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WGN

35:6
december 2007

Ursids
Sporadics
WGN editorship
Radio Commission

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Administrative

Ursids

Ongoing meteor work

History

Front cover photo

A Perseid photographed on 2007 August 12 at $22^{h}03^{m}$ UT by Manos Kardasis (member of the Hellenic Amateur Astronomy Association, `www.hellas-astro.gr`). Camera: Canon 300D. Lens: $f = 17$ mm. Exposure: 30^{s}.

Back over photo

A pseudorealistic view on major meteoroid streams in space around the Earth's orbit. The picture is calculated according to the mean orbital elements of showers. Widths of showers are not guite real. Parts of showers under the plane of the ecliptic are shown in a darker tint of of the color used. Provided by Peter Zimnikoval

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Editorial — Time for change

Chris Trayner

I have now been editing WGN for about five years. My first issue was 31:1 in 2003 February, though I helped with 30:6 to see what it was like. When I was asked to take over as Editor, I said I would do it for five years and then decide whether to continue.

In the event, after thinking hard about it for the last year and a half, I have decided that it is time for me to stop and someone else to take over. I enjoy doing it, but an organisation needs to evolve to prosper. I think I have managed to maintain the standard of articles, and improve the appearence (though it is the science that matters, not the prettiness).

The IMO Council is therefore calling for candidates for the position of Editor. The official announcement is on page 119. The date when the new Editor starts will depend on many things and is not clear yet. My guess is that it will be in Spring or Summer 2008.

Whoever the new Editor is, they will have the support of a very experienced and knowledgeable team of about half a dozen sub-editors. They will also have my support, certainly in the hand-over, and also after that if they choose to use the software I wrote to handle WGN.

Editing WGN is an enormously satisfying task — you really do get the feeling that you are making a small but worthwhile contribution to science. The Editor does not need any previous experience of Journal editing — I had none when I started. If you think that you might enjoy editing WGN, please contact us by responding to the official announcement. If you are uncertain, contact us with questions. Do not be shy: we will be delighted for the chance to consider you.

IMO bibcode WGN-356-editorial NASA-ADS bibcode 2007JIMO...35..117T

Results of the recent electronic ballot

Robert Lunsford, IMO Secretary-General

The final count of the electronic votes were:

I approve the financial report on 2006	Yes	34	No	1	Abstention	1
I approve the budget proposal for 2008	Yes	33	No	1	Abstention	2

There were no written votes.

As you can see there was a marked increase in participation over the last mail-only ballot. Further publicizing of our electronic ballot should assist in increased participation in upcoming elections.

IMO bibcode WGN-356-lunsford-voteres NASA-ADS bibcode 2007JIMO...35..117L

A new Working List of meteor showers: Correction

Table 2 of (Arlt & Rendtel, 2006) was mis-printed. The contents were correct, but the Table was too long for the page and the last line was lost. The entire Table is printed overleaf. We apologise for the mistake.

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

References

Arlt R. and Rendtel J. (2006). “A new Working List of meteor showers”. *WGN*, **34:3**, 77–84.

IMO bibcode WGN-356-arlt-correction NASA-ADS bibcode 2007JIMO...35..117.

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

The Editorship of WGN

The IMO Council

WGN Editor Dr. Chris Trayner has announced his resignation effective as soon as possible. The IMO Council therefore announces a call for candidates to fill the position of WGN Editor. The following describes what is required of the future Editor.

1 General

The Editor should produce an issue of WGN every two months. This involves the following tasks:

- Receiving items submitted for publication.
- Sometimes suggesting to people that they write and submit an item.
- Deciding whether the item is suitable for publication, often asking the author(s) to improve it.
- Often helping authors to make these improvements.
- Checking the English, and often helping the authors to improve this.
- Laying out the articles on the page. This often involves communicating with authors over the form of diagrams.
- Writing an Editorial and some administrative announcements.
- Adding the material for the covers.
- Arranging all this material into an issue.
- Preparing this as computer files.
- Sending these to another IMO officer for printing.

Note that the Editor does not have to arrange printing, mailing or checking who has paid their subscriptions. (S)he does not have to deal with finance.

Comment on the checking of language: the English needs to be correct as far as possible and certainly intelligible. However, no one is perfect and perfection is not required. Certainly the Editorship is not restricted to native English speakers.

The following notes give more detail.

2 Material

- The Journal deals with meteor science. This is its prime material, but there is often other material, e.g. historical, provided it has some relevance to meteor science.
- It should be suitable for both amateur and professional readers.
- Material published should be, as far as possible, correct. The Editor is not expected to make sure that no mistakes are ever published, of course! (S)he will have neither the time nor the knowledge to ensure this. Indeed, science often proceeds by publishing the best the author can achieve, then others finding and correcting mistakes.
- Material published should be of high quality. However, since WGN is a pro-am journal, some compromise is acceptable to allow less experienced workers to publish.

3 Submissions

Many WGN authors lack training in the writing of scientific papers. The approach of professional science journals, where papers are simply Referred for improvement with no help in doing so, is inadequate for WGN. The Editor must therefore communicate with authors who have submitted material for publication. This includes the following:

- Discussing any changes needed to make the submission suitable for publication. This sometimes involves helping the authors to improve their papers.

IMO bibcode WGN-356-imo-edann NASA-ADS bibcode 2007JIMO...35..119I

- Discussing any changes needed for technical reasons (e.g. diagrams submitted with inadequate pixel resolution).
- If at all possible, getting poor papers up to the standard needed for publication.
- Helping authors with their English, when needed.

4 Deliverables

The Editor's main product is a set of computer files ready to be taken to a printer who will print them. (The exception is the outside front cover. This is handled by Rainer Arlt; the Editor merely provides the photo and some captions.) These files are sent to Rainer in Potsdam; unless the Editor lives there, internet will be the only practical way of sending them.

Other deliverables are backup copies of each issue and material to be sent to NASA-ADS for their online service. (Much of the preparation of this is done by Mihaela Triglav, not the Editor.) In many cases authors request PDFs of their papers.

5 Computer issues

The Editor will require the use of a computer: this should really be a home machine, as it is unlikely that the Editing can all be done in spare time at work.

Storage space: the first five issues of this year have required up to 1.4 GByte each, with an average of about $^3/_4$ GByte per issue. The main reason for the size is images, which often tend to be kept as several copies. Tidying up could probably cut this space requirement down significantly.

Internet connectivity: The files of each issue, as sent for printing, have ranged from about about 3 MByte to 40 MByte (for the first five issues this year). This needs broadband, though a nearby internet cafe might be an option. The Editor often receives emails with attached images of several MBytes, sometimes 10 MByte or more.

WGN is currently edited in LaTeX. This is **not** a requirement of the job: the new Editor might want to use something else. (Note, though, that Word would probably be inadequate.) If the new Editor chose LaTeX, (s)he would inherit a useful body of software written by the present Editor to automate some parts of the job.

This description is an outline. More details are available by emailing the Secretary General, Bob Lunsford, at `lunro.imo.usa@cox.net` . Anyone interested is welcome to contact the present Editor to discuss what is involved in the job at `c.trayner@leeds.ac.uk` .

Radio Commission Director appointed

For many years the post of Director of the Radio Commission has been vacant. We are now glad to announce that Jean-Louis Rault has stepped forward to fill this position. We are delighted to welcome him.

More details of the Radio Commission will be published in the next WGN. Meanwhile, Jean-Louis' email address is `f6agr@orange.fr`; his other contact details are inside the back cover.

Photo: Jean-Louis Rault, the new Radio Commissioner. Jean-louis is the one on the right.

IMO bibcode WGN-356-anon-radiocomm NASA-ADS bibcode 2007JIMO...35..120.

From the Treasurer — Please support your organization!

Marc Gyssens [1]

1 Supporting members 2007

The following people have paid at least double the normal membership fee in 2007:

Lars Bakmann	Luc Bastiaens	Luis Bellot Rubio	Elaine Chapman
Marc Gyssens	Axel Haas	Casper ter Kuile	Marc de Lignie
Robert Lunsford	Sirko Molau	Tom Roelands	Paul Roggemans
Hans-Georg Schmidt	Arnold Tukkers	Cis Verbeeck	Jan Verbert

Several members also regularly give smaller gifts that are equally appreciated!

Thanks to these gifts, we were able to support some meteor workers to attend the 2007 International Meteor Conference in Barèges, France, who would otherwise not have been able to attend. Concretely, we supported four Bulgarian and one Romanian participants. By doing so, we try to prevent valuable meteor workers having to work in isolation and to ensure that they get integrated in the international network that is at the very basis of our Organization. Subsidies have been granted on the basis of a formal application. These applications were judged by the Council.

Some members assigned their gift specifically to providing IMO membership or membership renewal to meteor workers for whom this would otherwise have been very difficult financially.

To all these people, our sincerest thanks!

2 How to become a supporting member in 2008?

This is quite simple: by paying at least double the normal membership fee in 2008, i.e., €52 or $72 (€75 or $105 for airmail delivery outside Europe). Please mention 'supporting membership' as comment with your payment!

You can contribute greatly to our efforts by becoming a supporting member. An overview of the support given to participants of the International Meteor Conference can be found in (Rendtel & Gyssens, 2006). Up to now, the IMO has spent part of the reserves it has built up over the years for this purpose, over and above the gifts it received. However, we obviously cannot continue doing so, and, therefore, we appeal to our members to become supporting member if they can, so that we can balance the support we wish to provide against your gifts!

The 2008 Supporting Members will be listed in WGN late in 2008.

Also note, as already indicated above, that smaller gifts are of course also welcome as they also contribute to this goal!

3 Gift memberships

Another way to support the meteor community is by providing gift memberships to one or more meteor worker for whom this would otherwise constitute a considerable financial effort. If you want to do this, take the following, easy steps:

a. Inform the meteor workers concerned of your intention, to make sure he or she accepts your kind gift. After all, nobody can be forced to join or rejoin an organization!

b. In case of *new* members, i.e., for those meteor workers concerned that have not been IMO member before, ask them to fill out a membership form on the website. (It is possible to clarify that this concerns a gift membership by adding a comment.) In case of a *renewal*, the person is already in our membership database, and must therefore not take any special action.

c. In the comment accompanying your payment, please mention clearly for whom the membership fees are intended!

Providing gift memberships is another way to ensure that valuable meteor workers do not get isolated by providing them access to the information disseminated by the IMO!

Again, the International Meteor Organization needs your support! Any support is most welcome and the international meteor community will be grateful for it!

References

Rendtel J. and Gyssens M. (2006). "From the IMO Council". *WGN*, **34:5**, 126.

[1] Heerbaan 74, B-2530 Boechout, Belgium. E-mail: `marc.gyssens@uhasselt.be`

IMO bibcode WGN-356-gyssens-supportmemb NASA-ADS bibcode 2007JIMO...35..121G

Many hands make light work

Juergen Rendtel [1]

The International Meteor Organization is an organization of, for, and run by its members. This last point is illustrated by the fact that the Council can count on the support of several other IMO members who carry out important tasks in the operation of the IMO. Most of them do this work 'behind the scenes', and, therefore, you may not be aware of their valuable contributions. In this short note, we would like to present these often anonymous people to you.

1 The IMO Journal WGN

Council Member Chris Trayner is the editor-in-chief of WGN, but, of course, he is dependent on a lot of people, first of all the authors of articles! Some people also help in editing or proofreading: Rainer Arlt, Wayne T. Hally, Javor Kac, Juergen Rendtel, Paul Roggemans and Mihaela Triglav.

When WGN is finished, Chris sends the PDF file to Council Member Rainer Arlt who makes sure that it gets printed. He also prepares the front cover. For shipping WGN, including sending back issues to late subscribers, we can count on the invaluable help of our previous Treasurer, Ina Rendtel. The packing procedure is organized as a regular meeting of the (meteor) astronomy group in Potsdam, Germany.

2 Website

Needless to say, the IMO website is becoming ever more important. A lot of information can be found here, people can register as members or IMC participants and, quite recently, an electronic shop has become operational. Also, voting members can now vote electronically on various proposals instead of using the very involved procedure using snail mail (which is still available to be used, of course).

The maintenance of the website as well as all the improvements that have been made particularly during the recent months is the work of our webmaster, Luc Bastiaens.

3 Publications

Once an order is placed via the electronic shop and paid for, Treasurer Marc Gyssens sends the relevant information to the persons shipping the various items. The DVDs are taken care of by Marc himself. Council Member Huan Meng takes care of the Radio Meteor School Proceedings 2005, which have been recently reprinted in China, and are available again. All other publications are sent by Roland Winkler from Germany.

4 Finances

Of course, the Treasurer, Marc Gyssens, is responsible for the finances. He can count on the support of Jan Verbert, who does the book keeping. By separation of the book keeping and the actual bookings, a kind of control is possible at any time.

Steve Evans and Masahiro Koseki contribute as Assistant Treasurers for the United Kingdom and Japan respectively by collecting membership fees in these countries. Robert Lunsford collects payments from North America.

