meteors have been obtained. After the first year of continuous SPMN operation, the volume of data generated by both CCD and video cameras is overwhelming. In any case, data reduction is in progress and we have started to develop a software package called *Amalthea* to help with the astrometric and photometric tasks (see e.g. the photometric curve shown in Figure 8). At the end of the month, during twilight on Dec. 21/22 we observed a nice display of fireballs and bright meteors from the Ursids. However, the activity decreased in a couple of hours down to normal rates. The activity was probably produced by a dust trail of 8P/Temple (Lyytinen & Nissinen, 2006).

4 CCD and video recorded activity from minor showers

We have recently been motivated to follow the activity of minor showers on the basis of the newly available instrumentation of the SPMN (Trigo-Rodríguez et al., 2006b). The goal is not only to better define the flux of cometary meteoroids that are reaching the Earth from a variety of comets, but to also identify new cometary streams. Particularly useful to achieve such a goal are the video observations that the SPMN has been performing continuously since 2006 June. In order to study poorly-known meteor streams we developed an observing plan for orientation of our cameras dependant on the position of the most interesting radiants. However, in Meteor Science when you are trying to study a minor shower during a badly-covered observing period, you cannot rule out the chance of finding new unexpected sources of meteor streams. Here we briefly describe some interesting results, giving a few examples

Table 4 – 2006 bright (over absolute magnitude −6) fireballs imaged by SPMN stations.

Date	Time (UTC)		Max. Absolute magnitude	Imaging system	Station number(s)	Source (IMO code), Notes
2006 Jan. 11	03^h20^m	$\pm5^m$	-12±3	Only visual reports		SPO [1]
2006 Jan. 23	$22^h13^m40^s$	$\pm30^s$	-7±1	AS	4	SPO
2006 Apr. 15	$20^h54^m15^s$	$\pm15^s$	-9±1	AS	2	[2]
2006 Apr. 20	$23^h40^m15^s$	$\pm15^s$	-9±1	AS	2	SLE
2006 Jun. 3	$03^h08^m15^s$	$\pm15^s$	-6±1	AS	2	SAG
2006 Jun. 6	$03^h08^m15^s$	$\pm15^s$	-7±1 / -5±1	AS	2	THE? [3]
2006 Jun. 11	03^h52^m	$\pm1^m$	-10±3	Only visual reports		SPO
2006 Jun. 27	$03^h22^m15^s$	$\pm30^s$	-10±1	AS	2	JBO
2006 Jun. 28	$02^h58^m15^s$	$\pm30^s$	-6±1	AS	2	JBO
2006 Jun. 29	$02^h19^m29^s$	$\pm30^s$	-7±1	AS	4	JBO
2006 Jun. 29	$02^h52^m15^s$	$\pm30^s$	-9±1	AS	2	JBO
2006 Jul. 1	$23^h46^m20^s$	$\pm1^s$	-8±1	Only visual reports		JBO
2006 Jul. 20	$22^h24^m41.5^s$	$\pm0.5^s$	-12±2	AS+WFV	2, 5	CAP
2006 Jul. 21	$21^h00^m58^s$	$\pm30^s$	-7±1	AS+WFV	4	CAP
2006 Jul. 24	$04^h15^m15^s$	$\pm15^s$	-10±2	AS	2	SPO
2006 Aug. 10			-7±1	AS	4	PER
2006 Aug. 20	$18^h48^m57.1^s$	$\pm0.1^s$	-7±1	WFV	1	DAQ
2006 Aug. 21	$18^h48^m57.1^s$	$\pm0.1^s$	-7±1	WFV	1	PER?
2006 Aug. 31	$01^h44^m41.8^s$	$\pm0.1^s$	-9±1	WFV	1	SPO?
2006 Sep. 29	$00^h07^m20.5^s$	$\pm0.1^s$	-6±1	WFV	5	SPO?
2006 Oct. 16	$03^h16^m28^s$	$\pm45^s$	-6±1	AS	4	ORI
2006 Oct. 21	$03^h01^m59^s$	$\pm45^s$	-6±1	AS	4	ORI
2006 Oct. 21	$03^h25^m48^s$	$\pm45^s$	-5±1	AS+WF	4,8	ORI
2006 Oct. 21	$03^h41^m41^s$	$\pm45^s$	-8±1	AS	4	ORI
2006 Oct. 22	$03^h19^m34^s$	$\pm45^s$	-9±1	AS	4	ORI
2006 Nov. 17	$03^h15^m40.5^s$	$\pm0.1^s$	-9±2	WFV	5	TAU
2006 Nov. 18	$05^h33^m12^s$	$\pm45^s$	-9±1	AS	4	LEO [4]
2006 Nov. 19	$00^h41^m22.9^s$	$\pm0.1^s$	-8±2	WFV	5	TAU
2006 Nov. 19	$03^h52^m47^s$	$\pm45^s$	-5±1	AS	3	STA
2006 Nov. 19	$04^h53^m52^s$	$\pm45^s$	-6±1	AS	4	LEO
2006 Nov. 20	$06^h14^m38.3^s$	$\pm0.1^s$	-9±2	WFV	5	LEO
2006 Nov. 21	$00^h29^m28.6^s$	$\pm0.1^s$	-6±1	WFV	1	LEO
2006 Nov. 21	$05^h36^m44^s$	$\pm45^s$	-6±1	AS	4	LEO
2006 Dec. 1	$18^h48^m57.1^s$	$\pm0.1^s$	-7±1	WFV	1	SPO?
2006 Dec. 13	$18^h23^m50^s$	$\pm45^s$	-6±1	AS	4	SPO
2006 Dec. 14	$04^h36^m25^s$	$\pm15^s$	-10±1	AS+WF	4,8	GEM [5]
2006 Dec. 15	$04^h30^m03.4^s$	$\pm0.1^s$	-7±1	WFV	1	MON
2006 Dec. 21	$01^h09^m31^s$	$\pm45^s$	-6±1	AS	4	SPO
2006 Dec. 22	$18^h10^m16.0^s$	$\pm0.1^s$	-10±2	WFV	5	URS [6]

Notes:
1: Reported sound.
2: Artificial bolide: Seech-1 reentry.
3: Fireball twin (see Figure 4).
4: 15 minute persistent train (see Figure 6).
5: See Figure 9.
6: See Figure 8.

