journal of the international meteor organization

WGN

33:5
october 2005

IMC 2005
Pegasids
Camelopardalids
Persistent trains

ISSN 1016-3115

WGN Vol. 33, No. 5, October 2005, pp. 115 – 144

Administrative

Ongoing meteor work

History

Front cover photo

Detlef Koschny demostrating a meteor camera at IMC. *Photo: Rainer Arlt.*

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

Cover design Rainer Arlt

Editorial — New Treasurer, Two IMO conferences

Chris Trayner

Marc Guyssens has taken over from Ina Rendtel as Treasurer of the IMO. Ina has been Treasurer for many years, an impressive run in any committee position. The post of Treasurer in any organisation is essential, though it is less visible than other positions. It is also time-consuming and often thankless. The IMO owes Ina a deep debt of gratitude for all her work over the years.

The details of the current Treasurer are inside the back cover.

Radio Meteor School

This September saw the annual International Meteor Conference (see the the next two pages). As well as being a remarkable event in its own right, this year's IMC was held in conjunction with a new endeavour: the second IMO **Radio Meteor School**. This ran on the same site for five days before IMC, from September 10 to 14.

It was made possible by Prof. Dr. Oleg Bel'kovich, who gave most of the lectures on the physical and mathematical theory of radio meteor observations, with Dr Galina Ryabova and other participants giving others. It was an intense workshop, teaching the physics and mathematics behind radio meteor research. Those who attended it rated it as enormously valuable, though very hard work — the one thing not available was sleep!

Prof. Bel'kovich is a renowned Russian meteor scientist, and the IMO was fortunate to have him run this School. To record our thanks to him, the Commission of the IMO decided to make him an honorary member of the Organization.

In due course this Workshop will produce a volume of Proceedings. Details will be announced in this Journal, and on the IMO website `www.imo.net` .

Prof. Dr. Oleg Bel'kovich

IMO bibcode WGN-335-editorial NASA-ADS bibcode 2005JIMO...33..115T

Letter

Daniel Fischer

The Weber article on the old experiments with meteors [WGN **33:4**, pp.111–114] was superb! Perhaps you could watch out — or call — for more reviews of this kind. The bibliography alone he provided was (almost :-) worth the WGN subscription fee.

IMO bibcode WGN-335-fischer-letter NASA-ADS bibcode 2005JIMO...33..115F

The International Meteor Conference 2005

Jonathan "O. J." McAuliffe [1]

Received 2005 October 6

My First Time

So it begins. Or so I'm told. Apparently once you start attending IMC you never stop. You may miss a year here and there but once Immy has his hooks in you there's no escape. This year's IMC in Oostmalle Belgium was my first and I'm glad to say that I doubt it will be my last. It was also my first *amateur* conference, and to be perfectly honest it was nothing like I'd expected. Truth be told, I didn't think it would be any different from all the other stuffy boring conferences I'd been to previously. I guess the fact that the IMC is an amateur conference got by me.

I imagine that for no matter how long you're in the research game there'll always be an element of apprehension on the first day of a conference. And for me, arriving in Oostmalle on the Thursday afternoon, this was no different. New faces, strange unpronounceable foreign names, weird moon-base type facilities, it can all be a wee bit intimidating. But then I found out there was a **private bar** in our little enclosure and all my worries quickly faded away like a meteor trail in the Jovian atmosphere. The shared accommodation immediately brought me back to my summer camp days, although if memory serves, adolescent boys rarely imitate *freight trains* while sleeping, as certain English gentlemen (who shall remain nameless) tend to do.

Having not eaten all day, the *dinner* on that first evening, left me and many others wondering if we'd be sending out for take-away a few times over the weekend. And the news that they didn't have Guinness in the bar didn't sit well with me... but why, as they say, bring apples to the orchard? After dinner my trusted Macedonian side-kick and I headed to The Foyer and promptly procured our little yellow drinks cards. Great idea.

"Six Westmalle Triples bartender. And keep the change..."

Figure 1 – Informal meteor discussions. Left to right: Palm, Antonio Martinez, Cis Verbeeck, Juan Martín Semegone.

Figure 2 – The author studying hard for his PhD.

Bad idea. Like all conferences the real work at the IMC 2005 was done in the bar. Everyone was extremely friendly and the atmosphere was fantastically relaxed. Even after six Westmalle Triples. ***Especially*** after six Westmalle Triples. As always the bulk of the crew faded away soon after midnight but a few of us pushed on through the wee hours of the morning. God, did I pay for it the next day.

Although the following evening I stuck mainly to the orange juice the social festivities were no less festive. The standard of the cuisine had improved slightly so everyone was well fed, ready for another night's heavy drinking. By now I was on my third Immy Card and to my eternal shame the previous two and a half had been filled up with orange juices. Fresh as a daisy the next morning I still managed to miss breakfast but did (as I'm sure my supervisor will be glad to hear) manage to make all the morning talks. Then, off to Lier...

I love Belgium. And towns like Lier are the main reason. Well, towns like Lier, the beer, and the people... in that order. Lier is beautiful. And while we didn't quite manage a sing-song on the way there, we did, after a highly informative tour, manage to find the worst pub in all of Belgium — right in the shadow of Louis Zimmer's Tower. I mean, for the love of all that is just how, being 50 metres from such a monument to time-keeping, can it take 45 minutes to get a round of drinks?

[1]Armagh Observatory, College Hill, Armagh, BT61 9DG, Northern **Ireland** Email `jma@arm.ac.uk`

IMO bibcode WGN-335-mcauliffe-imc
NASA-ADS bibcode 2005JIMO...33..116M

Figure 3 – The IMC Commission discussing fluid dynamics.

When the beer did arrive we had but 5 minutes to knock 'em back before we had to hike back to the bus. That evening back at the compound will haunt me for the rest of my life. Chris Trayner had sparked my interest when he said that the IMC astropoetry show is something that everybody should experience at least once... or was it at most once? So I pulled up a chair and... Well more about what followed I won't say — I wouldn't want to spoil it for anyone who is thinking of attending next year.

Having most of the conference behind us we once again left our hair down Saturday evening. Jérémie serenaded us with his songs and Tom Roelandts liquored us up in this back garden — thanks Tom. I have to say it was one of the most fun meetings I've attended. What a great way to do science! By the time we made it back to The Foyer we were seeing things alright but they weren't meteors. Now that was a late night, and I even got to play Barkeep. I think I crawled into bed around 5 A.M. thankful of my MP3 player's success at drowning out the cacophony that was David and Geoffrey's snoring. Oops, I said I wouldn't name names didn't I...?

So that's what I remember of the social side of the IMC 2005. As I said it was one of the most chilled out and enjoyable conferences I've been to, thanks to Cis and all the Local Organising Committee for making it so, and to Benny for his chauffeuring services. And I will definitely see you all next year in Holland. *Oh won't you come, oh won't you come...*

Figure 4 – Nogami Nagatoshi, one of the delegates who came all the way from Japan.

Figure 5 – The astronomical clock of the Louis Zimmer Tower in Lier.

All photos: Chris Trayner

Ongoing meteor work

A determination of Population Index, τ, for persistent trains: a comparison between fireballs from main meteor showers and sporadics

Orlando Benítez Sánchez[1]

A procedure to obtain the persistent train population index, τ, is proposed. This is based on the assumption that train duration can be described by a population index, like meteor brightness. With this method we obtain τ for the fireballs from Perseids ($\tau = 0.919 \pm 0.400$ in the interval [1 s, 45 s]), Leonids ($\tau = 0.807 \pm 0.273$ in the interval [1 s, 10 s] and $\tau = 0.993 \pm 0.135$ in the interval [13 s, 600 s]), Geminids ($\tau = 0.820 \pm 0.670$) and the sporadic background ($\tau = 0.600 \pm 0.180$) from the SOMYCE database. These values are compared with those obtained for faint meteors to $+6^{\rm m}$. A global fit with the FIDAC Database gives $\tau = 0.899 \pm 0.157$ in the interval [1 s, 20 s] and $\tau = 0.997 \pm 0.230$ in the interval [21 s, 900 s]. Finally, a relationship between the visual magnitude and τ is sought in the interval $[-3^{\rm m}, -8^{\rm m}]$ with a fit $\tau = cm_{\rm v} + m_{\rm v0} = -0.018m_{\rm v} + 0.808$. Variations of τ are discussed.

Received 2004 October 19

1 Introduction

In previous papers published in WGN (Bellot Rubio, 1992; Benítez Sánchez, 2002b) a procedure, similar to that to obtain the population index r for the visual meteor magnitude, is used to obtain a persistent train 'population index', τ. This is based on the assumption that train duration can be described by a population index, like meteor brightness.