5 Commission Directors

Finally, we want to emphasize that not all the commissions are led by Council Members. The Visual Commission is directed by Rainer Arlt, and the enormous amount of data input is only possible with support given by Javor Kac and Pavol Habuda, as well as some others on specific occasions. Sirko Molau is the director of the Video Commission, while enquiries to the Photographic Commission are handled by Marc de Lignie. The Telescopic Commission is lead by Malcolm Currie, and the Radio Commission by Jean-Louis Rault.

We thank all these IMO members for their valuable contributions. Only if many members feel involved and step forward to carry out various tasks so that the workload can be shared, the continuity of our Organization can be guaranteed in the long run! If you feel inspired by this short note and want to contribute in this respect, do not hesitate to contact me or any Council member!

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IMO bibcode WGN-356-rendtel-helpers NASA-ADS bibcode 2007JIMO...35..122R

Letter — Naming names revisited

Alastair McBeath [1]

Like Chris Trayner (editorial, *WGN* **35:5**, 2007, p. 95), I was disappointed to see so little response in the journal to my letter in *WGN* **35:4** (p. 70), concerning the undiscussed change to using the '-iid' suffix for some meteor shower names that featured in the 2008 *IMO Meteor Shower Calendar*, with just Jürgen's reply (*WGN* **35:5**, p. 98). I was equally disappointed to see even Jürgen's support for the change mentioned no positive reasons for observers to do so. Apparently, we are just meant to accept it because it has been 'officially' decided upon, regardless of whether that benefits our subject or not.

Including the materials published in WGN, items passed between Council members, and notes sent to me directly, I have seen comments from a total of ten people regarding this matter, four favouring my position of retaining the '-id' suffix, three supporting the opposite position (changing to the '-iid' suffix), with three others 'neutral', either accepting there were arguments on both sides, or from people who simply asked why such a change had been made at all. Those preferring the '-id' suffix, or who were in the neutral category, are all involved with the public perception of, and involvement in, meteor (and other) astronomy to a much greater extent than those against, who are mainly involved in analyses, or the more technical aspects of meteor studies. However, this too is a disappointing total of responses. Perhaps it shows most people simply don't care what we call things, or how those decisions are arrived at. This time, the case is a minor one after all.

The naming of showers, with its mixture of Latin constellation names, Greek Bayer letter and Arabic Flamsteed numeral star designations, remains somewhat arbitrary, even after the proposed IAU changes noted in *WGN* **34:5** (2006, pp.127-128). The invented word 'Hydrusids', for when the constellation Hydrus is involved, shows clearly that Latin language purity is not employed uniformly anyway. Further oddities include the survival of the Quadrantids, a handy reminder that the IAU constellation nomenclature was not always the only option, which name could be amended to the 'January Böotids', and the α Monocerotids, which on the nearest, brightest star 'rule' probably should be the α Canis Minorids. There are others too, yet it seems *these* changes have not been suggested. On the IMO Working List of Visual Showers, we still have the 'Southern δ Aquari[i]ds', despite the fact the Northern branch is no longer considered independently active, subsumed instead into the artificial Antihelion Source, which latter, while it definitely improves matters for observers, isn't a strict shower at all!

As I said previously, it doesn't really matter what we call things, as long as we all understand what is meant by the words, but why make things more complex than they are already?

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IMO bibcode WGN-356-mcbeath-letter NASA-ADS bibcode 2007JIMO...35..123M

Solar Longitudes for 2008

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 2008. 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`.

References

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

IMO bibcode WGN-356-arlt-solarlong
NASA-ADS bibcode 2007JIMO...35..123A

Solar longitudes 2008. Dates refer to 00^h UT.

Jan	1	279.82	Mar	1	340.67	May	1	40.88	Jul	1	99.42	Sep	1	158.81	Nov	1	218.82
Jan	2	280.84	Mar	2	341.67	May	2	41.85	Jul	2	100.37	Sep	2	159.78	Nov	2	219.82
Jan	3	281.86	Mar	3	342.67	May	3	42.82	Jul	3	101.33	Sep	3	160.75	Nov	3	220.82
Jan	4	282.88	Mar	4	343.68	May	4	43.79	Jul	4	102.28	Sep	4	161.72	Nov	4	221.82
Jan	5	283.90	Mar	5	344.68	May	5	44.76	Jul	5	103.23	Sep	5	162.69	Nov	5	222.82
Jan	6	284.92	Mar	6	345.68	May	6	45.73	Jul	6	104.19	Sep	6	163.66	Nov	6	223.83
Jan	7	285.94	Mar	7	346.68	May	7	46.70	Jul	7	105.14	Sep	7	164.63	Nov	7	224.83
Jan	8	286.95	Mar	8	347.68	May	8	47.66	Jul	8	106.09	Sep	8	165.60	Nov	8	225.83
Jan	9	287.97	Mar	9	348.68	May	9	48.63	Jul	9	107.05	Sep	9	166.57	Nov	9	226.84
Jan	10	288.99	Mar	10	349.68	May	10	49.60	Jul	10	108.00	Sep	10	167.54	Nov	10	227.84
Jan	11	290.01	Mar	11	350.68	May	11	50.56	Jul	11	108.96	Sep	11	168.51	Nov	11	228.85
Jan	12	291.03	Mar	12	351.68	May	12	51.53	Jul	12	109.91	Sep	12	169.49	Nov	12	229.85
Jan	13	292.05	Mar	13	352.68	May	13	52.50	Jul	13	110.86	Sep	13	170.46	Nov	13	230.86
Jan	14	293.07	Mar	14	353.67	May	14	53.46	Jul	14	111.82	Sep	14	171.43	Nov	14	231.87
Jan	15	294.09	Mar	15	354.67	May	15	54.43	Jul	15	112.77	Sep	15	172.41	Nov	15	232.87
Jan	16	295.11	Mar	16	355.67	May	16	55.39	Jul	16	113.72	Sep	16	173.38	Nov	16	233.88
Jan	17	296.13	Mar	17	356.66	May	17	56.35	Jul	17	114.68	Sep	17	174.36	Nov	17	234.89
Jan	18	297.14	Mar	18	357.66	May	18	57.32	Jul	18	115.63	Sep	18	175.33	Nov	18	235.89
Jan	19	298.16	Mar	19	358.65	May	19	58.28	Jul	19	116.58	Sep	19	176.31	Nov	19	236.90
Jan	20	299.18	Mar	20	359.64	May	20	59.24	Jul	20	117.54	Sep	20	177.28	Nov	20	237.91
Jan	21	300.20	Mar	21	0.64	May	21	60.20	Jul	21	118.49	Sep	21	178.26	Nov	21	238.92
Jan	22	301.21	Mar	22	1.63	May	22	61.16	Jul	22	119.45	Sep	22	179.24	Nov	22	239.93
Jan	23	302.23	Mar	23	2.62	May	23	62.12	Jul	23	120.40	Sep	23	180.22	Nov	23	240.94
Jan	24	303.25	Mar	24	3.61	May	24	63.08	Jul	24	121.36	Sep	24	181.20	Nov	24	241.95
Jan	25	304.27	Mar	25	4.60	May	25	64.05	Jul	25	122.31	Sep	25	182.18	Nov	25	242.97
Jan	26	305.28	Mar	26	5.59	May	26	65.01	Jul	26	123.27	Sep	26	183.16	Nov	26	243.98
Jan	27	306.30	Mar	27	6.58	May	27	65.97	Jul	27	124.22	Sep	27	184.14	Nov	27	244.99
Jan	28	307.31	Mar	28	7.57	May	28	66.93	Jul	28	125.18	Sep	28	185.12	Nov	28	246.00
Jan	29	308.33	Mar	29	8.56	May	29	67.88	Jul	29	126.13	Sep	29	186.10	Nov	29	247.02
Jan	30	309.35	Mar	30	9.55	May	30	68.84	Jul	30	127.09	Sep	30	187.08	Nov	30	248.03
Jan	31	310.36	Mar	31	10.54	May	31	69.80	Jul	31	128.05						
Feb	1	311.38	Apr	1	11.52	Jun	1	70.76	Aug	1	129.00	Oct	1	188.07	Dec	1	249.04
Feb	2	312.39	Apr	2	12.51	Jun	2	71.72	Aug	2	129.96	Oct	2	189.05	Dec	2	250.06
Feb	3	313.41	Apr	3	13.50	Jun	3	72.68	Aug	3	130.92	Oct	3	190.04	Dec	3	251.07
Feb	4	314.42	Apr	4	14.48	Jun	4	73.64	Aug	4	131.88	Oct	4	191.02	Dec	4	252.09
Feb	5	315.44	Apr	5	15.47	Jun	5	74.59	Aug	5	132.83	Oct	5	192.01	Dec	5	253.10
Feb	6	316.45	Apr	6	16.45	Jun	6	75.55	Aug	6	133.79	Oct	6	192.99	Dec	6	254.12
Feb	7	317.47	Apr	7	17.44	Jun	7	76.51	Aug	7	134.75	Oct	7	193.98	Dec	7	255.13
Feb	8	318.48	Apr	8	18.42	Jun	8	77.47	Aug	8	135.71	Oct	8	194.96	Dec	8	256.15
Feb	9	319.49	Apr	9	19.40	Jun	9	78.42	Aug	9	136.67	Oct	9	195.95	Dec	9	257.16
Feb	10	320.50	Apr	10	20.39	Jun	10	79.38	Aug	10	137.63	Oct	10	196.94	Dec	10	258.18
Feb	11	321.52	Apr	11	21.37	Jun	11	80.33	Aug	11	138.58	Oct	11	197.93	Dec	11	259.19
Feb	12	322.53	Apr	12	22.35	Jun	12	81.29	Aug	12	139.54	Oct	12	198.92	Dec	12	260.21
Feb	13	323.54	Apr	13	23.33	Jun	13	82.25	Aug	13	140.50	Oct	13	199.91	Dec	13	261.23
Feb	14	324.55	Apr	14	24.31	Jun	14	83.20	Aug	14	141.46	Oct	14	200.90	Dec	14	262.24
Feb	15	325.56	Apr	15	25.29	Jun	15	84.16	Aug	15	142.42	Oct	15	201.89	Dec	15	263.26
Feb	16	326.57	Apr	16	26.27	Jun	16	85.11	Aug	16	143.38	Oct	16	202.88	Dec	16	264.28
Feb	17	327.58	Apr	17	27.24	Jun	17	86.06	Aug	17	144.35	Oct	17	203.87	Dec	17	265.29
Feb	18	328.59	Apr	18	28.22	Jun	18	87.02	Aug	18	145.31	Oct	18	204.86	Dec	18	266.31
Feb	19	329.60	Apr	19	29.20	Jun	19	87.97	Aug	19	146.27	Oct	19	205.85	Dec	19	267.33
Feb	20	330.61	Apr	20	30.17	Jun	20	88.93	Aug	20	147.23	Oct	20	206.85	Dec	20	268.35
Feb	21	331.62	Apr	21	31.15	Jun	21	89.88	Aug	21	148.19	Oct	21	207.84	Dec	21	269.37
Feb	22	332.62	Apr	22	32.12	Jun	22	90.83	Aug	22	149.16	Oct	22	208.84	Dec	22	270.38
Feb	23	333.63	Apr	23	33.10	Jun	23	91.79	Aug	23	150.12	Oct	23	209.83	Dec	23	271.40
Feb	24	334.64	Apr	24	34.07	Jun	24	92.74	Aug	24	151.08	Oct	24	210.83	Dec	24	272.42
Feb	25	335.64	Apr	25	35.05	Jun	25	93.70	Aug	25	152.05	Oct	25	211.83	Dec	25	273.44
Feb	26	336.65	Apr	26	36.02	Jun	26	94.65	Aug	26	153.01	Oct	26	212.82	Dec	26	274.46
Feb	27	337.65	Apr	27	36.99	Jun	27	95.60	Aug	27	153.98	Oct	27	213.82	Dec	27	275.48
Feb	28	338.66	Apr	28	37.96	Jun	28	96.56	Aug	28	154.94	Oct	28	214.82	Dec	28	276.50
Feb	29	339.66	Apr	29	38.94	Jun	29	97.51	Aug	29	155.91	Oct	29	215.82	Dec	29	277.52
			Apr	30	39.91	Jun	30	98.46	Aug	30	156.88	Oct	30	216.82	Dec	30	278.54
									Aug	31	157.84	Oct	31	217.82	Dec	31	279.56

Ursids

Strong Ursid shower predicted for 2007 December 22

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The imminent return of comet 8P/Tuttle is expected to cause Ursid shower outbursts on December 22. There are occasional visual and forward meteor scatter observations of such outbursts from the previous perihelion return of 1994, and the one before that in 1980. In this paper, we investigated what may cause these outbursts and make predictions on what to expect from dust trails ejected in the period AD 300 – 1400. Younger trails do not contribute to these Filament-type outbursts. Our knowledge of the position of older trails suffers progressively from an uncertain position of the comet in its orbit. The comet passed close to Jupiter's orbit 15 000 years ago, at which time it may have been captured. We find that Jupiter's influence at the ascending node causes some meteoroids to evolve into resonant orbits that move into Earth's path. For 2007, we expect a strong shower with a peak ZHR = 40 – 80 per hour and a duration of FWHM = 2 – 8.5 hours, centered on December 22 at $20^{\rm h}.0$ – $22^{\rm h}.2$ UT (most likely $21^{\rm h}.4$ – $22^{\rm h}.2$ UT). Peak rates in 2008 – 2012 will be less. The exact peak time and duration, as well as structure in the shower profile, can identify the age of the stream. To find out, an airborne observing campaign is being prepared that would deploy from NASA Ames Research Center in California and would observe the 2007 December 22 Ursid shower over the Canadian arctic.