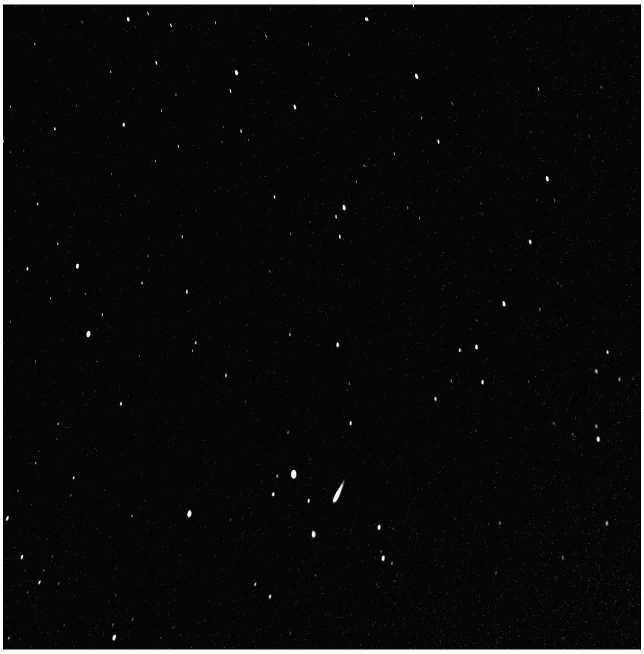


Figure 7 – An $m = -3$ almost stationary Lyrid appeared on 2006 Apr. 21 at $01^h44^m03^s \pm 30^s$ UTC. Part of an all-sky CCD image taken from Montseny (Girona).

of the orbital data.

No meteor showers were producing bright visual meteors until April. Some bright meteors of the Lyrids were imaged (see e.g. Figure 7) from April 20 to 24, but the activity was quite low (ZHR<10). A few members of the η Aquarids were detected in May, but the radiant was too low to generate good rates.

In June we imaged some bright meteors of τ Herculids, but the activity was normal during its activity period (ZHR<3). The June Boötids presented a background of fireballs, but no fainter meteors were imaged. In July the activity of bright meteors increased, but the α Capricornid stream was the only source of bright fireballs (see section 3).

Despite moonlight interfered with the Perseids in August, we recorded activity of some interesting minor showers. For example, during the second half of August the video cameras imaged five double-station meteors of π Eridanids (ERI), four of them brighter than $m = 0$. Two double-station κ Cygnid meteors were also obtained. The video systems recorded also π Eridanid activity in early September. Additional orbital data of other minor showers like e.g. δ Aurigids, σ Orionids and Taurids were obtained in the second part of September.

October was marked by the activity of several minor showers of scientific interest. Only a few (single station) October Camelopardalids were imaged by SPMN all-sky and video cameras, but the activity level from Europe seems to confirm its annual nature (Lyytinen, 2007). In mid October our video cameras detected some members of the δ Aurigids, but also two members of the ν Aurigids have been (at this point) identified by double-station work on Oct. 13 and 14. The derived trajectory and radiant data (Trigo-Rodríguez et al., 2007b) together with the averaged orbital elements (Table 2, page 14) are very similar to those ob-

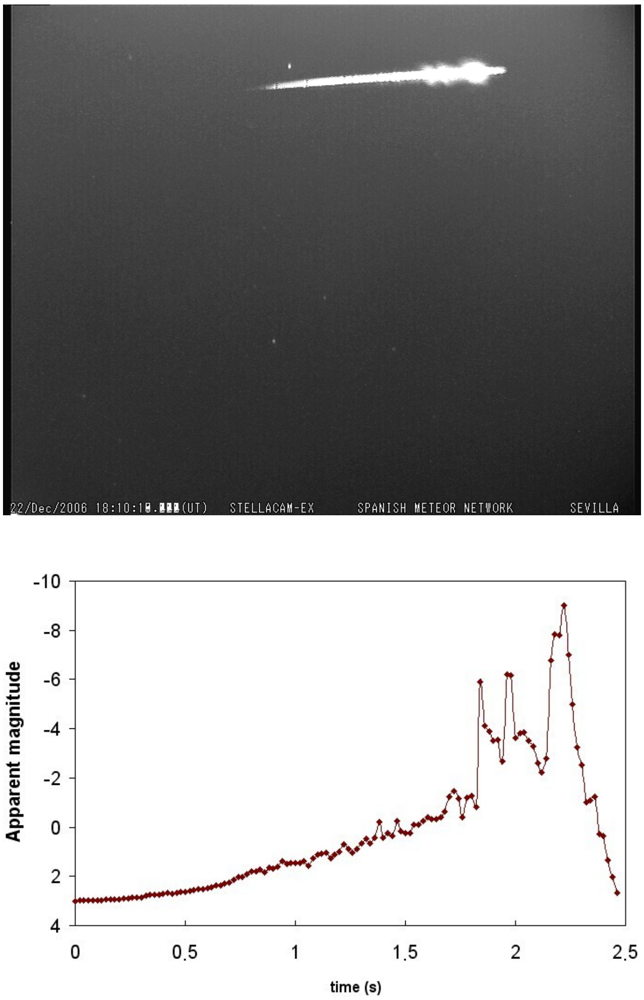
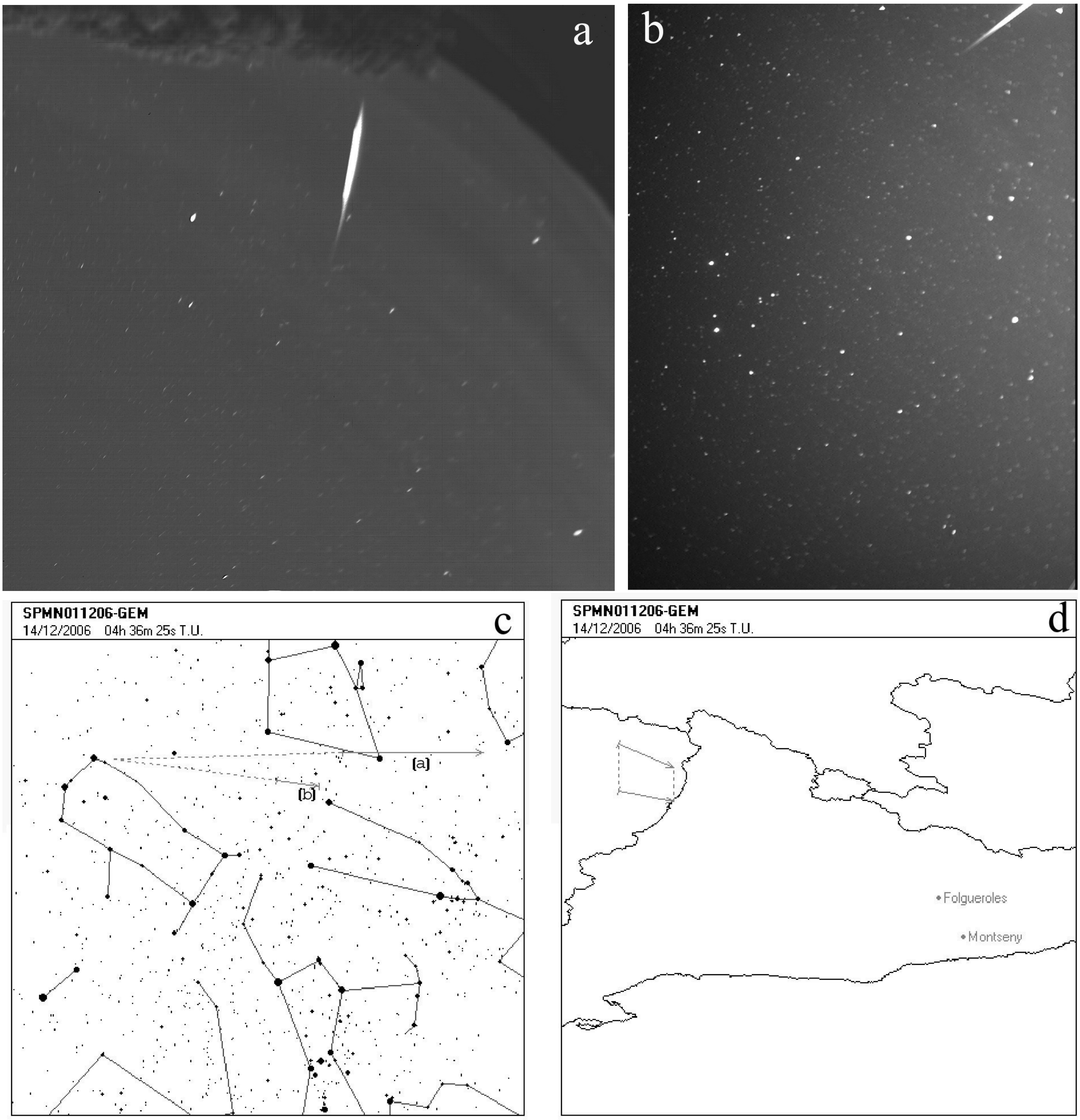