This procedure is explained briefly. First, we need to obtain the frequency, i.e. the number of persistent trains observed in duration interval d (e.g. (0.5 s, 1.5 s], (1.5 s, 2.5 s], centered on d=1, d=2 seconds, and so on). Interval (0 s, 0.5 s] has a different bin size, and is therefore omitted from the calculations. The remaining frequencies are obtained from the IMO train report forms. Then all the frequencies are summed to obtain the cumulative function of the trains from $d_{\max}$, (the duration in seconds of the longest visual persistent train observed) to start the procedure. This duration was different for each shower, so this data depends on observational data.

Finally, the cumulative number of persistent trains observed must be calculated 'counting backwards' from longer to shorter durations, as the number of persistent trains increases with decreasing duration.

To obtain τ, a linear fit of the duration interval, d, and log(Φ(d)), the log of the cumulative function of number of persistent trains, was calculated.

2 Dependence of τ on time duration and cumulative number

Meteor shower parameters are usually expressed in terms of Zenith Hourly Rate (ZHR) or Population Index (r). We propose to define a new parameter, τ, for persistent trains. This parameter could be interpreted as a 'population index' similar to that for meteor brightness; e.g. in the time duration class $d = 3$, there are τ times more persistent trains than in the trains class $d = 2$. Note here that the number of persistent trains varies inversely with duration, so $\tau < 1$. In other words,

$$N_{d+1} = \tau N_d \qquad (1)$$

where N_d is the observed number of persistent trains in duration interval d (i.e. ($d - 0.5$, $d + 0.5$]).

Let $\Phi(d)$ be the cumulative number of persistent trains within the duration interval d or longer, that is $\Phi(d) = \Sigma_d^{d_{\max}} N_d$, where d is a number to identify the interval as described in the introduction. Note that there are few very lengthy trains, so $\Phi(d)$ is not sensitive to variations in $d_{\max}$.

By definition (Bellot Rubio, 1995), $\tau \equiv \frac{N_{d+1}}{N_d}$ and therefore $\tau = \frac{\Phi(d+1)}{\Phi(d)}$ if we assume that there is no great difference between the observed and real numbers of persistent trains. We can write the relationship between the cumulative number of trains observed and the train duration in an exponential form: $\Phi(d) = \Phi(1)\tau^{d-1}$ or, in logarithmic form, $\ln(\Phi(d)) = \ln(\Phi(1)) + \ln(\tau^{d-1})$, from which we may conclude that

$$\begin{aligned} \ln(\Phi(d)) &= \ln(\Phi(1)) + (d-1)\ln(\tau) \\ &= y_0 + (d-1)a \end{aligned} \qquad (2)$$

with $y_0 = \ln(\Phi(1))$. Finally $a = \ln(\tau)$, and $\tau = e^a$.

We obtain τ by a linear regression. Errors for the τ values were computed as the mean deviation of the values from the predicted fit line.

3 The database set

In this study, 872 visual persistent trains are selected from 5855 fireballs reported by SOMYCE members (Benítez Sanchez & Ocaña González, 2004). All the fireball observations from meteor observations brighter than $-2^{\rm m}$ were reported on the standard FIDAC report form. Meteor shower associations were made carefully where possible, to find τ for all main meteor showers.

[1]Urb. El Pilar, Ptal. 20, 4°A. 35012 Las Palmas de Gran Canaria, Gran Canaria. Email: comisionvisual@somyce.org

IMO bibcode WGN-335-benitezsanchez-trains
NASA-ADS bibcode 2005JIMO...33..118B

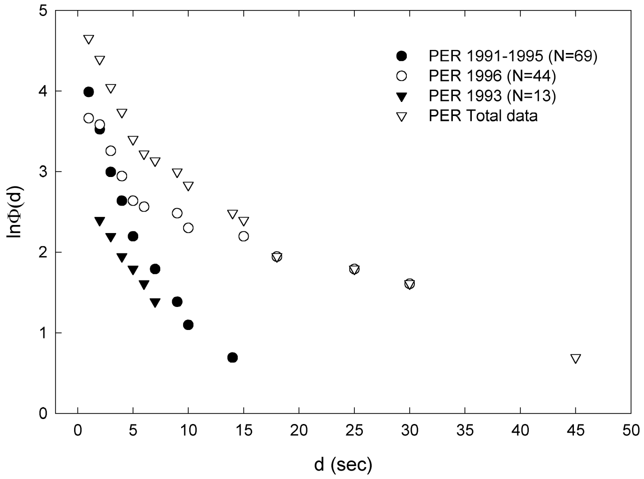

Figure 1 – The natural logarithm of cumulative number of persistent trains observed, $\Phi(d)$, versus time duration, d, for Perseid fireballs in 1996, 1993 and all the reports on 1991–1995 period.

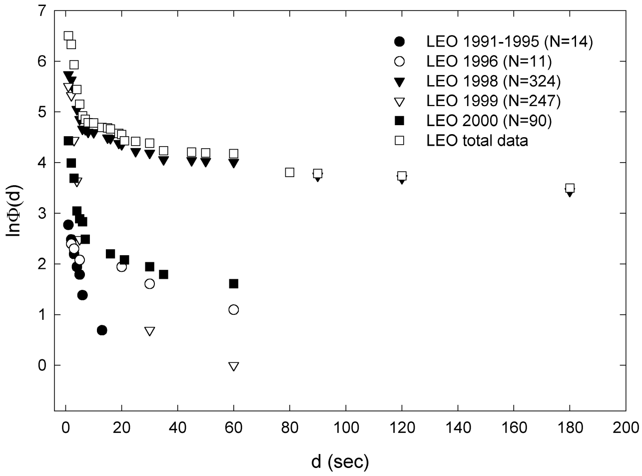

Figure 2 – The natural logarithm of cumulative number of persistent trains observed, $\Phi(d)$, versus time duration, d, for Leonid fireballs in 1996, 1998, 1999, 2000 and 1991–95.

This database was compared with all the FIDAC reports (over 10 000 visual fireballs) from 1989–1997 to obtain a global τ. A meteor shower association was not possible with this data. Finally, data on persistent trains from faint meteors for the period 1989–1991 (Bellot Rubio, 1992), and 2002 Perseids and Leonids (Benítez Sánchez, 2002b) were compared with the fireball dataset.

4 Persistent train population for Perseid, Leonid and Geminid fireballs

This analysis deals with 840 persistent trains from meteor showers and only 32 persistent trains for sporadic fireballs. The train duration, d, and the natural logarithm of the cumulative function of the number of persistent trains are represented on linear axes. The data are given in Table 1.

4.1 Perseids

Perseids show different values of τ (see Table 1 and Figure 1). In the period 1991–1995, with 69 persistent trains, this gives us $\tau = 0.775 \pm 0.312$, very different from the $\tau = 0.819 \pm 0.025$ for 1993 and $\tau = 0.938 \pm 0.303$ for 1996. This difference could be produced by a different number of persistent trains observed in each year or other observational causes, like low visual limiting magnitude (short-lived trains and enduring faint persistent trains are lost) or the presence of the Moon. The possibly different chemical composition of Perseid meteoroids must also be kept in mind. In this plot, Perseids in the period 1991–1995, 1996 and the total data appear to be curves up to around 10 seconds. Thus our basic supposition, expressed in (eqn. 1), may not be true unless we suppose a break in the linear fit at certain values. It seems that the curves comprise two logarithmic sections.

However, the linear correlation in all years is high ($R^2 \simeq 0.930$) over the entire duration interval. This shows that τ may vary from year to year.

4.2 Leonids

The persistent train distribution for Leonids is well covered, with 686 persistent trains reported (Figure 2). Most of these data were produced during the 1998 November 17 Leonid 'fireball' storm. For this shower we have found a great variability in τ. The mean seems to be around $\tau \simeq 0.930$. Variations with year and time interval are clear, for example for 1998 $\tau = 0.864 \pm 0.188$ in the interval [1 s, 10 s], while in the interval [35 s, 300 s] $\tau = 0.995 \pm 0.076$. In 1999, $\tau = 0.462 \pm 0.306$ for $N = 247$ persistent trains. When the sample is very good, this Leonid pattern clearly shows that there are two line sections, i.e. [1 s, 10 s] and (10 s, $d_{\max}$]. In some cases the linear fit is very good even as far as 20 seconds; in other cases, like the 1998 Leonids, we find one good fit for [15 s, 30 s] and another for [30 s, 300 s]. The reason for this may be explained by different populations of meteoroids, differences in the persistent train sample or even different heights where the meteors occur. For these reasons we cannot find a well-defined interval in which the cumulative fit works well.

In the 1998 data, amongst others (Figure 2), we find a data concentration around certain rounded values. This tendency may tell us that observers tend to round the persistent trains duration to certain values like 10, 20 or 25 s.