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1 Introduction

Comet 8P/Tuttle will return to perihelion on January 27, 2008, and has a favorable encounter with Earth, the best since the 1790 discovery, passing only at 0.25 AU on January 5. This could well be the brightest comet for 2008 and observing programs to study this comet are scheduled for the Hubble -, Spitzer -, and Chandra space telescopes, as well as from many ground-based observatories.

The Ursid meteor shower was discovered during an outburst in 1945, when the comet was at aphelion (Ceplecha, 1951). Another such outbursts occurred in 1986, and again in 2000. In most other years, this is only a minor shower with ZHR < 10.

The 2000 'aphelion' outburst was predicted (Jenniskens, 2000) and we now know that this dust is in the 6:7 mean-motion resonance with Jupiter, and in an orbit slightly longer than that of the comet (13:15), which, over time, causes a lag between the return of comet and the dust. It takes about 600 years for the dust to evolve inward to cross Earth's orbit, during which time the cloud of dust ended up lagging the comet by 600 times (13/15 x 7/6 -1) = 6.67 years, or half a typical 13.6-yr orbit (Jenniskens et al., 2002).

Occasional reports of high Ursid rates were also made in the years when the comet returned to perihelion during the previous two returns in 1980 and 1994. Jos Nijland of the Dutch Meteor Society observed an outburst in December 1982 (Veltman, 1983), and Japanese observers detected enhanced Ursid activity in

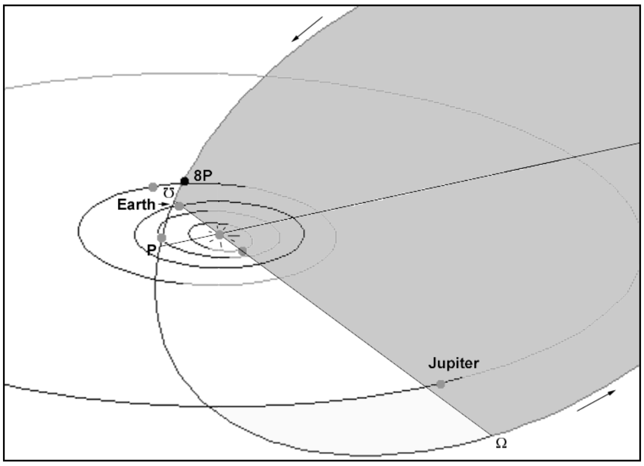

Figure 1 – The present orbit of 8P/Tuttle.

1994 (Ohtsuka et al., 1995). The high Ursid rate in 1994 was anticipated by Katsuhito Ohtsuka (1994), because he also had noticed high Ursid rates in 1981. Forward meteor scatter observations from Kuusankoski, Finland (Yrjölä & Jenniskens, 1998; Jenniskens et al., 2002), reproduced in Figure 2 (next page) demonstrated that the Ursids were in fact elevated in both 1993 and 1994 (Jenniskens, 2006). Significant activity was detected also in 1996, but not in 1995.

It is not clear at present what is responsible for these 'near-comet type' outbursts. 8P/Tuttle has a Halley-type orbit Tisserand invariant $T_{\rm J} = 1.60$. Other Halley-type comets, such as 55P/Tempel-Tuttle and 109P/Swift-Tuttle, have similar outbursts of meteors when the comet returns to perihelion, called the 'Filament' component for historic reasons. Mean-motion resonances are suspected to play a role in the stability of this dust cloud. However, if they do, then the dust grains can get trapped in other resonances than the comet and the dust will tend to quickly spread along the whole orbit of 8P/Tuttle. It is not clear why these outbursts are seen only when the comet returns.

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To find out what mechanism is responsible, we studied the past evolution of 8P/Tuttle and its dust trails.

2 The orbit of 8P/Tuttle (15 000 BC – AD 2000)

The orbit of comet 8P/Tuttle (Figure 1) is only known with certainty since AD 1790, when the comet was first spotted by P. Méchain in Paris. However, the comet is rather large, with a diameter of about 15.6 km (Lamy et al., 2008; Snodgrass, 2007), based on the comet nucleus brightness at aphelion when the nucleus was bare. Hence, non-gravitational effects are relatively small and can be assumed constant in time with some justification.

We made predictions for the upcoming Ursid showers using two different models, that by Lyytinen (1999) and by Vaubaillon (2005a,b), each using a slightly different initial orbit for 8P/Tuttle and different integrators. Lyytinen started from the orbit listed in the Minor Planet Center's Catalogue of Cometary Orbits, 12th edition (1997), with slightly modified non-gravitational parameters to better match the 1790 observation of the comet, and his own design integrator to calculate the comet orbit back in time. Vaubaillon started from the most current orbit of comet 8P/Tuttle and its non-gravitational parameters (JPL K074/18), which was integrated backwards using the HORIZONS JPL program.

For the most recent returns, there is not much difference in the outcome. The comet has evolved close to the 6:7 and 7:8 mean-motion resonances with Jupiter, the first corresponding to a slightly longer orbital period than the comet, the second to a slightly shorter. In recent times, the comet has had an orbital period of about 13.687 years, at least since about 1400 AD.

Before that time, the solutions for different integration techniques and initial orbits start to deviate slightly. Starting with similar orbits for 8P/Tuttle, Lyytinen and Vaubaillon differed in perihelion time by less than 0.1 day in 1899, increasing to about 8 days in AD 980. Going further back in time caused this difference to increase rapidly, being almost a year in AD 774 and more than two years around AD 555. This is due to relatively close passages by Jupiter, at a distance of around 1 AU. These encounters are in part keeping the comet in resonance, but when these encounters are incorrectly calculated, then the orbital evolution will be off. The difference between these solutions mostly reflects the uncertainty in the comet orbit. Here, we consider dust trails ejected in the period 300 - 1400 AD.

For going further back in time, we adopted a different integration technique. The orbit of the comet was integrated back to 15 000 BC using a customized version of INPOP, the planetary ephemerides developed by Fienga et al. (2006). We find that the ascending node of the comet orbit was close to Jupiter around 13 000 BC (Figure 3).

At the present time, the descending node of the comet orbit is rapidly moving towards Earth orbit. Currently, the comet orbit passes about 0.095 AU outside

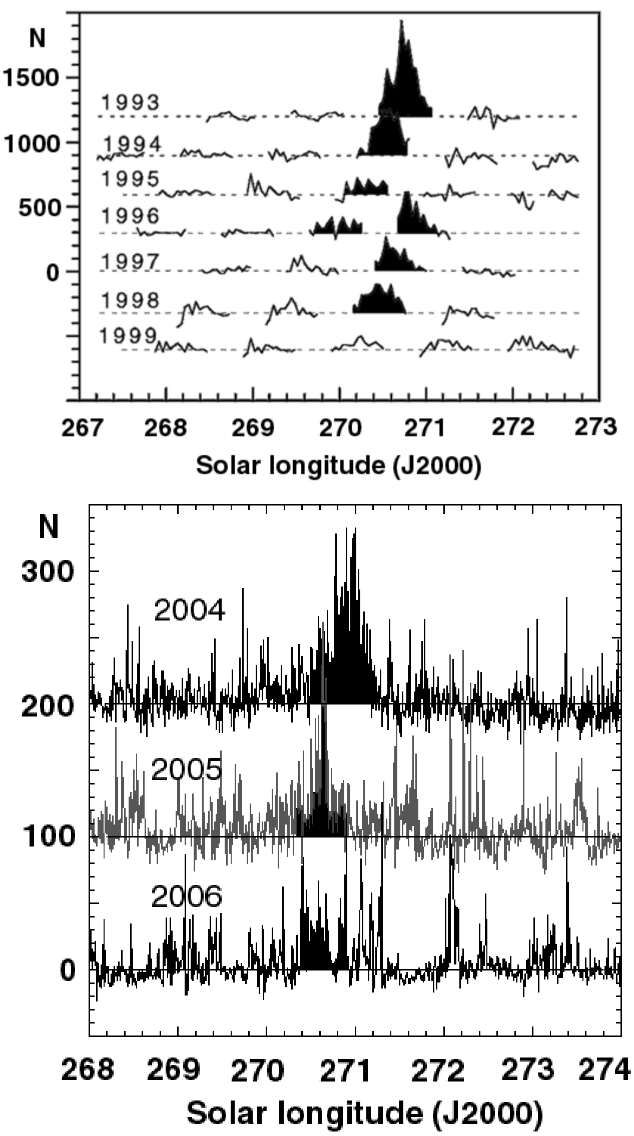

Figure 2 – Rate of meteors detected by forward meteor scatter from Kuusankoski, Finland, after subtracting the sporadic background. Counts have not been corrected for radiant elevation or instrumental geometry. The top graph is reproduced from (Jenniskens et al., 2002); black shaded areas are identified as enhanced rates that are likely due to the Ursid shower. The bottom graph shows more recent data (not on same scale).

of Earth orbit. In the next few hundred years, the node of the orbit will come only slightly closer, before moving outwards again.

3 The Lyytinen model

Based on the comet orbit, we generated dust particles at each perihelion between AD 307 and 788 and integrated the particles forward in time to the point of encounter with Earth orbit, following methods by Kondrat'eva and Reznikov (1985), McNaught and Asher (1999), and Lyytinen (1999). We have modeled the initial differences in orbit between comet and particle by changing the radiation pressure (ejection velocity being zero) and only positive radiation pressure test-particles are included.

Figure 4 shows how the dust moves in and out of Earth's path over time. Dust was near the Earth's or-

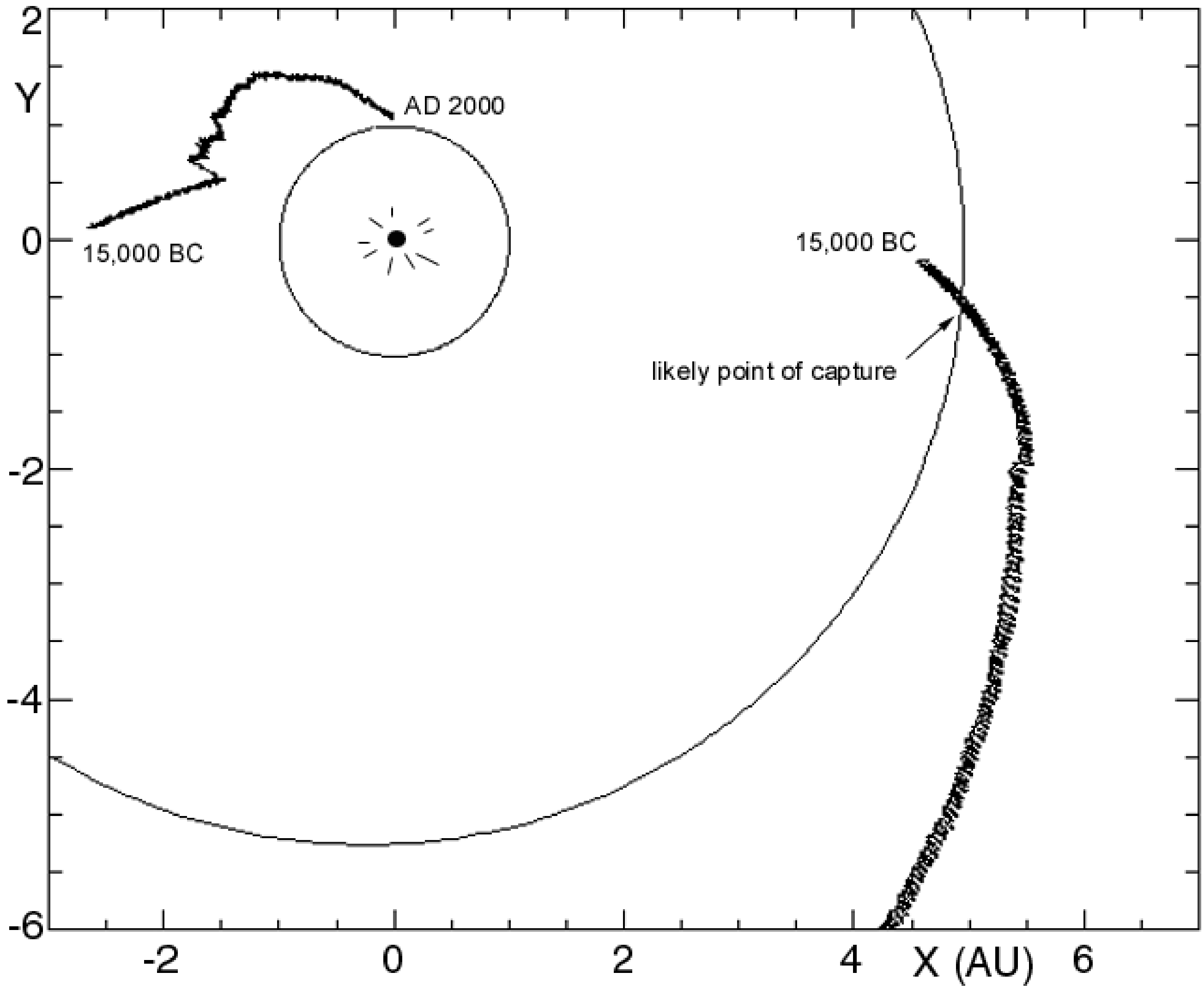

Figure 3 – The past long-term orbital evolution of 8P/Tuttle as indicated by the position of the ascending and descending node. The circles are the orbits of Earth and Jupiter. The curling lines are the calculated position of the nodes of the 8P/Tuttle orbit between 15 000 BC and AD 2000. The descending node is the one close to Earth orbit.

bit around the perihelion return in 1994 (and also that of 1980, not shown). We then calculated the anticipated dust trail encounters by counting those model particles that pass Earth orbit within 0.0015 AU at the time of the expected shower. Results are summarized in Table 1. All particles passing this point within 0.05 years are included.