Figure 8 – Top: an $m = -10$ Ursid fireball recorded on 2006 Dec. 22 at $18^h10^m16^s$ UTC from Sevilla SPMN video station. The summer triangle stars visible in the image can be used for comparison of the fireball's luminosity (though they may be hard to see in the printed version). Bottom: the light curve obtained by Amalthea software.

tained by (Sekanina, 1976) marked as shower #229 in Table 7 of (Jenniskens, 2006). We note that the activity of October Ursa Majorids reported by Uehara et al. (2006) was not detected by either the all-sky cameras or the video cameras. On the other hand, during October and November several multiple-station Taurids were recorded, although the activity of fireballs was remarkably lower than that exhibited by the two branches of the stream in 2005.

In November, our station #4 detected a likely increase in the α Monocerotids (AMO) on Nov. 18, between 03^h15^m and 03^h45^m UTC. This included three bright members (magnitudes -4, -2 and 0) with duration of about 0.5 second. Some other AMO members were detected during other nights, but the number of meteors is too low to be representative. Video cameras located in stations #5 and #6 also imaged meteors from this stream and several double-station trails were recorded between Nov. 17 and Nov. 20.

In the first half of December the activity of minor streams was mostly dominated by the σ Hydrids. A few



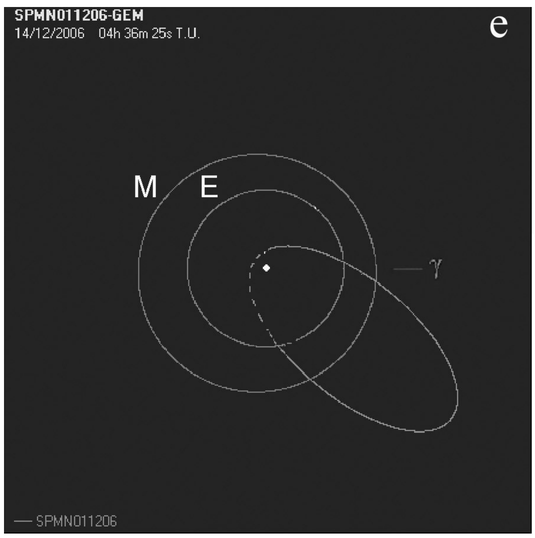


Figure 9 – The extraordinary Ribagorza bolide. This −10 magnitude Geminid (SPMN011206) was imaged on 2006 Dec. 14 at $04^{h}36^{m}25^{s} \pm 15^{s}$ UT from a) Montseny, and b) Folgueroles. c) Apparent trajectory of the meteor from both stations. d) Atmospheric trajectory and its projection on the ground. e) The heliocentric orbit of the meteoroid projected on the ecliptic plane, where the orbits of Earth (E) and Mars (M) are shown for comparison.