4.3 Geminids

Geminid fireballs data are poor (Figure 3) and show only one line, not two sections. The sum of all data for this shower gives us a value of $\tau = 0.820 \pm 0.670$ ($N = 28$ persistent trains, $R^2 = 0.956$).

5 Comparison of major meteor showers

Perseids, Leonids and Geminids (Figure 4) were compared. The Leonids produced the longest persistent trains while the Geminids produced the shortest. Table 2 shows the geocentric velocity, V_∞ (Rendtel et al., 1995) and the beginning and ending heights H_b and H_e as these may be important factors. For Leonids, this may affect the time that the persistent train is visible.

Table 1 – Linear fit for cumulative number of persistent trains and train duration, d, for main meteor showers: PER, LEO and GEM. ΣSHW is the sum for all showers, in two duration intervals. y_0 and a are defined in (eqn. 2) on page 118.

Shower	interval	y_0	a	R	R^2	Error	$\tau = e^a$
PER 1991–1995	[1 s, 14 s]	3.813	-0.255	0.966	0.932	0.312	0.775
PER 1993	[2 s, 7 s]	2.785	-0.200	0.998	0.997	0.025	0.819
PER 1996	[1 s, 30 s]	3.268	-0.064	0.903	0.816	0.303	0.938
LEO 1991–1995	[1 s, 13 s]	2.718	-0.169	0.964	0.929	0.204	0.845
LEO 1996	[2 s, 60 s]	2.327	-0.021	0.981	0.962	0.106	0.979
LEO 1998	[1 s, 10 s]	5.771	-0.146	0.925	0.856	0.188	0.864
	[15 s, 30 s]	4.800	-0.022	0.975	0.951	0.003	0.978
	[35 s, 300 s]	4.274	-0.005	0.999	0.980	0.076	0.995
LEO 1999	[1 s, 5 s]	6.596	-0.773	0.977	0.955	0.306	0.462
LEO 2000	[1 s, 7 s]	4.616	-0.320	0.975	0.950	0.174	0.726
	[16 s, 60 s]	2.348	-0.013	0.964	0.929	0.072	0.987
GEM 1993	[1 s, 15 s]	1.982	-0.116	0.930	0.865	0.328	0.890
GEM 1996	[1 s, 4 s]	3.730	-0.730	0.983	0.966	0.215	0.482
SPO	[1 s, 5 s]	3.669	-0.474	0.979	0.959	0.180	0.623
ΣSHW	[1 s, 16 s]	6.756	-0.138	0.926	0.858	0.284	0.871
	[19 s, 600 s]	4.534	-0.006	0.985	0.970	0.174	0.994

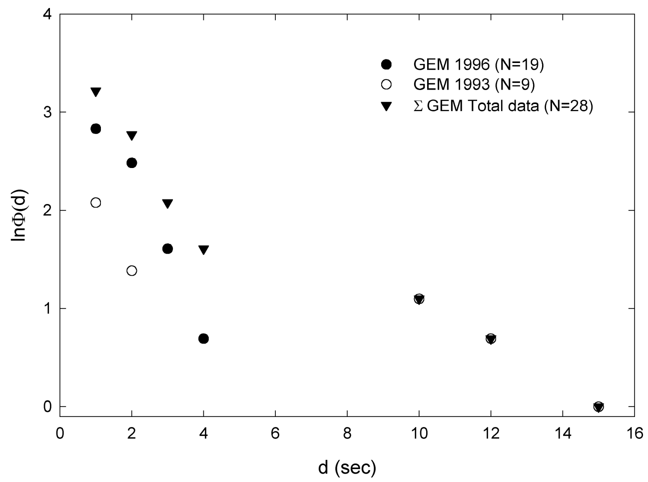

Figure 3 – The natural logarithm of cumulative number of persistent trains observed, $\Phi(d)$, versus time duration, d, for Geminids in 1993 and 1996; and the entire set of Geminid fireball data.

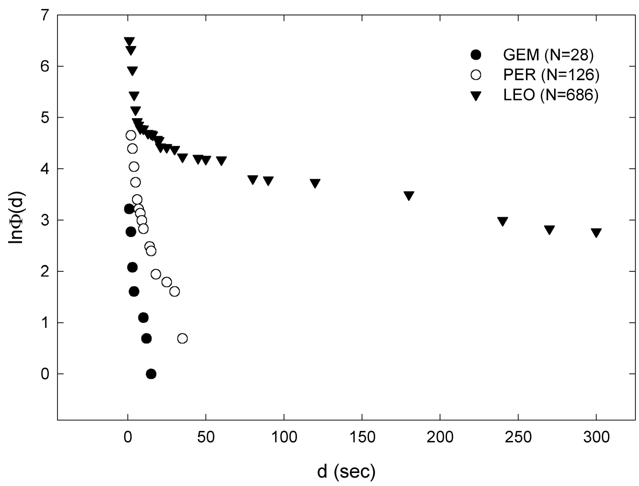

Figure 4 – The natural logarithm of cumulative number of total persistent trains observed, $\Phi(d)$, versus time duration, d, for Perseids, Leonids and Geminids for all years.

Other characteristics may be relevant, such as physical composition or meteoroid size. Future work may find a correlation with the meteor physics.

6 Comparison between sporadic fireballs and meteor showers

The Population index, τ, is lower for sporadics ($\tau = 0.622 \pm 0.180$ in the interval [1 s, 5 s]), than the mean for showers ($\tau = 0.871 \pm 0.284$ in the interval [1 s, 16 s]); see Table 3 and Figure 5. Sporadic fireball persistent trains may tend to be less persistent than the mean of the main showers studied. However, the sample for sporadics is poor ($N = 32$) compared with meteor shower data ($N = 840$). We have to keep in mind that these data sets have different Geocentric Velocities (with much variation within the sporadics, too) and this result shows a different conclusion from the shower data, where we found that faster meteoroids leave more enduring persistent trains.

7 Persistent train index in meteor showers

Data for this comparison were taken from (Bellot Rubio, 1992), where SOMYCE members observed about 26 000 meteors between 1987 and 1991. Perseid and Leonid persistent trains from Spanish observations in 2002 (Benítez Sánchez & Fraile Algeciras, 2003; Benítez Sánchez, 2002a) were added to this sample. First, we observe that the interval in which the fit is good is shorter, from 1 to 16 s at the longest; while for fireballs this interval is quite broad, even 900 seconds. That suggests the importance of the size of meteoroid particles, because we expect that fainter meteors (from smaller meteoroids) would leave less enduring persistent trains. In future work different physical processes in the upper atmosphere may be considered as causes of this, such as

Table 2 – Mean τ for major showers, the Σ indicating summation over all observed years. Geocentric velocity, V_∞, and mean H_b and H_e are shown.

Shower	d interval	y_0	a	R	R^2	Error	$\tau = e^a$	V_∞ (km/s)	H_b (km)	H_e (km)
Σ PER	[1 s, 45 s]	3.972	-0.084	0.936	0.877	0.400	0.919	59	114	94
Σ PER	[1 s, 10 s]	4.651	-0.201	0.960	0.922	0.131	0.818	59	114	94
Σ LEO	[1 s, 10 s]	6.511	-0.215	0.927	0.860	0.273	0.807	71	128	87
	[13 s, 600 s]	4.600	-0.007	0.993	0.986	0.135	0.993	71	128	87
Σ GEM	[1 s, 15 s]	2.967	-0.198	0.956	0.914	0.670	0.820	35	100	80

Table 3 – Mean τ for sporadic fireballs and all major showers data.

Shower	d interval	y_0	a	R	R^2	Error	$\tau = e^a$
SPO	[1 s, 5 s]	3.669	-0.474	0.979	0.959	0.180	0.622
All Meteor Showers	[1 s, 16 s]	6.756	-0.138	0.926	0.858	0.284	0.871
	[19 s, 600 s]	4.534	-0.006	0.985	0.970	0.174	0.994

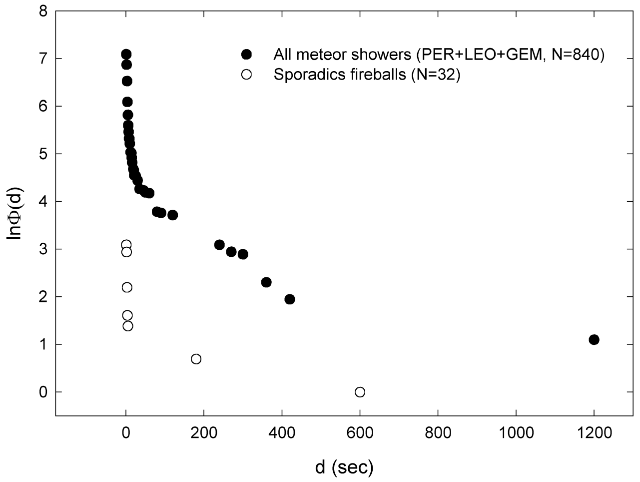

Figure 5 – The natural logarithm of cumulative number of total persistent trains observed, $\Phi(d)$, versus time duration, d, for all main meteor showers and sporadic fireballs. Fireball persistent trains of meteor showers tend to have longer time durations than sporadics.