If we investigate the dust density near Earth's path in the period 1993–1997, we see that much dust was near the Earth's path in 1993, 1994, and 1996, but not in 1995. This is in agreement with the radio forward meteor scatter data (Figure 2).

In later years, the commercial radio transmitters used in this experiment were shut down and other stations were used to make the counts (Figure 2, bottom diagram). As a result, the rates of recent years cannot be directly translated into a Zenith Hourly Rate, in the absence of a reliable scaling from visual ZHR estimates.

Based on the 1993 – 1997 Radio MS data and those from 2004 – 2006 (Figure 2), calibrated by scarce visual observations (Jenniskens, 2006, Table 5b; Jenniskens et al., 2006), the number of particles in the model was then multiplied by a factor of 1.10 to scale these counts to the peak ZHR values in Table 1.

The duration was calculated as the full spread of the particles in the model, keeping in mind that the actual spread is expected to be larger than calculated in absence of a variation in radiation pressure effects. All 1993–1997 outbursts had an FWHM (Full-Width-at-Half-Maximum) of about $0\overset{\circ}{.}35$ in solar longitude, or about 8.5 hours (Jenniskens et al., 2002). Our estimated durations in those years average 8.1 hours, in good agreement.

Based on these calculations, the upcoming Ursid shower encounter in 2007 would be quite promising, with a peak ZHR around 30–60. This estimate is uncertain by at least a factor of 3.6, judging from the standard deviation in the ratio between observed and calculated rates in the past. The outburst would have a duration of about FWHM = 4.9 hours (but perhaps as long as 8.5 hours if older trails are involved).

The meteoroids encountered in 2007 have beta values in the range 7.7×10^{-5} to 1.0×10^{-3}, with an average of 5.6×10^{-4}. These values for the radiation pressure

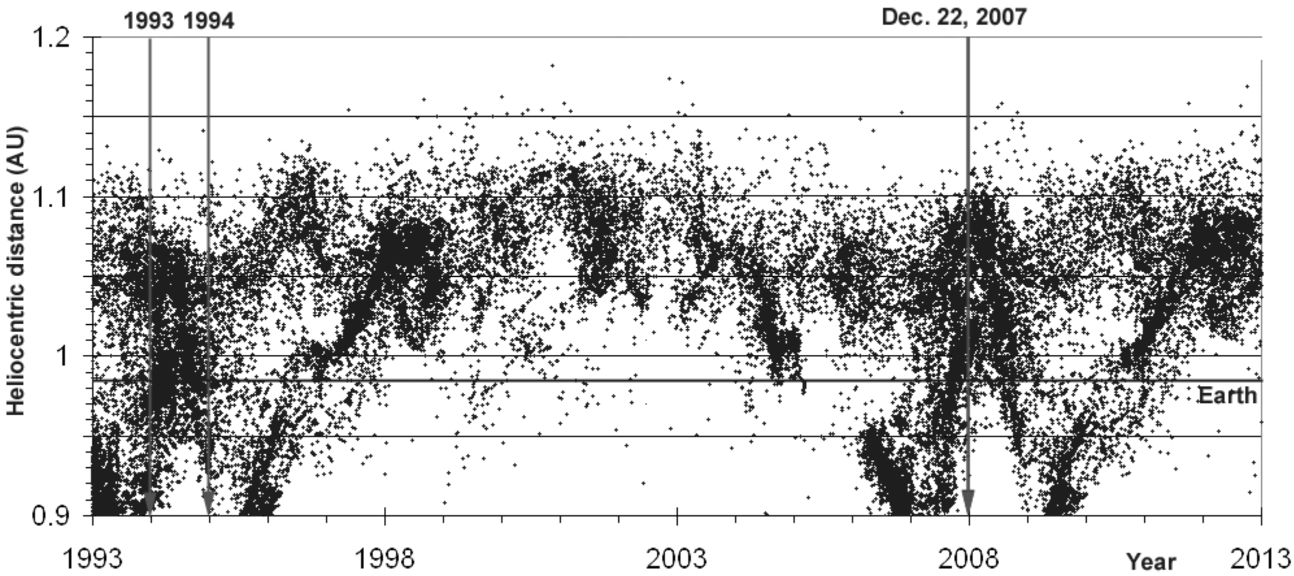

Figure 4 – Position of the node of the dust trails ejected in the period from AD 431 to 788 AD. The time of encounter of the Ursid meteors in Dec. 2007 is marked.

Table 1 – Calculated circumstances for the encounter with AD 307 – 788 dust trails of comet 8P/Tuttle, for all dust particles passing within 0.0015 AU from Earth orbit, according to the model by Lyytinen.

Year AD	Sol. Long. $\lambda_\odot$ (J2000)	Day	Time (UT)	FWHM (hr)	ZHR 413–788	ZHR 307–788	ZHR obs.
2008	270.°60	Dec. 22	05^h07^m	9.7	23	30	future
2007	**270.°57**	**Dec. 22**	$\mathbf{22^h08^m}$	**4.9**	**63**	**40**	**future**
2006	270.°70	Dec. 22	19^h03^m	14.6	12	15	15 ± 5
2005	270.°63	Dec. 22	11^h16^m	2.4	3	1	21 ± 6
2004	270.°90	Dec. 22	11^h24^m	7.3	40	18	48 ± 6
1998	270.°65	Dec. 22	16^h44^m	7.3	1	18	13 ± 3
1997	270.°60	Dec. 22	09^h26^m	7.3	18	35	16 ± 4
1996	270.°70	Dec. 22	05^h29^m	7.3	153	92	25 ± 5
1995	270.°60	Dec. 22	21^h01^m	6.1	31	20	-.-
1994	270.°75	Dec. 22	18^h21^m	9.7	67	62	50 ± 6
1993	270.°96	Dec. 22	17^h03^m	11.0	78	95	100 ± 10
1983	270.°95	Dec. 23	03^h24^m	7.3	8	32	-.-
1982	270.°90	Dec. 22	20^h00^m	8.5	26	23	> 35
1981	270.°90	Dec. 22	13^h53^m	9.7	17	39	55 ± 25
1980	270.°90	Dec. 22	07^h40^m	7.3	111	156	-.-

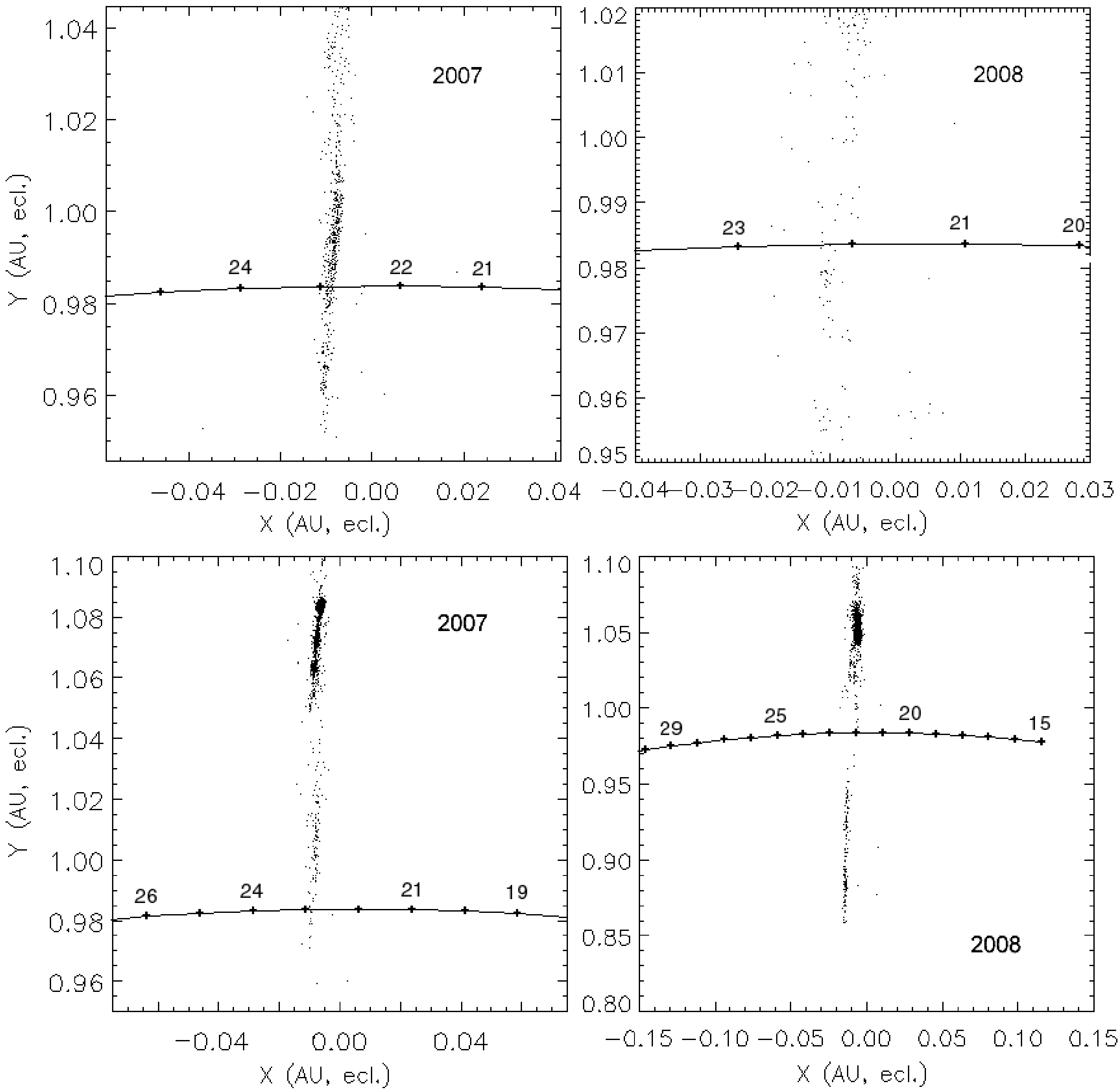

Figure 5 – Distribution of nodes of model particles ejected in AD 700 – 900 in the model by Vaubaillon, now projected on the ecliptic plane. The top diagrams are not merely enlargements of the bottom ones, but results from a second run of the model filled with more model particles.

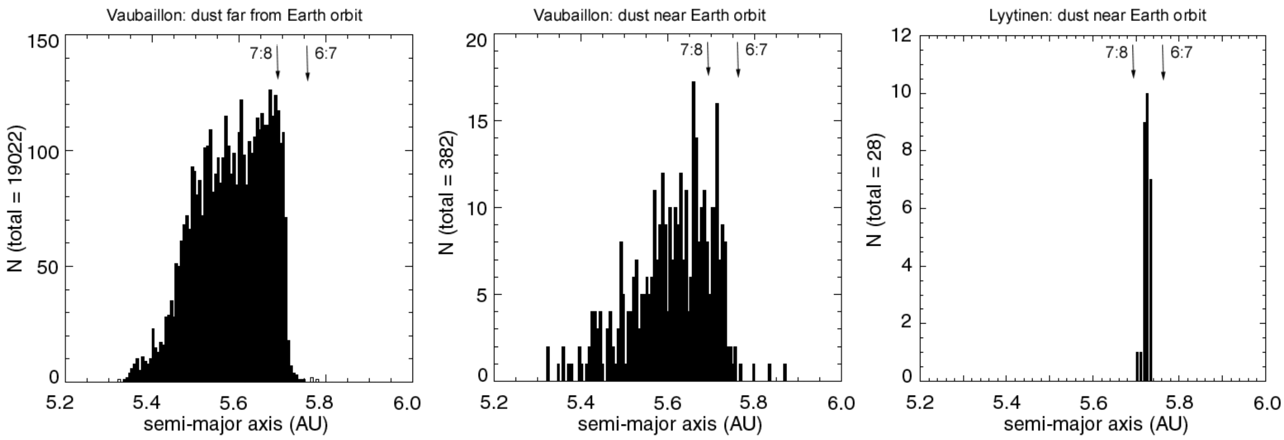

Figure 6 – Distribution of semi-major axis with mean-motion resonances marked. The two histograms to the right show particles that evolved into orbits close to the Earth's orbit, while the histogram to the left shows particles that did not.

are typical for large meteoroids seen as visual meteors, and do not need unusual shape or densities to meet Earth orbit. Past observations point to a high magnitude distribution index of $\chi \sim 2.6$ (Jenniskens, 2006), or a shower relatively rich in faint meteors. However, in 1996, the Ursid filament may have produced brighter meteors with $\chi = 1.9 \pm 0.3$ (Jenniskens et al., 2006).