bright χ Orionids and some meteors of the δ Arietids and the Monocerotids were also recorded. As mentioned in section 3, on Dec. 21–22 we recorded an outburst of the Ursids. This meteoroid stream is associated with 8P/Tuttle (Jenniskens, 2006). Some bright meteors and fireballs were imaged (Figure 6) and five double-station meteors were obtained. In the second half of December an unexpected Coma Berenicid (COM) outburst occurred on the night of Dec. 24–25. Four video cameras of the SPanish Meteor Network (SPMN) operated from two stations in Sevilla province (Spain) recorded this activity increase. In particular, two Watec video cameras operated under dark skies with fields of view $88^\circ \times 56^\circ$ and $57^\circ \times 43^\circ$ and limiting meteor magnitudes of +3 recorded 12 Coma Berenicids meteors between $03^{\mathrm{h}}30^{\mathrm{m}}$ and $04^{\mathrm{h}}30^{\mathrm{m}}$ UTC. Accurate single-station astrometry reveals that this activity comes from an apparent radiant located at RA $= 181^\circ \pm 2^\circ$ and DEC $= +25^\circ \pm 1^\circ$. This radiant is also consistent with a couple of bright Coma Berenicid double-station meteors. From this data Peter Gural (Science Applications International Corp., USA) performed a simulation taking into account sensor sensitivity, geometric loss, radiant altitude and position, as well as particle distribution ($r = 2.0 \pm 0.4$, for $N = 25$) in order to get a maximum meteoroid flux of 4×10^{-3} ($m_{6.5}$/km^2/hr) with corresponds to an equivalent (human) ZHR of 60 ± 25, about ten times the activity expected for this minor shower in such date. Additional forward scatter meteor observations performed by the SPMN from Cerro Negro (Sevilla) using a computer-controlled ICOM IC-PCR1500 radio scanner attached to a 1/2-wave vertical antenna and a Hamtronic LNK-50 preamplifier. This system was tuned to 55.249 MHz, and the whole observing session was recorded on hard disk. During the peak about 5 echoes/minute (mostly short-duration, less than 1^{s}) were recorded in sharp contrast with the sporadic background obtained on other December nights. Alastair McBeath (Society for Popular Astronomy, England) points out that a possible confirmation of this data is an anomalous peak observed in the 03^{h}–04^{h} UTC interval by Gaspard de Wilde from Belgium (McBeath, pers. com.). Data reduction has involved astrometric measurements to exclude contamination from other sources. In particular, the α Lyncids (ALY), ϵ Viriginids (EVR), and an unexpected possible radiant at RA $= 188^\circ$ and DEC $= +33^\circ$ were also active. On other nights COM activity exhibited ZHR < 10, although some bright COM members were imaged by all-sky CCD stations (see e.g. Figure 10).

5 Conclusions

CCD and video cameras can be used to obtain information on the meteor activity level anytime of the year. The only problem is to post-process the large amount of data that is collected. We have given a few examples of how the SPMN multiple-station observations can provide valuable orbital information on minor meteoroid streams. The year 2006 has been one for firm establishment of the SPMN project, but many of the data still need to be reduced. However, the good results obtained up until now are encouraging the participants to continue the data reduction work and a program called *Amalthea* is in the process of being developed by the SPMN to help with video and CCD data reduction. Finally, although our network is still in a preliminary stage, significant progress is expected for the next future. A good example is the recent grant received from the *Junta de Andalucía* that will allow us to set up other 2–3 additional stations in Andalusia during 2007–2008.

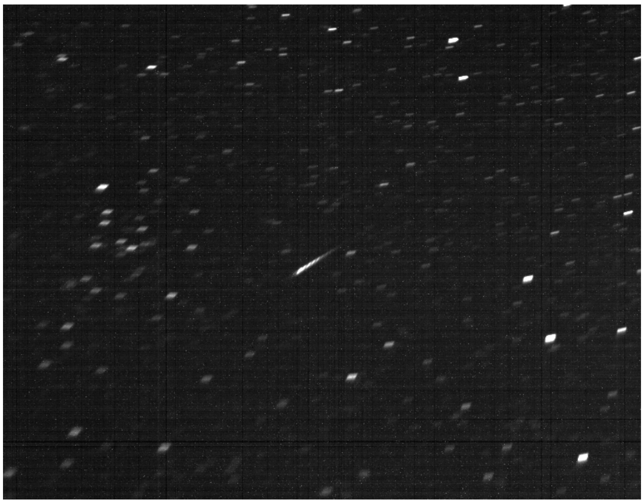


Figure 10 – An $m = -2$ Coma Berenicid meteor appeared on 2006 Dec. 21 at $03^{\mathrm{h}}56^{\mathrm{m}}23^{\mathrm{s}} \pm 45^{\mathrm{s}}$ UTC. Part of an all-sky CCD image taken from Montseny (Girona).

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History

Meteor Beliefs Project: *A Goodly Gallerye* — William Fulke's 'Meteors'

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

An examination is presented of meteorically-relevant material from Englishman William Fulke's treatise on meteors from 1563, which encompassed much more than would modernly fall into this category, and which remained continually in print for over a century.

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1 Introduction

William Fulke was born in London in 1538. He probably received his early education at St. Paul's school there, before matriculating at St. John's College, Cambridge, in 1555. He took his Bachelor of Arts degree in 1558, then his Master of Arts degree in 1563, the year his book on meteors, *A Goodly Gallerye*, was first published. In 1560 he had published an attack on astrology, written in a similar vein to his *Goodly Gallerye* — rationalistic and populistic. He was fascinated by natural philosophy, the precursor of true science, and intellectual games. He invented several games played on chess-like boards, including 'Ouronomachia' (1571), based on astronomy, where pieces representing the Sun, Moon and planets were moved by formulae concerning conjunctions, oppositions and so forth; and 'Metromachia' (1578), based on geometry, where elaborate geometrical pieces were moved towards a castle-like goal.

In 1564, he became a Fellow of St. John's College, after which he was closely associated with Cambridge University and its religious interests for the rest of his life. Sadly for us, this worked to the detriment of his earlier proto-scientific activities. Consequently, he received his Bachelor of Divinity degree in 1568, then his Doctorate in 1572, in the meantime becoming the Earl of Leicester's private chaplain (in 1569), simultaneously being granted incomes from parishes in Essex and Sussex. He was elected Master of Pembroke Hall, Cambridge in 1578, remaining an active clergyman and polemicist, as well as a noted debater in the anti-Papal controversies which his age saw in England, until his death in 1589[1].

It is of course Fulke's *Goodly Gallerye*, which was touched-on briefly in an earlier Meteor Beliefs Project article (McBeath, 2004), that we are interested in here. Its full title (1563 edition) was:

'A GOODLY GALLERYE *WITH A MOST PLEAsaunt Prospect, into the garden of* **naturall contemplation, to behold the naturall causes of all kynde of** *Meteors,* **as wel fyery and ayery, as watry and earthly, of whiche sort be blasing sterres, shooting starres, flames in the ayre &c. thõder, lightning, earthquakes, &c. rayne dewe, snowe, cloudes, springes &c. stones, metalles, earthes &c. to the glory of God, and the profit of his creaturs.** (Hornberger, 1979, Frontispiece and p. 12.)