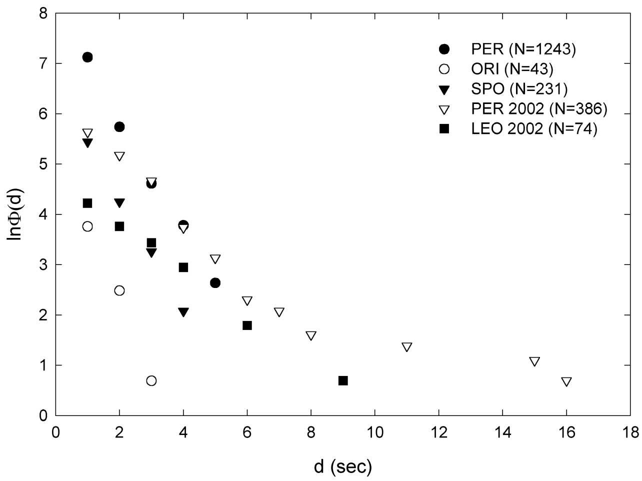

Figure 6 – The natural logarithm of cumulative number of persistent trains observed, $\Phi(d)$, versus time duration, d, for 'faint meteors' for Perseids, Orionids, Leonids and sporadics.

diffusive rates varying with height. For the moment this is pure speculation, as this observational report does not investigate the physics.

The population index tends to be higher in the fireball data than for normal meteors in the same showers. For example, for Perseids, during 1987–1991 $\tau = 0.335 \pm 0.165$ and in 2002 $\tau = 0.732 \pm 0.750$ (Table 4), whereas for fireballs $\tau = 0.919 \pm 0.400$ (Table 2). This difference may indicate that τ varies from year to year and with particle size.

We have no data from Orionid fireballs, however τ is similar to the Perseid data (H_b and H_e are similar) This seems to tell us that where the population index r is high, the duration of persistent trains is shorter. Thus a dependence on meteoroid mass may exist.

For the Leonids, τ varies greatly. In Leonids 2002, the sample of fireballs was poor, almost all the meteors being faint ($\tau = 0.636 \pm 0.117$, with full Moon that year, Table 4, Figure 6). But in 1998 the contrary occurred, and a lot of bright meteors were observed ($\tau = 0.864 \pm 0.188$, Table 1). The most important dependence here may be on meteoroid size.

This difference is greatest for sporadics: for faint meteors, $\tau = 0.330 \pm 0.062$ in the interval [1 s, 4 s] (Table 4); for fireballs, $\tau = 0.623 \pm 0.180$ in the similar interval [1 s, 5 s] (Table 1). As was commented before, a large variability in geocentric velocity and meteoroid size may explain this variation.

8 A FIDAC analysis: possible dependence of τ on visual magnitude

An analysis of the FIDAC data has been carried out for the period 1989–1997. All data were taken from the IMO web site. With this global data, we tried to find a relation between τ and the visual magnitude of fireballs.

First we computed a total τ, and found a $\tau = 0.899 \pm 0.157$ in the interval [1 s, 20 s] (Table 5); this value is similar to that obtained by the total for all showers, ΣSHW ($\tau = 0.871 \pm 0.284$ in the interval [1 s, 16 s], Table 1) by Spanish observers. Comparing them, we get a strong impression that, in the FIDAC database, an

Table 4 – Population Index for persistent trains computed with ‘faint meteors’. Perseids, Orionids and sporadics were taken from (Bellot Rubio, 1995).

Shower	d interval	y_0	a	R	R^2	Error	$\tau = e^a$	V_∞ (km/s)	H_b (km)	H_e (km)
PER	[1 s, 5 s]	8.059	-1.093	0.997	0.993	0.165	0.335	59	114	94
PER 2002	[1 s, 16 s]	5.076	-0.312	0.911	0.829	0.750	0.732	59	114	94
ORI	[1 s, 3 s]	5.381	-1.534	0.995	0.991	0.210	0.216	66	117	99
LEO 2002	[1 s, 9 s]	4.692	-0.452	0.997	0.994	0.117	0.636	71	128	87
SPO	[1 s, 4 s]	6.507	-1.108	0.999	0.999	0.062	0.330	-	-	-

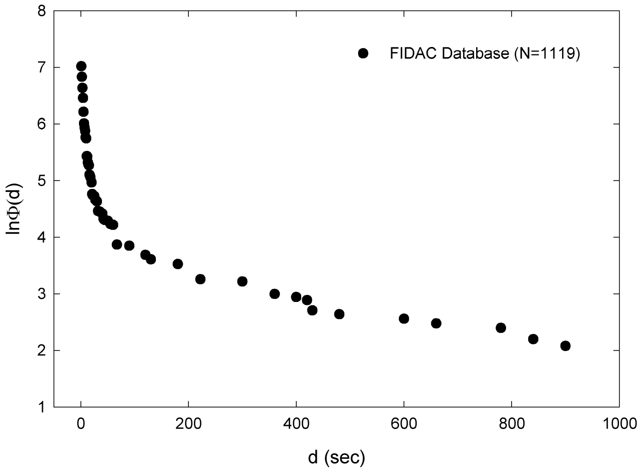

Figure 7 – The natural logarithm of the cumulative trains count $\ln(\Phi(d))$ versus the duration d for all fireballs. The fit obtained is $\tau = 0.743 \pm 0.129$ in the interval [1 s, 900 s], quite similar to the sum of all meteor showers.

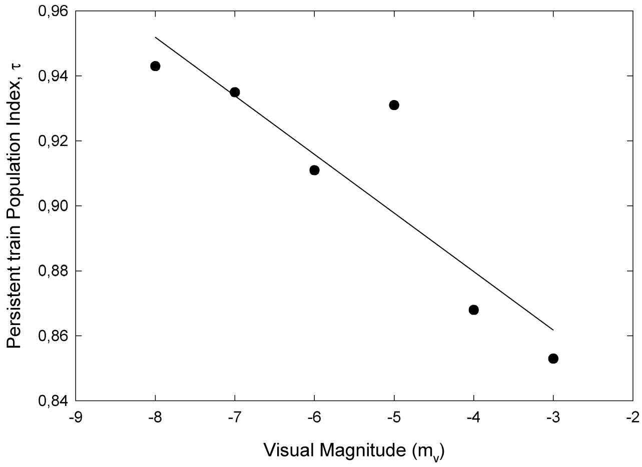

Figure 8 – Persistent train index τ *versus* the visual magnitude of fireballs. The straight line is the best fit. We would expect that brighter fireballs to leave longer persistent trains, so τ would tend to have larger values; however, this fit only happens in the interval $[-3^\mathrm{m}, -8^\mathrm{m}]$. The linear fit, to the equation $\tau = cm_\mathrm{v} + m_{\mathrm{v}0}$ obtain a slope of $a = -0.018 \pm 0.088$ with a correlation of $R = -0.907$.

important number of reports came from main showers like Perseids, Leonids and Geminids.

The amount of data permitted us to obtain a τ value for each magnitude (Table 5). Between -3^m and -8^m τ is larger for brighter fireballs. Moreover, the relation is approximately linear (Figure 8). A fit is found for $\tau = -0.018m_\mathrm{v} + 0.808$ with $R = -0.907$.

A global fit in the $[-9^\mathrm{m}, -16^\mathrm{m}]$ interval does not show any tendency, with a $R \simeq -0.50$. Several causes can be suggested for this. (a) There is a poor sample in the interval $[-9^\mathrm{m}, -16^\mathrm{m}]$ because the probability of seeing bright fireballs is very low. (b) Time durations are usually poorly reported, and sometimes there are great differences even between reports of the same fireball. (c) We could speculate about the cometary origins of ‘fainter fireballs’ and the asteroidal origins of the brightest. These may explain the double log pattern in the data.

With this in mind we had to study the different geocentric velocities of the fireballs; FIDAC data do not have a ‘radiant’ column. We know that the radiant is very relevant to the duration of persistent trains, and we expected brighter fireballs to leave more persistent trains. The data do not show this unambiguously for all the reasons mentioned before. Thus we cannot confirm that brighter fireballs have more persistent trains, but the supposition looks to be true.

Figures 9 to 12 show all the fits from -3^m to -15^m. All the global data are shown in Figure 7. Data for τ, a and R^2 are given in Table 5.