The results in Table 1 are derived mostly from very few dust trails. The most significant contribution to the outburst in the period 413 – 788 AD comes from the 582 AD dust ejecta. Before AD 413, dust trails from AD 349, 362, 376, and 390 contributed dust in Earth's path. Table 1 shows our estimates of peak activity including or excluding the early trails. The exact perihelion dates are uncertain, so it is not clear at present if it is these dust trails that create the Ursid shower activity at Earth.

4 The Vaubaillon model

These calculations were repeated using the approach by Vaubaillon (2005a,b), wherein thousands of meteoroids are rigorously integrated using a massive parallel super computer at C.I.N.E.S., France. The initial conditions of ejection are based on the comet dust ejection model by Crifo and Rodinov (1997), which is not unlike that of Whipple (1951). Particles were ejected, initially, in the returns of AD 406, 611, 802, 1007, 1213, and 1392. The distribution of nodes in the ecliptic plane in 2007 and 2008 are shown in the bottom two graphs of Figure 5. A denser model of particles was created subsequently, considering all trails ejected in the period AD 700 – 900 (top graphs of Figure 5).

Most trails do not evolve into the Earth's path. We found that the dust trails of 745, 761, 775, 788, 802, and 816 contributed dust in the path of the Earth in 2007. The peak time or encounter of the AD 802 trail alone is calculated at about 2007 December 22, $18^{\mathrm{h}}48^{\mathrm{m}}$ UT. The combined dust trails from AD 700 to 900 shift that maximum to December 22, $20^{\mathrm{h}}03^{\mathrm{m}}$ UT (Table 2) or to $21^{\mathrm{h}}24^{\mathrm{m}}$ UT if a stronger restriction is made on which particles are counted. We consider this $21^{\mathrm{h}}24^{\mathrm{m}}$ UT time the more likely value.

The 700 – 900 trails alone concentrate along a thin filament in Earth's path, suggesting a brief FWHM = 2-hr shower. If older trails are involved, this could well be longer, up to the typical 8.5 hours. Hence, due to these small shifts in node, trails from individual years can cause substructure on the profile. The time of the peak and duration of the shower will measure the epoch of ejection.

5 The cause of Ursid outbursts

We suspect that some trails are efficient at producing grains that intersect the Earth's orbit, and others not, because Jupiter passes by the ascending node at the time when the comet did so as well soon after ejection of the meteoroids. The biggest numbers of particles are affected if Jupiter passes by when the dust is still close together in a short dust trail.

Changes in argument of perihelion and perihelion distance will have the biggest effect on moving the particle node inwards to the Earth's orbit. However, changes in semi-major axis may be more important in the long run due to the effect of mean-motion resonances.

That is because most 'close' encounters do not initially lower the perihelion distance. The closest encounters tend to increase q, rather than decrease it. It appears to be the somewhat more distant encounters, in the range 1.5 – 2 AU, that decrease the nodal distance in the long run. The initial perturbation may move the particles efficiently into the grasp of mean-motion resonances.

To examine the role of mean-motion resonances on the orbital evolution, we studied the semi-major axis of the particles that are near Earth's orbit in 2007 December. In the Lyytinen model, all particles close to the Earth's orbit have a narrow range in semi-major axis, not much different from that of the parent comet (Figure 6, right). The semi-major axis of these orbits is in between the nominal values for the 6:7 and 7:8 resonances with Jupiter's orbit, but to recognize the mean-motion resonance in the particle's evolution, one would have to examine the complete orbital evolution. We followed one of the test particles of the 582 trail and found it to lag the comet orbit by about one revolution, as expected for it being in the 6/7 resonance.

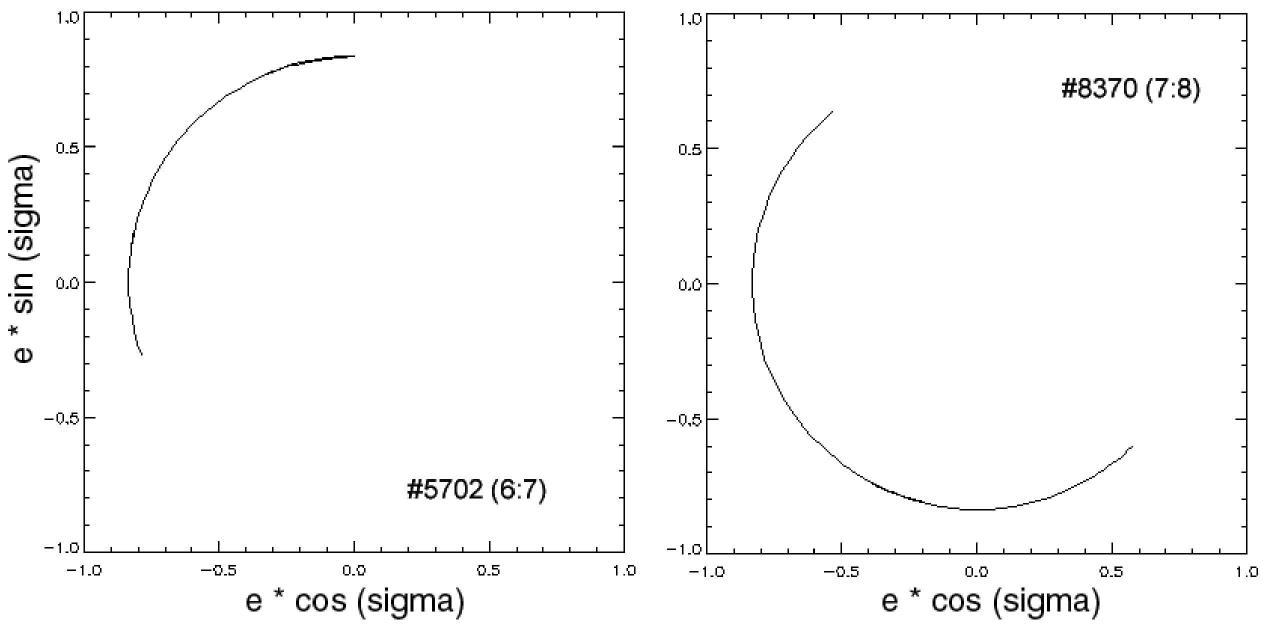

Figure 7 – Critical arguments for particle number 5702, moving in the 6:7 resonance, and particle number 8370, found to move in the 7:8 resonance.

Table 2 – Calculated circumstances for the encounter with AD 700 – 900 dust trails of comet 8P/Tuttle, for all dust particles passing within 0.002 AU from Earth orbit, according to the model by Vaubaillon.

Year AD	Sol. Long. $\lambda_\odot$ (J2000)	Day	Time (UT)	ZHR calc.	ZHR obs.
2012	270.49	Dec. 22	03^h01^m	15	(future)
2011	270.29	Dec. 22	16^h11^m	12	(future)
2010	270.42	Dec. 22	13^h02^m	23	(future)
2009	270.43	Dec. 22	07^h14^m	14	(future)
2008	270.48	Dec. 22	02^h18^m	20	(future)
2007	**270.48**	**Dec. 22**	$\mathbf{20^h03^m}$	**74**	**(upcoming)**
1999	270.44	Dec. 22	17^h54^m	14	-.-
1998	270.79	Dec. 22	19^h54^m	14	-.-
1997	270.48	Dec. 22	06^h33^m	13	16 ± 4
1996	270.54	Dec. 22	01^h44^m	22	25 ± 5
1995	270.62	Dec. 22	21^h28^m	14	-.-
1994	270.56	Dec. 22	13^h48^m	70	50 ± 6
1993	270.91	Dec. 22	15^h52^m	40	100 ± 10
1983	270.77	Dec. 22	23^h14^m	14	-.-
1982	270.94	Dec. 22	20^h54^m	58	>35
1981	270.80	Dec. 22	11^h36^m	23	55 ± 25
1980	270.80	Dec. 22	05^h24^m	25	-.-

In the model by Vaubaillon (Figure 6, left two graphs), we selected those particles that pass to within 0.02 AU, and compare the semi-major axis to those in the cloud further away. The adopted range of ejection speed and angle of ejection more efficiently moves particles into orbits that have 'close' encounters with Jupiter. The meteoroids found close to the Earth's path move in a range of orbits, although many are concentrated near the 7:8 and 6:7 mean-motion resonance. We see two spikes in the distribution that could correspond to these resonances.

We further demonstrated that the particles near the Earth are indeed moving in mean-motion resonances by calculating the critical arguments for a series of particles that pass near the Earth's orbit. Figure 7 shows how the critical arguments of particles number 5702 (in the 6:7 res.) and 8370 (7:8 res.) change over time. Resonances keep the orbital evolution from completing a full circle.

We can not yet be certain which trails contribute to the Filament outbursts, because that depends on the exact perihelion time of the comet in those years. The perihelion time determines the timing of close encounters with Jupiter.

Interestingly, it appears possible to infer from the peak time of the shower, and from substructure in the activity profile and the radiant distribution, which trails contribute to the Ursid outbursts. If so, the orbit of 8P/Tuttle could be reconstructed far into the past.

We can not exclude the possibility that the Filament component is much older than the 600 – 1,700 years considered in our model. In that case, the peak rate and time may be very different than predicted here. Dust could have been generated as far back as the time of capture in its current orbit by Jupiter. Careful observations of the Ursid shower may provide evidence when 8P/Tuttle was captured.

In our opinion, it is likely that 8P/Tuttle was captured during the most recent encounter of the comet node with Jupiter's orbit about 15 000 years ago. In some ways, comet 8P/Tuttle still looks fresh. Comet 8P/Tuttle spews out as much water vapor as does comet 1P/Halley, which is of nearly the same size as 8P/Tuttle. Comet Halley is thought to have been captured about 20 000 years ago (Jenniskens, 2006).

On the other hand, Tuttle is much less bright for a visual observer on the ground. That is because most of the dust is lost in the form of large dust grains (with sizes much larger than the 0.5 micron that efficiently scatters sunlight) that cause our Ursid meteor shower. Why is that?

How does the dust evolve from ejection to the point of being encountered by the Earth? It will be interesting to compare the meteoroid size distribution as measured in the shower and during ejection in the return of 8P/Tuttle in 2008. The meteor shower observations may help interpret the remote sensing observations of the comet and give new insight into the conditions of dust ejection. The meteor observations can also provide unique information on the main element composition of the comet dust. Conversely, a better understanding of the present day ejection conditions from remote sensing may provide new understanding of the origin and dynamical evolution of the meteoroid stream.

6 Conclusions

In December of 2007, we expect a strong Ursid shower with rates similar to that of a Perseid shower in summer for observers with clear sky and a radiant high in the sky. This will be the strongest outburst in this season's return of the comet to perihelion. The near full Moon will make this outburst hard to observe from the ground, especially because the shower might be relatively rich in faint meteors.

An airborne observing campaign is in preparation called the Ursid Multi-Instrument Aircraft Campaign, with the goal to deploy from NASA Ames Research Center in California and fly over the Canadian arctic at the predicted time of the shower. The mission is to measure the dust density in Earth path and, for the first time, accurately measure the spread of the dust in search of features that could still identify individual dust trails in the dust distribution. At altitude, the scattering of moonlight is less and, with a full-width-at-half maximum of about 5 hours, a 12-hour flight centered on 20^{h} UT is expected to cover most of the profile.

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Ongoing meteor work

Long-term variability of visual sporadic meteor rates

Audrius Dubietis [1] *and Rainer Arlt* [2]

Long-term variability of visual sporadic meteor rates is analyzed using Visual Meteor Data Base records collected in the years 1982–2007. It is found that sporadic meteor rates in the selected period of September vary within ±20% around the average hourly rate of $HR_{spo} = 11.7$. These variations have a period of 10.2 ± 1.2 years and exhibit a high degree of correlation (36%) with solar activity as expressed by the Zurich sunspot numbers. The occurrences of highest visual sporadic rates almost perfectly coincide with the sunspot maxima of 1990 and 2000. They support recent findings by Šimek and Pecina (2002) on a long-term radar sporadic meteor variability with the course of the solar cycle.