Note that in the above quote, along with the others we have used below, some slight amendments have been made from the original, such as showing all 'long-s' 's in their short form only, not showing line endings or hyphens where a single word may be continued on the following line, and the expansion of some contractions common to the period. We have retained the sometimes modernly unusual spellings, including the common swapping of 'u' and 'v', but have noted words or phrases which seemed to us particularly problematical, or open to interpretation. The boldface in the title citation shows text in the Black Letter style script of the original printing, while the '&c.' abbreviation is the equivalent of the modern 'etc.' for *etcetera*, 'and so on'.

The *Goodly Gallerye* remained in print for over a century, with subsequent new editions making only minor changes to Fulke's 1563 original. Known editions were published in 1563, 1571, 1602, 1634, 1639, 1640, 1654, 1655 and 1670 (*op. cit.*, pp. 12–16). Its popularity, especially in the middle third of the 17th century, seems to have been because there was no similarly good, detailed text on meteors available in the English language. It also demonstrated the strength of interest in the topic around that time.

Overall, Fulke's *Goodly Gallerye* was largely a synthesis of the works of earlier authors on the subject, from the ancients, notably Aristotle, Seneca and Pliny, through a host of medieval ones, to those of Fulke's day. As a scientific work, its modern value is negligible, but as a view on English beliefs about meteors in the Renaissance transition between the late medieval to early modern periods, it is unparalleled. We have extracted notes on particularly relevant sections of the text here, and to avoid endless repetition, we have given citations only by the page numbers in (Hornberger, 1979), unless otherwise stated.

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NASA-ADS bibcode 2007JIMO...35...23M

[1] This brief biography was mostly derived from pp. 7–10 of the Introduction in (Hornberger, 1979), who also provided reference pointers for those wishing to trace further details on Fulke and his life.

2 'The First Booke'

Following an opening dedication to his patron, Lord Dudley, Fulke started his book proper with a general discourse on the derivation of the term 'meteor', and how the ancient Greek fourfold elemental division of the universe — into fire, air, water and earth — also divided meteors into four main types. As we might anticipate from the comments in (McBeath, 2004), most of the meteors we would still call such, fell into Fulke's 'fiery meteors' category. Their origins he described as due to hot, dry *exhalations* of the Earth (as opposed to cold, moist *vapours*), "whiche because they are thinne, and lyghter then *vapors*, passe the lowest and midle region of the ayre, and are caried vp euen to the highest region, wherefor the excessive heat, by nearenes of the fier, they are kindled, and cause many kinde of impressions" (pp. 27–28). He continued that some exhalations were *viscous*, clinging together and not dispersing, and when ignited, "appeare somtims like Dragons, somtim like Goats somtime like candels somtime like speares" (p. 28). Exhalations were said to occur by a denser body becoming less dense, in Fulke's words, "by making a grosser body more thinne" (p. 28), so that if air were made 'thinner', it would become fire, or fire made 'grosser' would become air.

The vapours and exhalations were drawn up from the Earth's surface by the Sun, and once high above, they might become visible as the "diuerse kinde of *Meteores*" (p. 29). Even so, the strength of the Sun might equally dissipate or consume the vapours and exhalations before they could ignite as meteors, so that in places where the Sun's rays struck most directly — within the tropics — no fiery meteors would be possible. By a similar thought process, in the far north, where the Sun's rays struck the Earth most obliquely, meteors would be few and watery. Extending more or less logically from this premise, Fulke proposed that meteors would be commoner in the temperate zones in autumn and spring than in summer or winter. Considering 'meteors' in the broad sense Fulke assumed, these suggestions did not appear to be based on observations.

Goodly Gallerye divided the places of occurrence for meteors in two, in the air or in the earth. Airy meteors were the kinds we would again expect from previous discussions, including rain, dew, shooting stars and lightning, but Fulke included in the earthly meteors "welles, springs, earthquakes, metalls, minerals, etc." (p. 31).

The discussion then moved on to the various layers from the Earth to the upper atmosphere, tying them in to the Greek elemental scheme. The air or atmosphere above the surface was divided into three. The highest layer, nearest the realm of fire, was very hot; the lowest layer nearest the cold earth and water was temperate; while the middle region was perpetually very cold.

Much of this Book was largely as explained by the Classical authors, but for the first time was readily accessible to those without knowledge of Greek or Latin. Fulke concluded it with these lists of examples (p. 32):

"In the hyghest region, be generated Cometes or blasing starres, and such lyke of diuerse sortes.

"In the midle region cloudes, rayne, stormes, wyndes, etc. In the lowest region, dewe, frost, horefrost, mistes, bryght rods, candels burning about graues, and gallowses, where ther is store of clamy fatty or oyly substaunce, also lightes and flammyng fiers, seen in fieldes, etc."

'Bryght rods' were discussed in Aristotle's *Meteorologica* III.II.372a and III.VI.377a–378a (Lee, 1952, pp. 242–243 and 286–287), where something similar to mock Suns, or parhelia, was intended, possibly part of the parhelic circle nearest the 22° solar halo's location. The seemingly more obvious upper Sun-pillar was not intended, as *Meteorologica* made very clear the effect was seen beside the Sun, never above or below it.

3 'The seconde Booke of fyery *Meteores*'

A large part of this book was derived from Aristotle's commentary in his *Meteorologica*, with 'fiery meteors' those appearing to be burning in the highest or lowest divisions of the air, as outlined in Fulke's Book One. The list of names given to the various forms by Fulke included: "burning stoble, torches, daunsing of leapinge Goates, shooting or falling starres, or candels, burning beames, round pillers, spears shieldes, globes or bowles, fier brandes, lampes, flying dragons or fire drakes, pointed pillors or broched steples, or blasing stars, called Cometes" (p. 33). 'Broched' meant stone carved by a chisel, so perhaps having a linear, fluted form, which would suggest auroral rays.

We shall discuss those with more probable modern meteoric leanings in the order Fulke gave them, presenting his description or discussion first, then our notes, where relevant.

'Of the generation of the impression, called burned stoble or sparcels of fire.' An exhalation of equal density throughout, but which was linearly extended vertically, so the higher part was ignited before the lower in the very highest air, giving the impression of sparks flying out of a chimney, "so much that the common people suppose, that an infinit number of starres fal down" ... "sparkling as when sawe dust or coole dust is cast into the fyre" (p. 33).