9 Conclusions

A linear fit is obtained between persistent train duration, d, and $\ln(\Phi(d))$, the log of the cumulative number of the persistent trains observed. This fit has $R \geq 0.95$ even for the longest duration for 900 seconds (15 minutes) for visual naked-eyed persistent trains observed. However, most of time, two or even three straight-line sections are observed if the sample is good. This may be indicative of the presence of different meteoroids populations. When all the data are used (e.g. all FIDAC, all PER or all LEO data) the sample is good. However, when working in some magnitude interval (e.g. -3^m for FIDAC data), the sample is often poorer and the above conclusion cannot be drawn.

In fireballs from the main showers studied, Perseids, Leonids and Geminids, τ varies year from year and between fireballs and ‘faint meteors’. Its value depends on several factors such as the number of observations, presence of the Moon, light pollution and other physical parameters, such as geocentric velocity, size of meteoroid, and H_b and H_e of the meteor path.

We need more data from fireballs with persistent trains. We have to send our reports to FIDAC with special care to make a correct shower association. The

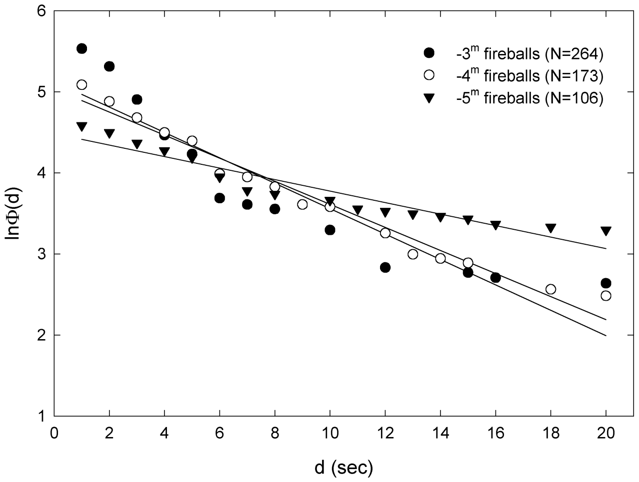

Figure 9 – The natural logarithm of the cumulative trains count $\ln(\Phi(d))$ versus the duration d for all fireballs in the interval $[-3^{\mathrm{m}}, -5^{\mathrm{m}}]$ from the FIDAC database. Two straight line sections appear to exist in the interval 6 to 10 seconds.

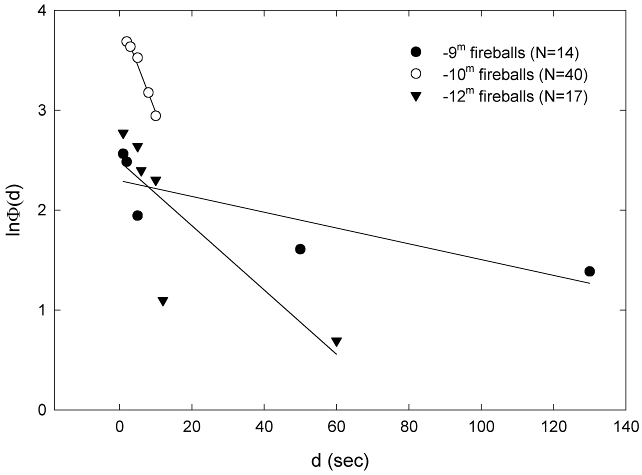

Figure 11 – The natural logarithm of the cumulative trains count $\ln(\Phi(d))$ versus the duration d for all fireballs in the interval $[-9^{\mathrm{m}}, -12^{\mathrm{m}}]$ (omitting -11^{m} for which there is no data) from the FIDAC database.

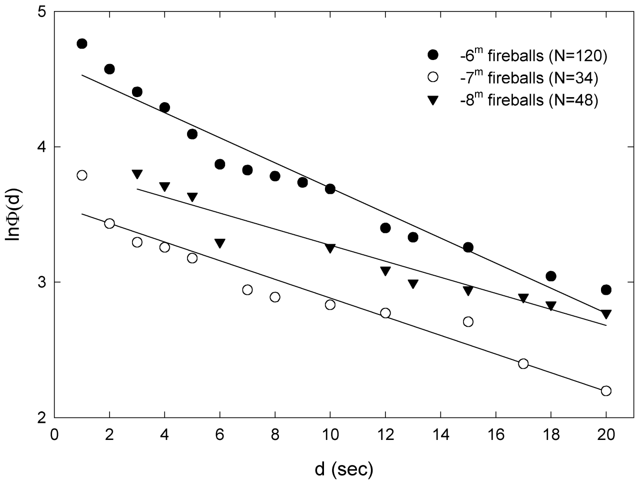

Figure 10 – The natural logarithm of the cumulative trains count $\ln(\Phi(d))$ versus the duration d for all fireballs in the interval $[-6^{\mathrm{m}}, -8^{\mathrm{m}}]$ from the FIDAC database. Here, linear fits describe the data to 20 seconds.

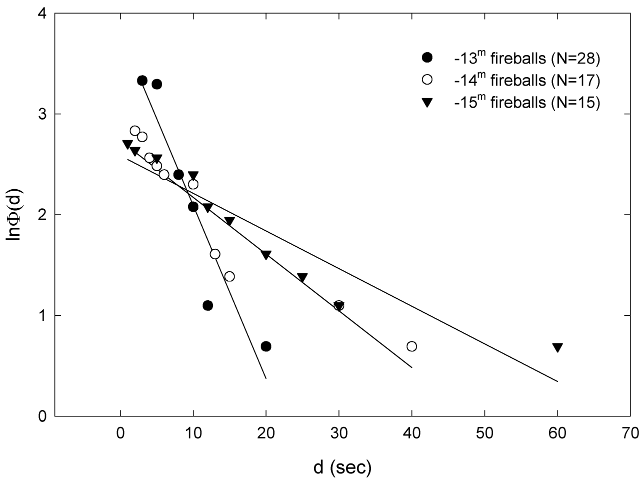

Figure 12 – The natural logarithm of the cumulative trains count $\ln(\Phi(d))$ versus the duration d for all fireballs in the interval $[-13^{\mathrm{m}}, -15^{\mathrm{m}}]$ from the FIDAC database.

observer should show clearly on the report the presence or absence of a train, and its visual duration. A detailed analysis with more faint meteors and other showers should be made in a future, to try and find a relation between the observational and the physics of persistent trains, such as visual diffusion coefficients.

Acknowledgement

My best thanks to Chris Trayner for his time and patience in the correction of the preliminary text.

References

Bellot Rubio L. R. (1992). "On the presence of trains in meteor showers". *WGN*, **20:3**, 140–149.

Bellot Rubio L. R. (1995). "Effects of a dependence of meteors brightness on an entry angle". *Astron. Astrophys.*, **301**, 602–608.

Benítez Sánchez O. (2002a). "Análisis global de las observaciones españolas de las Perseidas". *Meteors*, **4:20**.

Benítez Sánchez O. (2002b). "On the presence of persistent trains in Leonids fireballs from 1998, 1999 and 2000 observations". *WGN*, **30:4**, 111–119.

Benítez Sánchez O. and Fraile Algeciras E. (2003). "La tormenta de las Leónidas en la madrugada del 18 al 19 de noviembre de 2002". *Meteors*, **5:21**.

Benítez Sanchez O. and Ocaña González F. (2004). "A fireball analysis from Spanish meteor observations". *WGN*, **32:1**, 29–34.

Rendtel J., Arlt R., and McBeath A. (1995). *Handbook for visual meteor observers.* International Meteor Organization, Potsdam.

Table 5 – τ computation for each visual magnitude with FIDAC data. (There were no observations of -11^{m}.)