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1 Introduction

The impact of solar variability on the terrestrial environment is apparent through numerous connections between the Sun and Earth, including the variability of space weather, stratospheric ozone production rates and climate (Lean 1997, Lean 2005). The most severe disturbances of the terrestrial environment are traced in the high atmosphere (ionosphere), where temperature and number density of charged particles at 150–800 km height varies within broad margins during the course of 11-year solar cycle. Specifically, auroras that typically emerge at 100–500 km height are the direct signatures of enhanced solar activity. Solar flares and coronal mass ejections resulting in solar wind gusts cause a rapid expansion of the auroral oval and extend auroral visibility down to mid-latitudes. The impact of solar variability on the mesosphere is manifested in a different manner, controlling the frequency of the occurrence of noctilucent clouds (Gadsden 1998, Romejko et al., 2003), and more generally, the periodic shrinking and expansion of the entire polar mesospheric cloud layer (DeLand et al., 2006). Unlike auroras, noctilucent clouds exhibit the lowest occurrence frequency at maximum solar activity, the ice crystal growth dynamics being related to solar radiation-induced changes in the ambient temperature and water vapor concentration at the mesopause level. Since meteoroid ablation heights straddle the border between the ionosphere and mesosphere, it is quite natural to expect that solar activity should have some detectable impact on the observed meteor rates as well.

Sir J.F. Herschel was probably the first who conjectured the link between meteor activity and the solar cycle. However, his idea was based on erroneous assumptions that the Sun gains its energy by converting kinetic energy of infalling meteoritic objects, and the sunspots are the scars left by those impacts (Hughes 1995). The problem of a possible link between the meteor rate variability and the solar cycle in its modern formulation has been put forward some 80 years later by Bumba (1949), who studied meteor and fireball activity in the years 1844–1943 and concluded that highest meteor rates occur in the years close to the minimum of solar activity. The interest in possible solar influence on meteor rates has been brought back to attention after the anomalous increase of radar meteor counts reported worldwide in 1963. Hughes (1974) and Lindblad (1976) analyzed available records at that time and concluded that the frequency of radar meteor echoes varies inversely with the solar activity. Moreover, the magnitude of this variation was found to be considerable, suggesting an almost twofold increase of radar echoes close to the sunspot minimum (Lindblad, 2003). Lindblad (1978) and later Prikryl (1983) also established the idea that the geomagnetic activity influences the detected radar meteor rates on much shorter time scale (on the order of days) as well, with an apparent decrease of meteor echoes during geomagnetic storms. These analyses, however, did not strictly distinguish between the sporadic and shower meteors; the numbers of latter are strongly influenced by the local encounter conditions. The topic, however, still remains controversial since the most recent analysis of sporadic radar meteor rates, which covered more than a 40-year period (almost four solar cycles) arrived at the directly opposite result, indicating a strong (70%) correlation between the two processes of interest (Šimek and Pecina, 2002), with enhanced of radar sporadic meteor rates two years after the solar maximum.

2 Physical origins of meteor rate variability

The 11-year solar variability is barely detectable in the visible part of its spectrum. However, changes in the radiation flux are considerable in the radio wave, X-ray and in the extreme ultraviolet (EUV) spectral (100–250 nm) range. Enhanced EUV radiation is absorbed in the upper atmosphere, and therefore promotes enhanced ionization rates of the atmospheric gases. Energy excess raises the ambient temperature, the heating being relevant at 150–800 km height, with a temperature difference for the quiet and active Sun and as high as 500 K (Lean, 1997). A still appreciable change in

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ambient temperature of a few tens of degrees is traced down to 100 km, where meteoroid ablation processes are taking place.

Ellyett and Kennewell (1980) proposed a model of atmospheric density changes that qualitatively explained the variability of radar meteor rates as being due to atmospheric effects. According to their model, the terrestrial atmosphere experiences periodic compressions and expansions responding to changes in the flux of solar X-ray and EUV radiation. At low solar activity, meteoroids encounter a steeper atmospheric density gradient at ablation heights, which in turn results in ablation of a meteoroid of a given size over a shorter path length. Indeed, Lindblad (1976) measured that the endpoint heights of the radar-detected Perseid meteors vary considerably from 85 km near sunspot maximum to 96 km at sunspot minimum, thus indicating an apparent shortening of meteor trajectories at solar minimum. Interestingly, this is not the case for the beginning heights of meteoroid ablation, as was found by Porubčan and Getman (1992) from the height studies of photographic Perseid meteors. According to the model of Ellyett and Kennewell (1980), the detected meteor rates should be highly sensitive to their mass distribution index s. It is suggested that for $s < 2$ a decrease of atmospheric density scale height results in an decrease of detected meteor rates, whereas for $s > 2$ the trend is opposite. It is therefore expected that shower and sporadic meteor rates should behave differently during the course of the 11-year solar cycle. However, in the light of most recent results, new issues had been raised and plausible physical explanations seem to be missing. Pecina and Šimek (1999) analyzed long-term variations of the background sporadic radar meteor rates in December during the Geminid observing campaigns and derived a directly opposite relationship of radar sporadic rates to that of Lindblad, pointing to a high direct correlation between meteor rates and sunspot numbers. In an extended analysis, the same authors also obtained strong correlations for the January and August sporadic radar meteor rates (Šimek and Pecina, 2002). Their results point out that enhanced radar sporadic meteor rates are detected during the years of solar activity maximum, with a possible 1–2-year shift between the sunspot and radio-echo maxima as due to a secondary maximum of large solar flares, contrary to model predictions and previous observations.

On the other hand, it remains still an open question whether visual meteor rates respond to atmospheric density changes. In this respect, the only extended analysis of visual meteor rates performed so far is that of Bumba (1949). His assumptions, however, were based on relatively small meteor numbers collected by various observing techniques, and the topic deserves to be re-examined.

3 Data analysis

In order to study whether a relationship between the visual meteor rates and solar activity exists, our choice is cast on the sporadic meteor rates observed around the autumn equinox (September 10–30). Sporadic meteors represent a good target to be investigated, since their annual activity is well studied and is not affected by variable encounter conditions inherent to annual meteor showers. Sporadic meteors seem to emanate from rather randomly distributed radiant points. The only exception is a diffuse concentration of radiant points near the antihelion point. In September, the antihelion source is discriminated as a distinct meteor shower in the VMDB, formerly designated as (Southern) Piscids (SPI), and ANT in the modern meteor shower list; see (Arlt & Rendtel, 2006). In present analysis it has been subtracted from the dataset, in order to exclude apparent dependence of the sporadic meteor rates on the zenithal radiant distance. However, a weak dependence on the zenithal radiant distance (known as diurnal variation of the sporadic meteor numbers) still remains due to the extended apex source, which rises in the second half of the night. This factor has been minimized, since the bulk of observations were carried out during local evening hours. In order to avoid differences in sporadic rates seen from the northern and southern hemispheres, we also restricted ourselves to observations from the northern hemisphere where all the observing locations fit into an interval from 30° to 60° northern latitude. The chosen period of September 10–30 is free from any major shower activity; the available data on sporadic meteors contained in the Visual Meteor Database (VMDB) thus comprise a homogenous set of observations carried out by a standardized observing technique and amounts to a total of 29 369 sporadic meteors observed in the years from 1982 to 2007. The investigated period covers 26 years of observations, which equals to 2.5 solar cycles, whose variability is represented in terms of the Zurich sunspot numbers (also known as Wolf numbers) plotted in Fig. 1, using data from `http://solarscience.msfc.nasa.gov`.

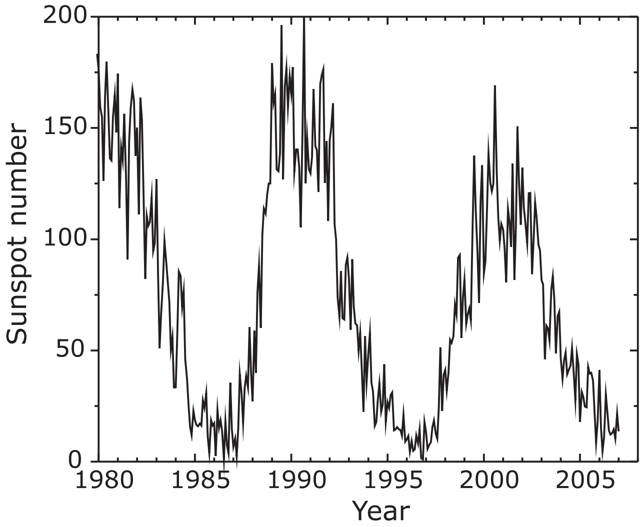

Figure 1 – Solar variability expressed by the monthly Zurich sunspot numbers from 1980 to 2007. (adapted from `http://solarscience.msfc.nasa.gov`.)

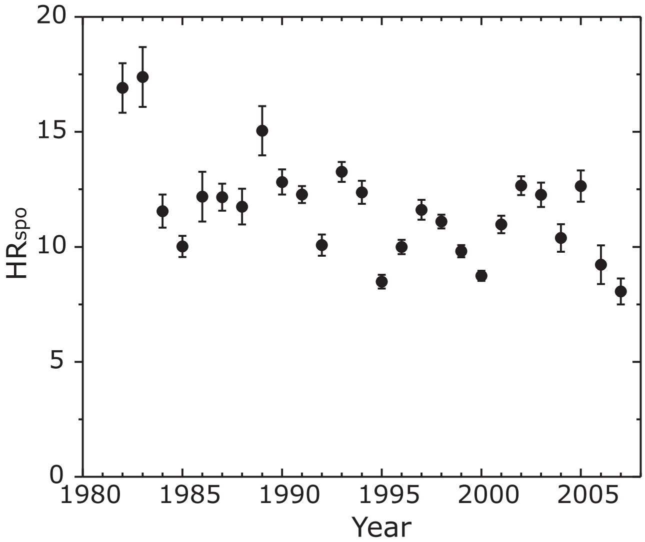

Figure 2 – Average sporadic meteor hourly rates of September derived for limiting magnitudes $lm \geq 6.0$.

The hourly rate for sporadic meteors, $\mathrm{HR_{spo}}$ was calculated using a standard procedure:

$$\mathrm{HR_{spo}} = \frac{N_{\mathrm{spo}} r^{6.5-\mathrm{lm}} F}{T_{\mathrm{eff}}}, \tag{1}$$

where N_{spo} is the individual number of sporadic meteors observed during a time period T_{eff}, lm is the limiting magnitude, r is the magnitude population index and F is the field obstruction factor. The error bars were estimated as:

$$\Delta\mathrm{HR_{spo}} = \frac{\mathrm{HR_{spo}}}{\sqrt{\sum_i N_{\mathrm{spo}}}}. \tag{2}$$

In the analysis we applied a constant magnitude population index of $r = 3.00$, which was obtained using the evaluation procedure described in detail by Arlt (2003). For hourly rate calculations we have chosen only the observations with limiting magnitudes $lm \geq 6.0$, since the expected impact of solar activity (if any) might be pronounced on faint meteors only. A single average value of $\mathrm{HR_{spo}}$ was calculated for each year, and the long-term activity profile obtained is illustrated in Fig. 2. The numerical data of the sporadic meteors and the sunspot numbers are given in Table 1. The resulting long-term activity profile suggests that some variations of sporadic meteor hourly rates indeed are taking place, oscillating around the average value of $\mathrm{HR_{spo}} = 11.7$. The mean amplitude of this oscillation is ± 2.3 and does not exceed $\pm 20\%$, however being still well-detectable above the error bars estimated for each individual data point.

A straightforward method to verify if any periodicity in time variations of a given process (sporadic meteor hourly rates) exists is to calculate its auto-correlation function, which means sampling the dataset with itself introducing a time shift. Statistically the autocorrelation function reads as:

$$\mathrm{ac}(l) = \frac{(\mathrm{HR_{spo}}(t) - \overline{\mathrm{HR_{spo}}})(\mathrm{HR_{spo}}(t+l) - \overline{\mathrm{HR_{spo}}})}{\sigma(\mathrm{HR_{spo}})}, \tag{3}$$

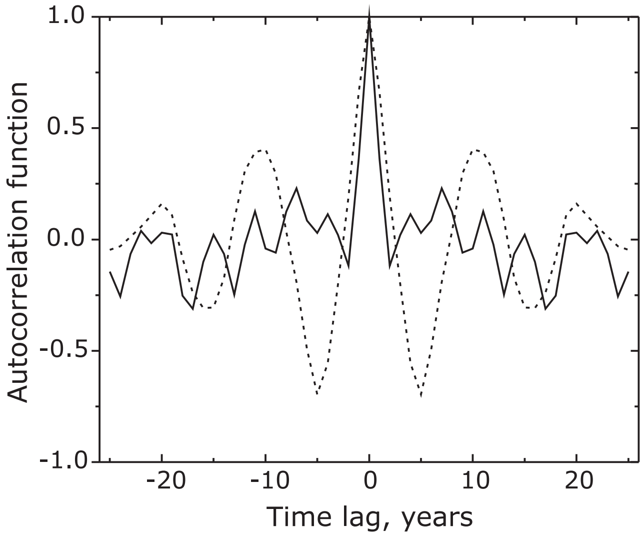

Figure 3 – Autocorrelation function of sporadic meteor hourly rates (solid curve) and sunspot numbers (dashed curve).

Table 1 – Numerical data of the visual sporadic meteor activity in the period of September 10–30, 1982–2007. N_{spo} is the total number of observed sporadic meteors, n_{obs} is the number of contributing observers, $\mathrm{HR_{spo}}$ is the average hourly rate calculated for limiting magnitudes $\mathrm{lm} \geq 6.0$, S_n is the Zurich sunspot number for September taken from `http://solarscience.msfc.nasa.gov`.