The term thus seems to have been used to describe a very strong to storm strength meteor shower, while the suggestion of an ascending linear 'exhalation' may imply a loose knowledge of the radiant effect seen with such great meteor activity. It also reverses the real effect, where a linear meteoroid stream in space 'descends' on its orbit towards the Earth to produce such a display.

'Of Torches.' Also called 'torches of firebrands', these were each said to be generated by a long, thin exhalation, which ignited in the highest air at one end, so burning up its substance in sequence, then extinguishing like a burning torch which had expended its fuel (p. 34).

Probably a type of slower, bright meteor.

'Of dansyng or leaping Goates.' Dancing goats were those torch-like meteors where the exhalation was divided in two, and the ignited part seemed to leap or dance from one part to the other (p. 34).

This seemed to suggest a fragmenting, bright meteor, or perhaps a meteor showing a marked variation in its lightcurve. The goat-meteors in Aristotle's *Meteorologica* I.IV.341b (Lee, 1952, pp. 30–33) were definitely fragmenting, bright, shooting-stars, as the shaggy nature of goats and goat-derived ancient Greek similes would imply (as discussed earlier — see McBeath, 2006). Authors after Aristotle struggled to understand what he meant however, a difficulty Fulke too seemed to have felt. The 'dancing' or 'leaping' aspect is not found in the Classical authors, which may suggest amendment by later oral or lost written traditions. Perhaps it was Fulke's own elaboration to explain a misunderstood concept.

'Of shotyng and falling Starres.' Fulke advanced several ideas about these shooting, falling or flying stars (pp. 34–35). He said one type was due to an exhalation being gathered in a rounded mass near the top of the lowest region of the air. After being ignited, this was held in check by the iciness of the middle region, and thus gave the impression of a star falling or sliding across part of the sky, the coldest air acting like an invisible, impenetrable barrier.

An alternative kind was attributed to a long, narrow exhalation, ignited at one end, so the fire ran rapidly along the track, "as when a silke thread is set on fyer at the one end" (p. 34).

Fulke then noted that others suggested the shooting-star exhalation lay directly beneath a fixed star, and reflected the star's light without actually igniting at all, while still seeming to be a star. He concluded that this might sometimes be true, but not commonly. This could have been an explanation for point-source or very short-pathed meteors, assuming they were recognised as such, apart from the more normal shooting-star tracks.

Continuing his discussion, Fulke mentioned the Epicureans, whom he said believed stars did fall from the sky, producing lightning by their shining light, and thunder when their great heat was suddenly quenched on entering a watery cloud, much as hot iron reacted when cast into cold water. Fulke rejected this, saying that the stars could not fall, as they were fixed in place at God's command (something which rather missed the point, as in Epicurean belief, the gods existed, but had no interest in, nor acted to influence, things which impinged upon the Earth). Fulke proceeded that the stars, should they fall, would not be stopped by the clouds, as their weight would carry them down, and they would cover the whole Earth, "For the least starre that is seen in the firmament, is greater then all the earth" (p. 35).

'Of burnyng Candels.' An exhalation, long, thin and of equal density, having risen into the highest air, might be ignited and burn like a candle flame, until its fuel — the exhalation — should be consumed (p. 36).

The difference between this type, torches and shooting-stars seems rather minimal, although a difference in brightness and physical appearance might be inferred.

'Of burning Beames and round Pillers.' "These are caused, when the *Exhalation* being long and not very broad, is sett on fyre, all at once and so burneth like a great beame or logge" (p. 36). 'Beams' lay horizontally, while 'pillars' stood upright.

Either might be considered auroral effects, the latter especially suggestive of rays, although the zodiacal light, or a comet's tail when its coma lay beneath the horizon, might be other causes. The possibility for something more meteoric stems from the stated rapid ignition, which might relate to high velocity meteors, which often seem linear, rather than as moving points of light. Overall, more probably auroral.

'Of burning Speares.' Fulke's description (pp. 36–37) was of a substantial number of exhalations gathered in a 'dry cloud', which was then set on fire, such that many fiery spears or shorter darts would shoot out in waves, the fire periodically dying down, then rekindling. He suggested this might persist more than a dozen times, depending on the size of the exhalation cloud. He went on to detail a 'burning spears' event, seen from London on January 30, 1560, at 8 p.m. What the event was was not entirely clear, but probably an aurora, as Fulke noted the sky was very dark except to the north-east, where a cloud burned as light as daybreak (the literal translation of 'aurora', of course), casting shadows. The cloud's edge was like a rainbow, but much brighter, "and often tymes casting foorth almoste innumerable dartes, of wonderful length lyke squybbes, that are cast vp into the ayre, sauing that they moued more swiftly then any squybbes" (p. 37).

A 'squib' was a simple type of firework, a tube of paper or card filled with gunpowder, set alight and sometimes flung by hand into the air. This would produce a bright, glowing trace of light, somewhat more like a meteor than an auroral ray, especially considering the notable speed that Fulke mentioned. Set upright on the ground, an ignited squib would give a bright, fiery ray, which imagery transferred into the sky in multiple forms would equate well with auroral activity. He may have seen the display of 1560 January himself. The description could imply a simultaneous strong meteor shower and an aurora, though we have not found any correlating strong meteor activity in the Chinese reports, for instance. It had similarities with the 1765 November event on three consecutive mornings, seen from Transylvania in (Gheorghe & McBeath, 2004), but we cannot be sure what either may have been. However, a solely auroral explanation again seems the more plausible in the Fulke case.

'Of shieldes, Globes or Bowles.' Comparable in appearance to the earlier types of shooting-star meteors, but broad and round in shape (p. 37).

Probably bright fireball-class meteors.

'Of Lampes.' A lamp was considered due to a broad, dense exhalation which was narrower at one end than the other. When fired, this gave the aspect of a lamp. Fulke went on to mention that the seeming roundness of some of these objects need not mean they were genuinely so, but because they were very distant. He ended with a brief referral to such a meteoric lamp, seen to fall at Rome in the time of Germanicus Caesar (p. 37).

Again, a form of bright fireball, as ancient sources regarding the Germanicus Caesar event(s) attest (Seneca, *Natural Questions* I.1.3 — a brilliant meteor seen about the time of Germanicus' death in 19 AD — and Pliny *Natural History* II.XXV.96 — a bolide seen in daytime during a gladiatorial contest ordered by Germanicus. The Pliny version is the one Fulke particularly mentioned).