Visual Magnitude (m_{v})	d interval	y_0	a	R	R^2	Error	$\tau = e^a$
-3^{m}	[1 s, 20 s]	5.127	-0.157	0.921	0.849	0.408	0.853
	[25 s, 222 s]	2.391	-0.011	0.971	0.943	0.239	0.989
-4^{m}	[1 s, 20 s]	5.036	-0.142	0.986	0.972	0.143	0.868
	[22 s, 90 s]	2.433	-0.018	0.952	0.907	0.210	0.982
-5^{m}	[1 s, 20 s]	4.485	-0.071	0.952	0.907	0.136	0.931
	[21 s, 60 s]	3.336	-0.026	0.991	0.982	0.057	0.974
-6^{m}	[1 s, 20 s]	4.623	-0.093	0.974	0.950	0.128	0.911
	[22 s, 60 s]	2.973	-0.012	0.989	0.977	0.035	0.988
-7^{m}	[1 s, 20 s]	3.572	-0.067	0.962	0.926	0.123	0.935
	[21 s, 67 s]	2.600	-0.031	0.939	0.882	0.201	0.969
-8^{m}	[3 s, 20 s]	3.866	-0.059	0.964	0.929	0.104	0.943
	[29 s, 90 s]	2.914	-0.012	0.909	0.826	0.131	0.988
-9^{m}	[1 s, 130 s]	2.296	-0.008	0.843	0.711	0.324	0.992
-10^{m}	[1 s, 10 s]	3.924	-0.095	0.989	0.978	0.055	0.909
	[30 s, 780 s]	2.527	-0.002	0.9852	0.971	0.124	0.998
-12^{m}	[1 s, 60 s]	2.743	-0.034	0.995	0.999	0.119	0.967
-13^{m}	[3 s, 20 s]	3.811	-0.172	0.945	0.892	0.402	0.842
-14^{m}	[2 s, 40 s]	2.734	-0.056	0.9435	0.890	0.266	0.946
-15^{m}	[1 s, 60 s]	2.584	-0.037	0.942	0.887	0.248	0.964
All magnitudes	[1 s, 20 s]	6.840	-0.107	0.970	0.942	0.157	0.899
All magnitudes	[21 s, 900 s]	4.421	-0.003	0.941	0.886	0.230	0.997

The 2005 October 5 outburst of October Camelopardalids

Peter Jenniskens [1], Jarmo Moilanen, Esko Lyytinen, Ilkka Yrjölä and Jeff Brower

Jarmo Moilanen (Finland) detected twelve meteors from a compact geocentric radiant at RA = $164\overset{\circ}{.}1 \pm 2\overset{\circ}{.}0$, Dec. = $+78\overset{\circ}{.}9 \pm 0\overset{\circ}{.}5$, on the border of Draco and Camelopardalis, in the evening of 2005 October 5. The differential mass distribution index was a low $s = 1.4 \pm 0.2$ (+0 to -6 magnitude). The new shower was confirmed by Esko Lyytinen (2 meteors, early period only, located at $25\overset{\circ}{.}00$ E, $+60\overset{\circ}{.}25$ N) and Ilkka Yrjölä (4 meteors: $26\overset{\circ}{.}4$ E, $+60\overset{\circ}{.}9$ N) at nearby locations, and by Sirko Molau in Germany (7 meteors). Esko Lyytinen calculated an apparent speed of $V_g = 47.3 \pm 0.5$ km/s from one two-station meteor, close to the parabolic limit. We conclude that the event was caused by the 1-revolution dust trail of a yet unidentified potentially Earth-threatening (Halley-type or) Intermediate Long-Period comet with orbital elements similar to those of the meteoroids: Epoch = 2005 October 5, $a = \infty$ (range $15 - \infty$) AU, $q = 0.993 \pm 0.001$ AU, $\omega = 170\overset{\circ}{.}5 \pm 1^\circ$, $\Omega = 192\overset{\circ}{.}59 \pm 0\overset{\circ}{.}04$, and $i = 78\overset{\circ}{.}53 \pm 0\overset{\circ}{.}55$ (J2000.0).

Received 2005 October 17

1 Introduction

October 5 was a suspected date of outburst events, with earlier anecdotal reports dating from 1902 ($\lambda_0 = 192\overset{\circ}{.}5006$: 50 light tracks behind clouds by G. Percey Bailey (1902)), 1942 ($\lambda_0 = 192\overset{\circ}{.}58$: significant shower of $+3^{\mathrm{m}}$ meteors, radiating from near Cassiopeia, by Werner Sander (1943) while in Russia; see also (Teichgraeber, 1943)), and 1976 ($\lambda_0 = 193\overset{\circ}{.}534$, 113 meteors moving North to East by E. Root, Pompano Beach, Florida (Root, 1976; MacKenzie, 1980)).

2 2005 October 5 outburst

In the evening of October 5, Jarmo Moilanen of Finland ($26\overset{\circ}{.}5735$ E, $+64\overset{\circ}{.}5392$ N) operated a low-light-level Watec LCL-902K video camera (1/2" Sony EXview HAD CCD-chip) with wide angle $f = 3.8$ mm, $f/0.8$ aspherical Computar lens, in a multi-station program with Esko Lyytinen and Ilkka Yrjölä. Moilanen first started operating his fireball camera in March of 2004. He is well known as an observer of halos. Analysing the data he discovered that of 19 filmed meteors in the period $17^{\mathrm{h}}06^{\mathrm{m}}$ until $22^{\mathrm{h}}41^{\mathrm{m}}$ UT, as many as twelve radiated from a compact radiant, with most observed in the first three hours of operations. The magnitudes derived by the UFOCapture software were: $-1, -6, +0, -1, -2, +0, +1, -2, -2, -6, -2, +1$, suggesting a shallow magnitude distribution index $\chi = 1.4 \pm 0.2$ or differential mass distribution index $s = 1.4 \pm 0.2$. Figure 1 shows the -5.6^{m} fireball of $17^{\mathrm{h}}08^{\mathrm{m}}40^{\mathrm{s}}$ UT. Jarmo determined the radiant at RA = 162°, Dec. = +79°.

The radiant is on the border of Draco and Camelopardalis, with no bright star nearby that readily identifies the radiant position. In order to avoid confusion with the October Draconids, we will choose here to name this shower the October Camelopardalids.

In subsequently checking their video records, Esko Lyytinen confirmed having detected two stream members in the first half hour of the night, including the $17^{\mathrm{h}}08^{\mathrm{m}}40^{\mathrm{s}}$ UT fireball. After that clouds interfered.

Figure 1 – The $17^{\mathrm{h}}08^{\mathrm{m}}40^{\mathrm{s}}$ UT Camelopardalid meteor by Jarmo Moilanen.

Ilkka Yrjölä operated from $17^{\mathrm{h}}00^{\mathrm{m}} - 21^{\mathrm{h}}30^{\mathrm{m}}$ UT and detected four stream members. Sirko Molau (private correspondence), in Germany, reported having detected seven stream members in the period $17^{\mathrm{h}}27^{\mathrm{m}} - 04^{\mathrm{h}}35^{\mathrm{m}}$ UT with a similar low-light level camera (Molau, 2001). Two of Ilkka's Camelopardalids are shown in Figure 2.

The total number of detected meteors is not very high and we checked among radio forward meteor scatter observations to see if the outburst might have been detected as an increase of long-duration echoes. Radio forward meteor scatter observations of participants in Global-MS-Net (Illka Yrjölä in Finland and Jeff Brower in British Columbia, Canada) show a flurry of bright meteors between $18\overset{\mathrm{h}}{.}0$ and $22\overset{\mathrm{h}}{.}8$ UT (Figure 3). The systems record the sum duration of all meteors, the total count, and the longest echo duration in 10-minute intervals (Jenniskens, 1998). No significant enhancement of the meteor count was detected, which implies that the shower was not rich in faint (underdense) meteors, say those of magnitude 5–8. This is consistent with the low magnitude distribution index. In contrast, both the systems by Yrjölä and Brower show an increase of the sum echo duration and longest echo in the relevant time period. From a plot of number versus total echo

[1] SETI Institute, 515 N. Whisman Road, Mountain View, CA 94043, USA. E-mail: tt pjenniskens@mail.arc.nasa.gov

IMO bibcode WGN-335-jenniskens-camelopardalids
NASA-ADS bibcode 2005JIMO...33..125J

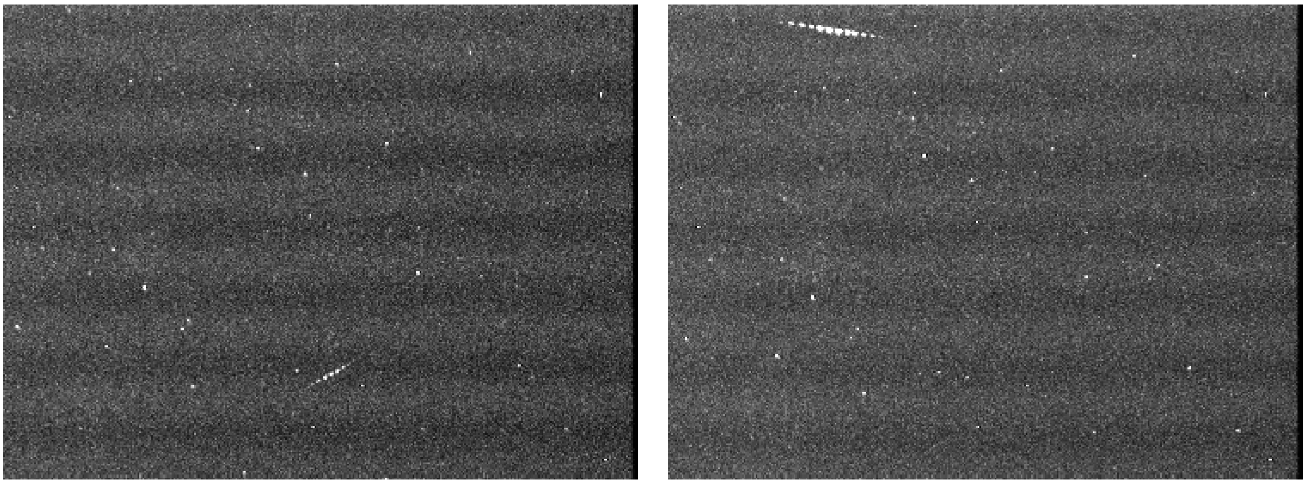

Figure 2 – Two of the Camelopardalids filmed by Ilkka Yrjölä at $19^{h}26^{m}10^{s}$ (left) and $19^{h}31^{m}18^{s}$ UT (right) on 2005 October 5.

duration, we confirmed that aurora or sporadic-E were not responsible for these spikes. Those tend to cause much longer echo durations.