Year	N_{spo}	n_{obs}	$\mathrm{HR_{spo}}$	S_n
1982	361	17	16.9 ± 1.1	118.8
1983	452	12	17.4 ± 1.3	50.3
1984	345	9	11.6 ± 0.7	15.7
1985	1109	39	10.0 ± 0.5	3.9
1986	575	22	12.2 ± 1.1	3.8
1987	621	21	12.2 ± 0.6	33.5
1988	346	18	11.8 ± 0.8	120.1
1989	375	16	15.1 ± 1.1	176.7
1990	727	18	12.8 ± 0.6	125.2
1991	1441	32	12.3 ± 0.4	125.3
1992	796	18	10.1 ± 0.5	63.9
1993	1564	43	13.3 ± 0.4	22.4
1994	896	28	12.4 ± 0.5	25.7
1995	1127	30	8.5 ± 0.3	11.8
1996	1862	39	10.0 ± 0.3	1.6
1997	2432	42	11.6 ± 0.4	51.3
1998	2688	60	11.1 ± 0.3	92.9
1999	4015	67	9.8 ± 0.3	71.4
2000	2365	35	8.7 ± 0.2	109.9
2001	1075	23	11.0 ± 0.4	150.7
2002	1115	17	12.7 ± 0.4	109.5
2003	627	11	12.3 ± 0.5	48.7
2004	397	12	10.4 ± 0.6	27.7
2005	514	14	12.6 ± 0.7	22.1
2006	1335	13	9.2 ± 0.8	14.5
2007	209	2	8.1 ± 0.6	6.2

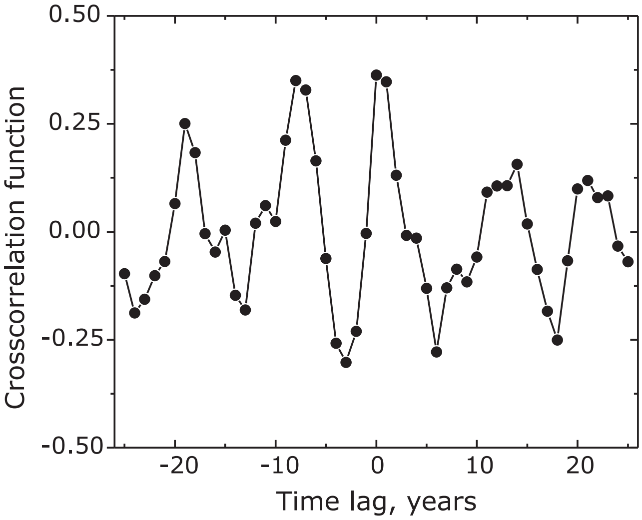

Figure 4 – Calculated cross-correlation function between $\mathrm{HR_{spo}}$ and S_n.

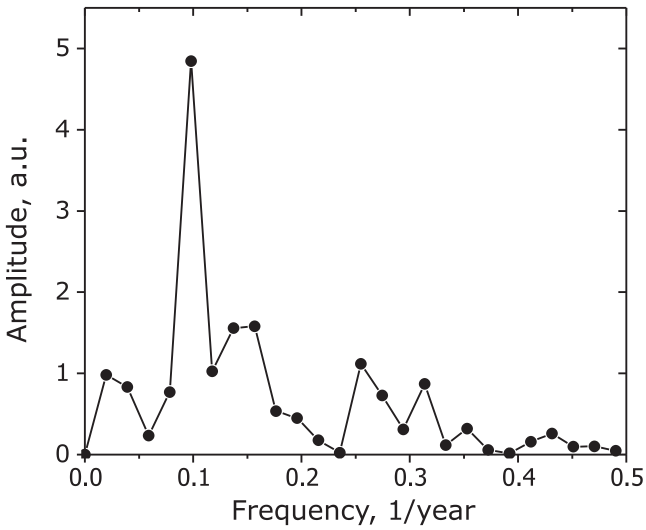

Figure 5 – Frequency spectrum of the cross-correlation function.

where where l denotes the time lag, the overline operator means time averages, and $\sigma(\mathrm{HR_{spo}})$ is the variance of the time series of sporadic meteor hourly rates.

Obviously, the auto-correlation function is symmetric and yields perfect unity at zero time delay (time lag). It is also worth mentioning that fewer data points contribute to the auto-correlation function at large time lag, with the leftmost and the rightmost points in the ac(l) plot being produced just by two single marginal points from the hourly rate dataset. The result is plotted in Fig. 3. The auto-correlation data (solid curve) shows that weak, but still clearly detectable periodic variations in sporadic meteor hourly rates are present over a $\sim$ 10-year time scale. The effect of periodicity is visually amplified by adding an auto-correlation function of the sunspot numbers depicted by a dashed curve. It has to be noted that more data would notably improve the precision of our calculations, which crucially depends on the ratio between the expected (11-year) variability period and the actual time scale covered by the observations (26 years). Since the individual auto-correlation functions for each process are always symmetric, it provides almost no information how in fact the two processes are coupled together. Therefore we take a second step in the statistical analysis, which involves the calculation of the cross-correlation function:

$$\mathrm{cc}(l) = \frac{(\mathrm{HR_{spo}}(t) - \overline{\mathrm{HR_{spo}}})(S_n(t+l) - \overline{S_n})}{\sqrt{\sigma(\mathrm{HR_{spo}})\sigma(S_n)}}, \qquad (4)$$

where the meanings and notations of physical quantities are the same as in Eqn. 3. Differently from the auto-correlation, the sampling between the two time-shifted variables (sporadic meteor hourly rates and sunspot numbers) is performed here. The values of cc(l) always fall into the range between -1 (inverse correlation) and 1 (direct correlation), while 0 corresponds to no correlation at all. It is important to note that the cross-correlation function reveals not only the strength of a mutual coupling, but also the phase shift between the two processes varying in time. The calculated cross-correlation function cc(l) is plotted in Fig. 4. It suggests a high degree of correlation between the two variables with the highest value of $\mathrm{cc}(l) = 0.36$ and distinct periodic oscillations on an approximately 10-year time scale. It is interesting to note that we obtained a lower cross-correlation coefficient by choosing a lower limit for lm for the data selection (function not shown). Another relevant feature seen from the plot is that the positive cross-correlation peak nearly coincides with a 0 time lag, indicating that maximum sporadic rates occur shortly (within one year) after the sunspot maximum. The results obtained are almost identical to those reported by Pecina and Šimek (1999) and Šimek and Pecina (2002), who found a similar relationship and a similar phase shift of radar sporadic meteor rates with respect to sunspot numbers.

Finally, we have evaluated more precisely the oscillation period by performing a frequency analysis by means of a Fourier transform on the cc(l) data. The Fourier frequency spectrum is depicted in Fig. 5. It indicates a prominent peak at $1/T = 0.098\ \mathrm{yr}^{-1}$, suggesting a variability period of $T = 10.2 \pm 1.2$ years, the error bars being evaluated from the estimation of the full width at half maximum of the peak. For a given time resolution (being defined by the number of data points), it provides a clear signature that long-term variations of the visual sporadic meteor rates are driven by the 11-year solar cycle.

4 Conclusions

In conclusion, we have investigated the activity of the sporadic meteors over a period of 26 years (1982–2007) on the basis of the available VMDB records. In the time interval of September 10–30, visual sporadic meteor hourly rates oscillate from year to year around the mean value of $\mathrm{HR_{spo}} = 11.7$ with an amplitude of $\pm 20\%$ (± 2.3). Statistical analysis reveals a certain periodicity of these oscillations, and the period (10.2 years) is almost coincides with 11-year solar activity cycle, represented by the Zurich sunspot numbers in this Paper.

These two processes exhibit a high degree of mutual correlation (0.36), indicating that the maximum visual sporadic meteor rates are recorded in the years of maximum sunspot numbers. Our result is much in contrast to that reported by Bumba (1949), who found exactly the opposite dependence (highest visual meteor rates occurring in the years of solar activity minimum). On the other hand, our findings for visual sporadic meteor rate variability are in good agreement with the results of the recent analysis of radar sporadic meter rates carried out by Šimek and Pecina (2002). It has to be noted that the relationship of visual meteor rates in general and solar activity appears to be weaker in terms of the amplitude and maximum cross-correlation coefficient. These differences might be attributed to a different magnitude range of visual and radar meteors, and probably some smoothing effect which occurs due to time averaging of visual meteor counts.

Finally, in order to make our result more conclusive, it is necessary to investigate variations of visual sporadic meteor rates at other times of the year, and/or extend, if available, the analysis over a longer range of years.

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History

Meteor Beliefs Project: Notes from some early medieval annals

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

A selection of probable meteoric items from early medieval manuscripts written in Europe and the Near East is presented and discussed, the events dating from 525 to 917 AD. Notes on the various sources used are also given.

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1 Introduction

Previously in this Project, we have extracted and discussed more or less probably historical reports of meteoric events from old manuscripts (Gheorghe & McBeath, 2004; 2006). Here, we return to this general concept, with some fresh notes from a selection of early European and Near Eastern annals. The events we have chosen are those that seemed at least more likely to be meteoric, or have significance for historical meteor studies (notably the great Antioch earthquake, first on our list), and spanned dates from 525 to 917 AD. Whether the notes preserved in the annals used here were originally written by people who witnessed the events is not always clear. Some of the manuscripts long post-date the times they detail, certainly.

We have not constructed a comprehensive catalogue for this whole time interval, but we have attempted to identify all the more probably meteoric events in the sources referred to. For each entry, we have given an AD year-date, as closely as this can be established, a description of the event, source references, and, where appropriate, our comments in square parentheses, thus '[ ]'.

Some chronicles used a dating system based on when certain officials held an annually-appointed post. While this usually allows a reasonably precise dating and cross-indexing with other texts, not all systems like this ran to the modern calendar, or even the March to March year of Roman practice. If a critical interpretation is required, please refer to the specific source cited here for advice.

2 Source notes

Before presenting details of the items found, some comments on the sources themselves are appropriate, given in main name alphabetical order.

Chronicon Paschale: (Whitby & Whitby, 1989). The name translates as 'Easter Chronicle'. No known author. Dated to the early 7th century from its final surviving entry in 628 AD, but it originally probably ran to 630. Standard late Roman/Byzantine chronicle, running from the creation of the universe (given as 5509 BC) to the time of writing. Written in Greek, probably at Constantinople. It especially concentrates on the dating of major Christian festivals, notably the timing of the movable feast of Easter, hence its modern name. Our extract here is from a probably 11th century AD insertion from a historical source called the 'Great Chronographer'.

The Annals of Clonmacnoise: (Murphy, 1896/1993). No known author. Dated to circa 1408 AD (final entry). Format covers events from the Christian concept of the creation of the world to the time of writing. Written in Irish Gaelic, probably in the Clonmacnoise area of central Ireland, near the River Shannon and the borders of modern Counties Roscommon and Westmeath. It is particularly concerned with Irish history during its covered period. Abbreviated below as 'Clonmacnoise'.

Gregory of Tours, 'The History of the Franks': (Thorpe, 1974). Gregory lived circa 539–594 AD, and was Bishop of Tours (north-west central France modernly, at the confluence of the Rivers Cher and Loire) for 21 years. His 'History' was completed by him at Tours in 591 AD. Its format covers events from the Christian world's creation to 591 as a chaptered narrative, written in Latin. It centres on Frankish/French history during the 6th century, with seven of its ten books detailing events during Gregory's lifetime. Abbreviated here as 'Gregory'.

The Chronicle of John of Nikiu: (Charles, 1916). John lived and flourished in Upper Egypt in the late 7th century AD, where he was Coptic Bishop of Nikiu (location uncertain). The manuscript has several missing sections, but covers events from the supposed world's creation down to John's own time, at the end of the 7th century. Originally written in Greek, later translated into Arabic, both versions of which have been entirely lost. The surviving text is an Ethiopic translation, transcribed in 1594. The text deals chiefly with a history of Egypt in short chapters.

The Chronicle of John Malalas: (Jeffreys et al., 1986). John Malalas, literally 'John the Scholar', probably lived around the 490s to 570s AD. His is the earliest surviving Byzantine world chronicle. It covers events from the time of Adam to circa 565 AD. It was originally written in Greek, partly at Antioch (now Hatay in southern Mediterranean Turkey, near the Syrian border). It partially survives in various other languages. The text details matters of perceived importance relevant to the later Roman/Byzantine Empire. Abbreviated below as 'Malalas'.

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The Chronicle of Theophanes Confessor: (Mango & Scott, 1997). Theophanes (circa 759–818 AD), later canonized, was a high-ranking Christian church official who lived and worked in Constantinople, parts of modern Asian Turkey and on several Aegean islands. His Chronicle continues from an earlier work by a monk called George Synkellos, and covers events in the Eastern Roman/Byzantine Empire and the Christianized Near East in short, normally annual, sections, from 284 to 813 AD. Originally written in Greek. Abbreviated here as 'Theophanes'.