'Of flying Dragons or fyre Drakes.' "Flying Dragons, or as Englyshmen call the fire drakes" (p. 37), occurred when vapours (not exhalations for once) were gathered in a compact mass, and ascended through the lower air to the extreme cold of the middle region, where they were violently thrown back by the cold, forcibly enough to kindle them to fire (or some said when a hot and a cold cloud met [an exhalation and a vapour, perhaps; Fulke is not clear on the point]). Then the highest, least dense, part, still ascending, appeared as the smoking dragon's neck, while the part most repulsed was bowed or crooked, and became the dragon's belly. The final part, the dragon's tail, was turned up by the cold impact. The dragon then flew along in the air, sometimes turning to and fro as it was deflected by other cold clouds, causing terror in those seeing it. Some called it the Fire Drake, others the Devil. Fulke recounted a tale where such a 'Devil' was seen flying above the River Thames at London, around 6 a.m. on May 1 "More then sixtene yeares ago" (p. 38; so in 1546 or earlier, a memory of a report from his own childhood). Rumours of a man with cloven hooves for feet, caught and put in the stocks at Stratford ($\sim$ 130 km north-west of London), followed, but these were unconfirmed (pp. 37–39).

Fulke's somewhat confused description suggested a class of brilliant, very persistent-trained meteors, from his comments about the distorted neck, belly and tail. The very specific shape — high neck, high tail, low crooked belly — reminds us that the Moon's path in the sky was known, certainly by medieval times at the latest, as 'the Dragon', and that the ascending and descending node symbols, were called 'the dragon's head' and 'the dragon's tail' from the same period (McBeath, 1997a). The shape Fulke indicated was in essence that of the node symbols, modified after the look of real meteors with very long-lasting trains, in an apparent attempt to reconcile the two, the meteoric version of which he had likely not seen, judging by his odd comments. Other such'fire drakes' or 'flying dragons', some of which featured previously in articles under this Project, were definitely bright fireballs.

4 'The thirde Booke of aery impressions'

While there was little in this book of direct relevance to 'our' sort of meteors, we have included some of Fulke's material which dealt with thunderstones or thunderbolts, objects that showed many similarities with meteorites in popular belief over the centuries. Our extracts are from the sections on thunder (pp. 56–59) and lightning (pp. 59–66).

'Of thonder.' Fulke noted that sometimes thunder dispersed the clouds with a tremendous gunshot-like sound, sometimes with force great enough to cast out stones, but most commonly it did so with fire, which could set tall buildings alight. He cited a specific example, when the steeple of St. Paul's church in London was set on fire on June 4, 1561 by such a strike (p. 58).

It is not certain whether the 'stones' might be unusually large hailstones, as may occur from very powerful thunderclouds, or whether geological stones — perhaps even real meteorites — might at times be involved.

'Of the fourth kynde [of lightning] called Fulmen.' "The moste dangerus, violent, and hurtfull, kinde of lightning" (p. 61). A hot exhalation trapped in a cloud, might burst forth, setting itself on fire, and striking down to the Earth with terrific force. The thunder-crack thus created was sudden, short, and like a great gun. "And often tymes a greate stoone is blowne out, with it, which they call the tonder bolt" (p. 62). This thunderbolt was believed composed of earthy matter coagulated together with moisture within the exhalation (itself having come out from the earth). It consisted of brimstone (sulphur) and other metallic substances, hardened by the great heat of the exhalation like a brick in a kiln, so that when it was hurled down by the exploding exhalation, it could strike down steeples and other tall buildings of stone. Wooden structures it could smash through and set on fire, as also living trees, "and the stronger the thynge be that resisteth it, the more harme it dothe to it" (p. 62).

The bolt itself was "sharpe poynted at one ende, and thycke at the other ende, which is caused by reason, that the moyster part, as heauyer, goeth to the bottome of it. So is the toppe smal, and the bottom thick" (p. 62). It was supposed never to delve more than five feet (1.5m) into the ground.

In this description, it is easy to see where the concept of burning hot meteorites setting fire to surface objects probably derived, the act of causing fire really due to the lightning strike. A lightning strike does behave like a solid object in its destructive power quite often. Aside from this, the shape of the thunderbolt is exactly as commonly given elsewhere in folklore, where fossil belemnites were frequently said to be thunderbolts, as was mentioned by (McBeath, 1997b), for instance, though here reversed from the sometimes spear-like concept of the pointed end leading, to a more hammer-like idea of the weightier end preceding.

5 'The fourth booke *of watry impressions*'

As in Book Three, we anticipated finding little of immediate interest, but there were a couple of items in the section on unusual rains, pages 93–95.

'Of monstruous or prodigious rayne.' Fulke indicated that following from the thunderbolt argument, it was quite reasonable for earthy matter to gather as stones inside clouds. He continued that some people said winds from caves in the Earth, breaking violently upwards, might carry earth and stones with them in so doing, which the air could not support. Consequently, these would fall as rains of stones. He concluded that it was "no great meruayle" (p. 94) that the great heat burning in the clouds should turn the clay-like earthy matter into hardened bricks.

A little later, Fulke mentioned rains of iron from the clouds. He wrote that, "The generall matter of all metalles, which is quicksiluer, and brymstone, with the special matter of mixtion, that maketh irone, weare all drawen vp together, and there concocted into the metall" (p. 95), which subsequently rained down.

Quicksilver (literally the apt 'living silver') was mercury, an alchemically essential ingredient in activities to generate new substances. The 'special matter of mixtion' was the vital additional material believed necessary to alchemically create iron. The 'concoction' was due to the action of heat within the clouds.

Fulke ended this section by citing Avicenna, who claimed to have seen a lump of iron weighing 100 pounds (45kg) fall from the clouds, which was later used to make excellent swords. This reference, although inaccurate regarding the making of swords, was to Avicenna's *Congelatione et Conglutinatione Lapidum*, a text we hope to return to for some more detailed comments later in the Project.

The anciently-recorded rains of stones needed some explanation, as we saw earlier (Gheorghe & McBeath, 2006), and Fulke certainly provided one, consistent with the ideas he invoked. Iron falling from the sky seems more plausibly meteoritic, especially that object in Avicenna, which from Avicenna's description cannot have been anything else.

6 'The fift booke of earthly *Meteores* or bodies perfectly mixed'

Once more, our attention in this book was drawn chiefly to a fall from the clouds, although there was one other minor item.