Further corroborating evidence comes from the SkiYMET meteor radar of the Leibniz-Institut für Atmosphärenphysik of the Universität Rostock, located at ALOMAR, Andoya Rocket Range in Norway (Werner Singer). Daily postings of the meteor count are provided at: `http://www.iap-kborn.de/radar/Radars/Skiymet/sky_main.htm` . These counts show a drop in rates at this time, presumably due to overdense echoes preventing the detection of underdense echoes. These data are summarized in Figure 3.

From the radar and video counts, we conclude that the peak of the shower was at $19^{h}.7 \pm 1^{h}.0$ UT with a FWHM of about 3.6 hours (gray line in Figure 3). The forward meteor scatter and radar observations confirm that this was a brief flurry of bright meteors, global in scale, as expected for a dust trail crossing. This confirms that the event was a meteor outburst, rather than annual activity of a minor shower.

3 Analysis and interpretation

Moilanen and Yrjölä measured the position of the video meteors and all measurements were plotted on a gnomonic chart (Figure 4). Measurement errors can increase the apparent size of the radiant. However, at least twelve meteors diverge from an apparent radiant at R.A. $= 163^{\circ} \pm 2^{\circ}$, Dec. $= +79^{\circ}.5 \pm 0^{\circ}.5$. Single station observations imply a speed of $V_{\infty} = 48.3 \pm 2.6$ km/s. This translates to geocentric radiant $RA_g = 164^{\circ}.1 \pm 2^{\circ}.0$, Dec.$_g = +78^{\circ}.9 \pm 0^{\circ}.5$ and $V_g = 46^{\circ}.9 \pm 2^{\circ}.6$ km/s.

Lyytinen examined the best five meteors , and found those at $17^{h}08^{m}40^{s}$, $20^{h}54^{m}26^{s}$, and $19^{h}26^{m}10$ UT to fit well to a very tight radiant at $RA_g = 166^{\circ}.0$, Dec.$_g = +79^{\circ}.1$, while the $19^{h}01^{m}49^{s}$ UT and $19^{h}31^{m}18^{s}$ UT meteors appear to pass by about $0^{\circ}.6$ or $0^{\circ}.7$, possibly having a radiant a few degrees higher in Right Ascension. The tight cluster appears to represent most of the meteors in the sample of Figure 4. These meteors are single station and radiant solutions for individual meteors can be derived by adjusting the radiant in one dimension and checking for reasonable height and speed. A good fit to beginning and end heights for the first group of three meteors is reached with V_{∞} about 1 km/s lower than that of the second group. This is consistent with the speed expected for a near-parabolic orbit with those radiants differing by a few degrees, adding confidence that the radiants of the outliers are really different. The resulting orbital elements from the derived speeds are given in Table 1, first column, for the tight group. For the second group, the inclination is about $76^{\circ}.5$ and ω is about $169^{\circ}.5$.

The one multi-station $17^{h}08^{m}40^{s}$ UT meteor has a small convergence angle, with the radiant well defined in one dimension but less well in another. The two station solution gives $RA_g = 161^{\circ}.5$, Dec.$_g = +78^{\circ}.5$. The discrepancy with the earlier solution is mostly due to the small convergence angle and the fact that the track recorded by Lyytinen is only two degrees in length. The much longer track from Moilanen passes very close to the tight group (above). The entry speed is $V_{\infty} = 47.6 \pm 0.5$ km/s, not far from the (radiant dependent) parabolic limit at $V_{\infty} = 48.6$ km/s for the derived two station radiant, or 47.9 km/s for the more reliable solution from the three examined meteors above. These V_{∞} values translate into $V_g = 47.3$ and 46.6 ± 0.5 km/s, respectively. The resulting orbital elements for this single meteor are given in Table 1 (second column). Alternatively, if we adjust the radiant solution to match the more probable tight radiant grouping, we have the result in the third column. The node now reflects the time of this meteor, rather than the peak time of the shower.

No comet is known with similar orbital elements. We conclude that the presence of a new potentially Earth-threatening Intermediate-Long-Period comet has been detected from its 1-revolution dust trail from a prior return (Jenniskens et al., 1997; Lyytinen & Jenniskens, 2003). We can not fully exclude the possibility that a Halley-type comet may be responsible also.

In years when the dust trail is not in Earth's path, a low-level of activity would be expected from this radiant

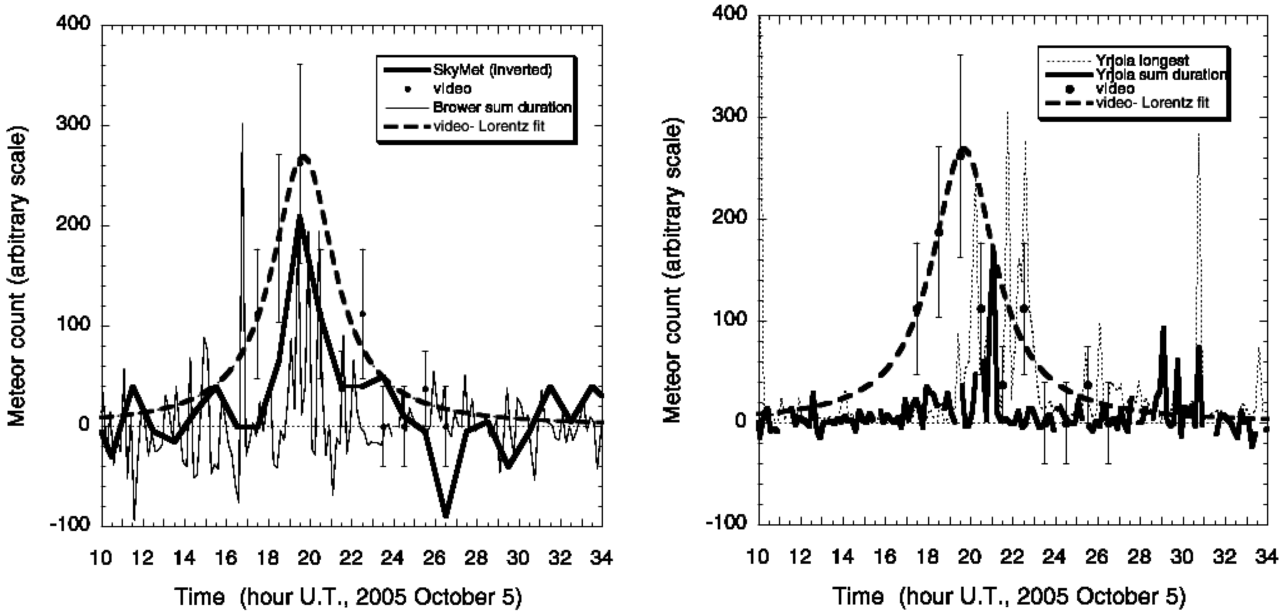

Figure 3 – Overview of rate measurements at the time of the reported outburst. The graph on the left shows the decrease of counts due to overdense echoes in the SkyMet data (inverted) and the sum duration counts by Jeff Brower. The graph on the right shows sum duration counts and the echo of longest duration in 10-minute intervals measured by Ilkka Yrjölä. The fit is a Lorentz curve with peak intensity, width, and peak time matched visually to the video counts.

Table 1 – Orbital elements from video observations (J2000.0, Epoch = 2005 October 5).