The Annals of Ulster: (Mac Airt & Mac Niocaill, 1983). No known author. Fragmentary in places, the surviving texts were probably prepared at various times from the late 15th to late 16th centuries in the form we have them. The earliest surviving partial entry dates to circa 84 AD, the last in the part covered by this translation, is 1131. Mostly written in Latin, probably in what is modernly Northern Ireland. Format is of normally short, annual notes of major events. Its main emphasis is on Irish and Scots-Irish history. Abbreviated below as 'Ulster'.

3 Events

525: The destruction of the city of Antioch by an earthquake and a terrible fire. John of Nikiu, XC.24: 'For there came an earthquake from God and fire fell from heaven on the city of Antioch' (Charles, 1916, p. 135). Most of the city was burnt and fires burst out along the trade routes of the lands around, lasting for six months, while many people died or wasted away — 250,000 in Antioch alone. John of Nikiu, XC.27: 'Burning coals of fire like thunderbolts fell from the air and set fire to everything they touched, and the city was overthrown to its foundations' (op. cit., pp. 135–136). [The falling coals like thunderbolts sound possibly meteoric or meteoritic, but this is not clear. The same event was recorded by Malalas, in a slightly different way.]

Malalas, 17.16: The great Antioch earthquake was in May 525. Those trapped by falling buildings were incinerated, 'and sparks of fire appeared out of the air and burned anyone they struck like lightning. The surface of the earth boiled and foundations of buildings were struck by thunderbolts thrown up by the earthquakes and were burned to ashes by fire, so that even those who fled were met by flames. It was a tremendous and incredible marvel with fire belching out rain, rain falling from tremendous furnaces, flame dissolving into showers, and showers kindling like flames' (Jeffreys, et al., 1986, p. 238). [This description seems more like events associated with a severe earthquake, rather than meteors or meteorites now (the thunderbolts shoot *up* from the ground, for instance), but the tenor of the piece could have fed back into beliefs in meteors as catastrophic world-ending events. We were reminded of the Livy and Obsequens notes regarding 186 BC, when people's clothing was scorched by 'flames shining in the sky', apparently some kind of 'weak lightning' (Gheorghe & McBeath, 2006). Theophanes also featured this disaster, but in a further variant form.]

Theophanes, 525/6 had a great fire precede the earthquake in Antioch, which burnt in places for six months from October 525. 'No one was able to discover from where the fire was lit, for it flared up from the roof-tiles of five-storey buildings' (Mango & Scott, 1997, p. 263). The earthquake followed on 526 May 20, causing the whole of the city to collapse, and some of those buried alive by the fallen buildings were burned by a fire that came out of the earth. 'Another fire came down out of the air like sparks, and burned whomever it touched, like lightning' (ibid). Earthquake aftershocks continued for a year. [While the two Johns lived closer in time to the events (Malalas was contemporary), Theophanes' text, with a great fire weakening the city first, sounds more rationalistic, unless it was merely *rationalized*. The fresh fires from beneath the ground would certainly make more sense this way, burning on due to the length of the earlier conflagration, along with the sparks in the air, assuming these were thrown up by collapsing buildings from the subterranean fires. Although Theophanes set the earthquake a year later than either of the Johns, the events seemed too much alike to be separate earthquakes, and a simple dating error is more plausible, as well as quite common between such manuscripts. We have discussed this at length, as it is one of the very few 'fire from heaven' tales where more than a single detailed account exists. It shows clearly the need to examine as much evidence as available in such cases, and not to assume that one meteorically-interpreble report shows the event *must* have been meteoric or meteoritic.]

530–532: In 530, Malalas, 18.52 reported a brilliant comet: 'a tremendous great star in the western region, sending a white beam upwards; its surface emitted flashes of lightning. Some people called it the Firebrand. It continued shining for 20 days, and there were droughts and murders during riots in every city and many other events full of ill omen' (Jeffreys, et al., 1986, p. 266). [This was Halley's Comet at a fine return in September 530, passing from LMi, through southern UMa, Com and Boo to Vir and Lib (Ottewell & Schaaf, 1985, pp. 23 & 139). For once, the presages were 'proven right', as the factional Nika riots tore apart Constantinople the following year. There were other signs as well.]

Malalas, 18.75 for 531/2: 'In that year there occurred a great shower of stars from dusk to dawn, so that everyone was astounded and said, "We have never known anything like this to happen" ' (Jeffreys, et al., 1986, p. 282).

[Theophanes added a little to both events, specifically dating the comet to September 530.]

Theophanes, 530/1: '...there appeared an enormous and frightening star in the west. It was a comet that sent upward its flashing rays. People called it the Torch and it continued to shine for twenty days. All over the world riots and murders occurred' (Mango & Scott, 1997, pp. 275–276).

[On the other side of the Nika riots the next year, he detailed the meteor storm.]

Theophanes, 531/2: 'In the same year there occurred a great movement of stars from evening till dawn.

Everyone was terrified and said, "The stars are falling, and we have never seen such a thing as that before." ' (op. cit., p. 280).

[Note that in neither case was a link between the comet and the meteor storm made, except in the sense of both being dire portents at a time of great social unrest.]

556/7: Malalas, 18.122, for 556: 'In the month of November of the 5th indiction fire appeared in the sky shaped like a spear, extending from the eastern regions to the western' (Jeffreys et al., 1986, p. 295). Theophanes, 556/7: 'Fire appeared in the sky in the shape of a spear from north to west' (Mango & Scott, 1997, p. 338). [Though the Malalas report might be auroral, the two notes together could indicate sightings of one bright fireball from slightly different places.]

580: Gregory, V.33: In Touraine [the region around the city of Tours], 'one morning before the day had dawned, a bright light was seen to traverse the sky and then disappear in the East. A sound as of many trees crashing to the ground was heard throughout the whole region, but it can hardly have been a tree for it was audible over fifty miles and more' [50 miles is $\sim$ 80 km] (Thorpe, 1974, p. 295). Other portents noted for this year included an earthquake at Bordeaux whose effects were felt in neighbouring parts of Spain and the Pyrenees: 'Villages around Bordeaux were burned by a fire sent from heaven ... There was no other apparent cause of this fire, and it must have come from God' (op. cit., p. 296). Gregory, V.34, following on from this directly, began, 'A most serious epidemic followed these prodigies', of dysentery and boils (ibid). [The first report was a possibly meteoritic, brilliant, sonic-producing fireball, while the earthquake and seemingly inexplicable fire recalled the events of the Antioch earthquake in 525. We also draw attention to this 'fire from heaven' report, as it was simply a fire without an immediately identifiable cause, not something which was stated as seen to drop from the sky.]

583: Gregory, VI.25: On January 31 (a Sunday), at Tours, just after the bell had rung for matins [early morning service, before dawn] and the people were on their way to church, 'The sky was overcast and it was raining. Suddenly a great ball of fire fell from the sky and moved some considerable distance through the air, shining so brightly that visibility was as clear as at high noon. Then it disappeared once more behind a cloud and darkness fell again. The rivers rose much higher than usual' (Thorpe, 1974, p. 353). The Paris region was badly flooded as a result. [An impressively brilliant fireball, partly seen in a cloud-gap, most likely; a possible alternative might be some kind of ball-lightning, though this seems less plausible due to its extreme brightness.]

584: Gregory, VII.11: In December [presumably during an otherwise unstated unusually mild spell], new vine shoots appeared, along with misshapen grapes, and the trees blossomed for the second time that year. 'A great beacon traversed the heavens, lighting up the land far and wide sometime before the day dawned' (op. cit., p. 395). A coronal auroral storm was also seen for two hours, there was an earthquake in the Angers district [west of Tours], and many other portents. 'In my opinion all this announced the coming death of Gundovald' (ibid). [A fine bright fireball report from an interesting month. Gundovald was supposedly the son of King Lothar, and nephew to King Childebert I, both Frankish kings, though there seemed some doubt as to his true lineage from the discussion in Gregory.]

585: Gregory, VIII.8: In July, 'Portents appeared. Rays of light were seen in the northern sky, although, indeed, this happens often. A flash of lightning was observed to cross the heavens. Flowers blossomed on the trees' (op. cit., pp. 439–440). [The lightning flash was possibly meteoric to warrant this level of attention. Tree blossom would normally occur rather earlier in the year than July, of course. The years 584 and 585 were good for auroral sightings in northern France, as the famous October report of a superb all-sky display appearing to Gregory like a gigantic coloured pavilion happened in 585 - Gregory, VIII.17 (op. cit., p. 449).]

586: Gregory, VIII.42: In another year with numerous portents, the trees blossomed again in September, and many fruited with a second crop that lasted till Christmas. 'A flash of lightning was observed to run across the sky in the shape of a serpent' (op. cit., pp. 473–474). [Perhaps another bright fireball, especially given the meteors-dragons/serpents link known from elsewhere.]

590: Gregory, X.23: 'In the same year so bright a light illumined a wide spread of lands in the middle of the night that you would have thought that it was high noon. On a number of occasions fiery globes were also seen traversing the sky in the night-time, so that they seemed to light up the whole earth' (op. cit., p. 581). [Both portent types could have been meteoric, particularly because of the emphasis placed on their respective quantities of illumination. The first item could have been an especially brilliant aurora, however.]

734: Clonmacnoise: 'There was a Dragon both huge & ugly to behould this harvest seen, and a great Thunder heard after him in the firmament' (Murphy, 1896/1993, p. 116). [The dating of this probably meteoric bolide-dragon is not entirely certain, as the next short section is dated 734, but the one after that is 733, then 734 again, before resuming a more definite chronological order. Ulster has an almost identical description down for 734, but the manuscript date has been copied incorrectly, and should have been 735.] Ulster, 735, item 6: 'A huge dragon was seen, with great thunder after it, at the end of autumn' (Mac Airt & Mac Niocaill, 1983, pp. 188–189). [The Ulster reference was previously discussed in (McBeath, 2003).]

742: Clonmacnoise: 'There was Drogons seen in the skyes' (Murphy, 1896/1993, p. 118). [Presumably more bright meteors. The dating is again a little suspect, as the section this note is in follows one for 744, but the next is 742, and subsequent ones run in a normal datal sequence. See also the next entry.]

746: Ulster, item 2: 'Dragons were seen in the sky' (Mac Airt & Mac Niocaill, 1983, pp. 200–201). [The manuscript date is once more a year wrong (given as

745) — see 734 item notes above. The implication from the two Irish annals is that notably bright fireballs were seen in several years during the decade ending in 746, at least.]

750/1: Chronicon Paschale, Great Chronographer, passage 13: 'At the time of the birth of Leo the son of Constantine Copronymus, all the stars of the heavenly place seemed to be shifting and moving downwards throughout the whole night. But those which came near the earth were immediately destroyed. And many say that the said extraordinary sight was displayed throughout all the world' (Whitby & Whitby, 1989, p. 198). [Whitby & Whitby, footnote 13 (pp. 198–199), discussed the dating of this event in detail, suggesting another chronicler, Nicephorus, may have been the source for the Great Chronographer in this instance. Nicephorus, 65.8–13, linked the meteor storm with Leo's coronation in 751, not his birth, however. The Whitbys helpfully cited the relevant passage from Nicephorus: 'It seemed to them that all the stars were moving from the heavenly place appointed for them and being brought down to earth.' They further noted that Theophanes mentioned Leo's birth and coronation, but not the meteors. Instead, they inferred Theophanes' report of 762/3 (see next item) should really refer to events in 750/1.]

762/3: Theophanes: '...in the month of March the stars were falling from heaven all at once, so that all the observers thought it was the end of the present world. Then there was a great drought, so much so that the sources dried up' (Mango & Scott, 1997, p. 601). [Nothing in this entry indicated this was the same meteoric event as in 750/1, but Mango & Scott (footnote 15, p. 602), albeit again on little evidence, suggested the drought may have been a reference to another severe drought three years later. The year 762/3 was an odd one, as the winter was dreadfully cold, and from October to February, a large part of the northern and western coastal Black Sea froze solid, to a depth of ~ 14 m, with a further ~ 10 m of snow on top, according to Theophanes, who recalled seeing it from his childhood (op. cit., pp. 600–601). When it all broke up in the spring, the Bosphorus and northern Sea of Marmara filled up with huge icebergs, so it was possible to cross the Bosphorus on foot!]

917: Ulster, item 1 (dated wrongly to 916, but corrected in the manuscript): 'Snow and extreme cold and unnatural ice in this year, so that the chief lakes and rivers of Ireland were passable, and causing death to cattle, birds and salmon. Horrible portents also: the heavens seemed to glow with comets; and a mass of fire appeared with thunder in the west beyond Ireland, and it went eastwards over the sea' (Mac Airt & Mac Niocaill, 1983, p. 367). [A fine bolide to end with, though whether it and the comets were folklorically linked with the cold was not clear.]

4 Conclusion

The continuation of recording lists of portents and prodigies from ancient Roman times obviously persisted throughout the period covered here, even in places like Ireland, which were never officially Roman provinces, though long subject to Roman influence, particularly through the Christian church. The events discussed here are not always open to only one interpretation, and the uncertain dating in parts is unhelpful, but there remains much of interest for all that, along with some evocative descriptions.

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Meteoroid streams in the Solar System

By Peter Zimnikoval

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