'Of Quicksiluer.' Fulke wrote that some authors suggested quicksilver/mercury was a substance making up the heavens, a little of which dropped from there to Earth at times. Another variant was that it was formed in the clouds, and fell only from there to the ground. When it fell, it did so in a circle, sometimes called a fairy ring. As Fulke had mentioned earlier, under unusual rains, quicksilver had been recorded as falling from clouds in the past, though he doubted it could fall in such ring shapes (p. 117).

Mercury, a metal which is liquid at room temperature, was long a fascination for medieval proto-scientists and others. Its behaviour created a mystique about it, admitting of many, sometimes fancifully magical, possibilities. The creation of circular fairy-ring fungi patches in grass by meteors, though not mercury meteors, has been discussed in these pages before (Beech, 1993; McBeath, 1993). To those comments, we would add that Ramsbottom (1953, pp. 114–115), regrettably without citing his source, mentioned that in some (unstated but probably European) places, the rings were said to be due to a fiery dragon resting on the grass, and that in the Tyrol region of southern Europe, such rings were believed created by the tail of a fiery, winged dragon passing over the fields, "at the epoch of Pegasids (10 August) and Martinmas (11 November)". While Ramsbottom then suggested these dates related to 'Celtic' solar-fertility associations, presumably intended by him as meaning they were of ancient origin, a more likely explanation is that the two dates coincided with the Perseid and Leonid maxima in the second half of the 18th century. As detailed above, and elsewhere during this Project (e.g. WGN 31:6, 2003), 'fiery dragons' were bright meteors, liable to be spotted particularly around such times of year.

'Of the vertue of stones.' The "precious stone called *Astroites*, moueth of it self in vinegar, the sharpenes of the vinegar, percing it, and the ayer excluded, driuing it forward" (p. 120). We have met 'astroites', 'starry stones', in WGN before too (McBeath, 1997b, p. 129), which was the name for fossil skeletons of coral, often preserved in limestones or other lime-rich rocks. Fulke accurately described, though slightly misattributed, the action of a weak acid on limestone, partly dissolving it, releasing gas, which would then propel the stone across a surface where friction was reduced by lubrication — in a shallow vinegar bath, for instance.

7 Conclusion

Fulke's *Goodly Gallerye* gave a fascinating picture of meteoric, and other, beliefs in the 16th–17th centuries, preserving and reinterpreting the wisdom of earlier authors, with fresh comments and examples. For all its failings, this was the state of meteoric science in the English-speaking world at the time, and in many cases was not bettered as an explanation until the beginnings of modern meteor science, in the 18th–19th centuries.

Endnote

As the observant among you may appreciate, this is the article referred to as "(McBeath & Gheorghe, 2006)" in the last paragraph of Section 3 in (McBeath, 2006), which is why it was not listed among the references there. Unfortunately, the planned order of articles was changed, but this point evaded amendment until after publication! Please accept our apologies for any confusion caused.

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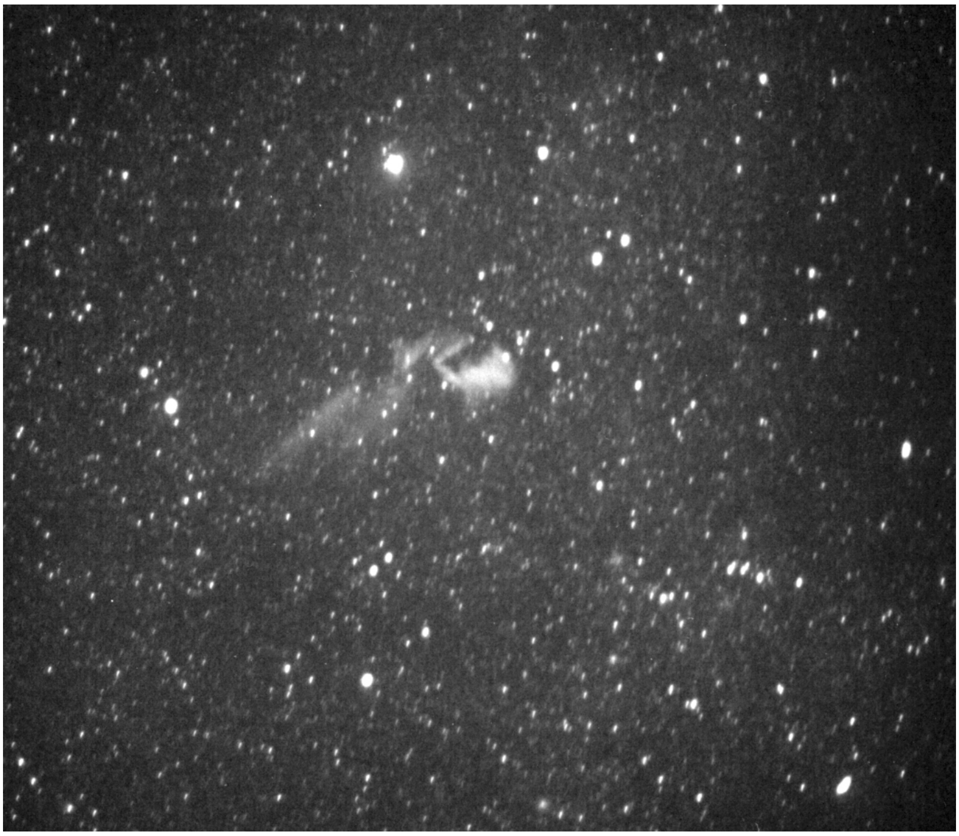
An $m = -10$ Geminid persistent train



Evolution of an $m = -10$ Geminid persistent train in Auriga. Photograph by Valentin Grigore, SARM. Taken from Priboiu-Târgovişte, Romania, on 2006 Dec 14/15, with the fireball occuring at $23^{\mathrm{h}}24^{\mathrm{m}}22^{\mathrm{s}}$ UT. Top photo: 30 seconds, starting at $23^{\mathrm{h}}25^{\mathrm{m}}22^{\mathrm{s}}$ UT. Bottom photo: 30 seconds, starting at $23^{\mathrm{h}}25^{\mathrm{m}}52^{\mathrm{s}}$ UT. Camera: Canon T70 with $f = 50$ mm, $f/1.4$ Canon lens. Film: Konica VX400.