	Average of all	Meteor $17^{\mathrm{h}}08^{\mathrm{m}}40^{\mathrm{s}}$ UT	Tight cluster
RA	$164^{\circ}\!.1 \pm 2^{\circ}\!.0$	$\sim 161^{\circ}\!.5$	$166^{\circ}\!.0$
Dec.	$+78^{\circ}\!.9 \pm 0^{\circ}\!.5$	$\sim +78^{\circ}\!.5$	$+79^{\circ}\!.1$
V_g	$46^{\circ}\!.9 \pm 2^{\circ}\!.6$	~ 47.3	46.6 ± 0.5
a (AU)	∞ (Range $15 - \infty$)	13.7	47
q (AU)	0.993 ± 0.001	0.992	0.993
ω	$170^{\circ}\!.5 \pm 1^{\circ}$	$169^{\circ}\!.7$	$170^{\circ}\!.4$
Ω	$192^{\circ}\!.59 \pm 0^{\circ}\!.04$	$192^{\circ}\!.484$	$192^{\circ}\!.57$
i	$78^{\circ}\!.3 \pm 0^{\circ}\!.5$	$79^{\circ}\!.2$	$78^{\circ}\!.2$

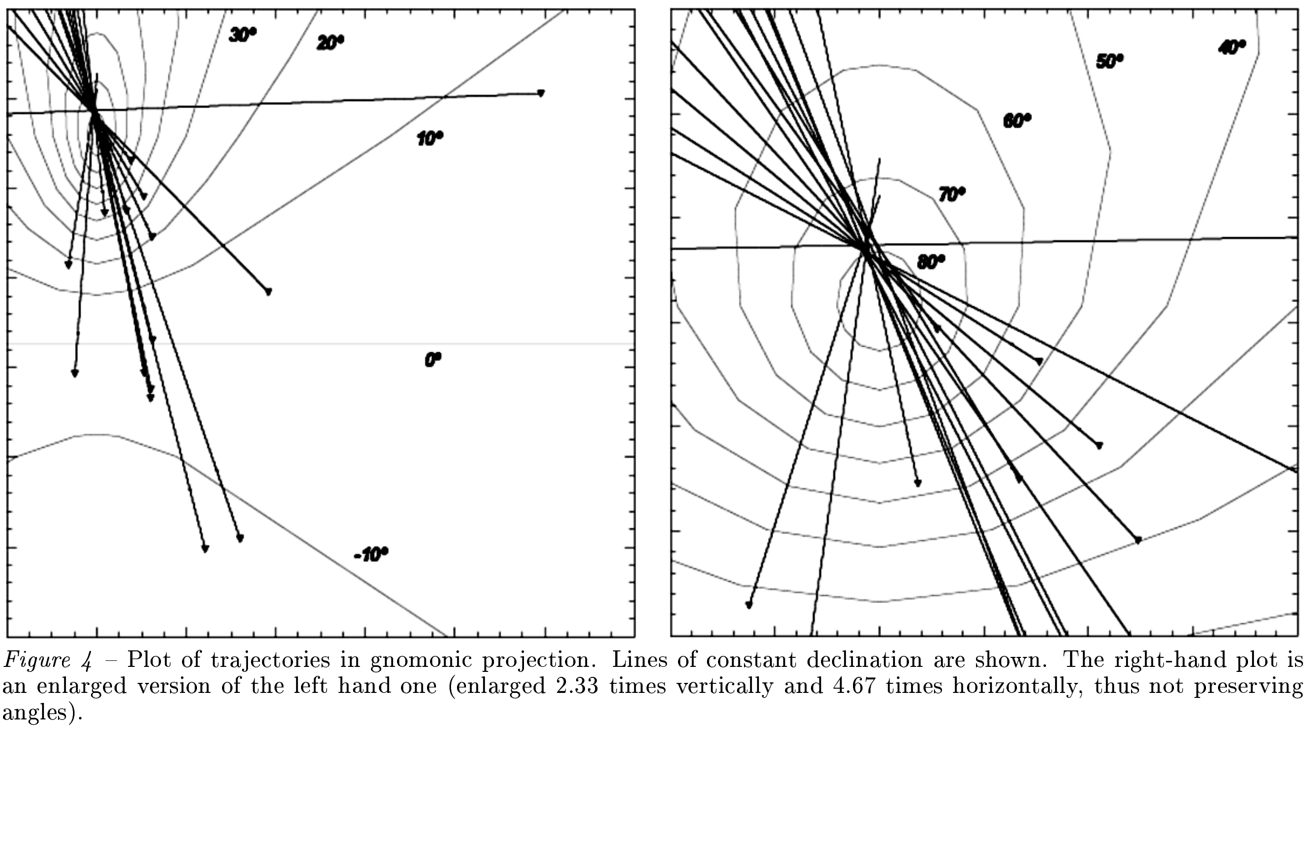

Figure 4 – Plot of trajectories in gnomonic projection. Lines of constant declination are shown. The right-hand plot is an enlarged version of the left hand one (enlarged 2.33 times vertically and 4.67 times horizontally, thus not preserving angles).

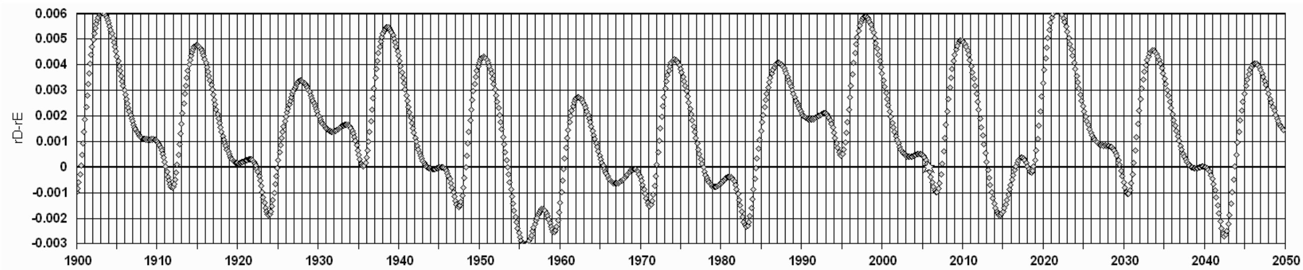

Figure 5 – The position of the node of meteoroids in a one-revolution dust trail ejected during a previous return of a long-period comet in the orbit of the October Camelopardalids. Outbursts are expected when the node is at Earth orbit ($\Delta r = 0$) on October 5 of a given year.

by dust from orbits more than 1 revolution ago, more so if this is a Halley-type comet (orbital period 20 – 200 years) instead of an Intermediate Long-Period Comet (200 – 10 000 years). Indeed, we found one reference to a radiant close to the given position in a radiant list compiled in the yearly astronomical almanac by the German astronomer Robert Henseling (perhaps from (Henseling, 1941), reproduced in a Finnish Handbook published in 1947 (Anonymous, 1947)). This has an entry for October 4 with radiant RA = $132^{\circ}\!.5$, Dec. = +79 (B1950?). Even though the Right Ascension differs by more than two hours, this is only about 6° on the sky. It is also possible that the observation on which this record is based, now lost, dated from a prior sighting of the dust trail.

Calculations of the planetary perturbations on a 1-revolution trail ejected in a previous return from this long period comet by Esko Lyytinen (Figure 5) show that the 1942 outburst may have been an encounter with the same dust trail. The 1976 and 1902 events are not readily identified with this trail. The picture is valid for a long period comet or intermediate long period comet, but would be different for a Halley-type comet.

Future encounters with this dust trail may occur in A.D. 2018 and 2038 (Figure 5).

4 Conclusion

An outburst of meteors from a minor shower is identified as the debris of an as yet unknown long-period (or perhaps Halley-type) comet passing close to Earth's orbit. This is the first time a new shower has been identified since we understood how the 1-revolution dust trails of intermediate long-period comets can wander on occasion into the Earth's path in 1995, and subsequently Global-MS-Net was founded to help detect such dust trails in 1997. The orbital elements of the meteoroids, derived from low-light-level TV observations, provide a first indication of the orbit of this Earth-threatening comet. The predicted future encounters with this dust trail may provide further insight into the comet orbit and identify whether the comet is approaching.

Acknowledgements

Foundation of Global-MS-Net was supported with a grant of the NASA Planetary Astronomy/Atmospheres program.

References

Anonymous (1947). *Tähtitieteen Harrastajan Kirja.* Rsan Julkaisuja III (URSA Publications III), Suomalaisen Kirjallisuuden Seura Kirjapaino Oy (Association of Finnish literature printing house). A book for amateur astronomers.

Bailey G. P. (1902). "A possible meteor shower on October 4". *Nature*, **66**, 577.

Henseling R. (1941). *Kleine Sternkunde.* P. Reclam, Leipzig.

Jenniskens P. (1998). "First results of Global-MS-Net: Annual report for 1997". *WGN*, **26**, 79–85.

Jenniskens P., Betlem H., de Lignie M., and Langbroek M. (1997). "The detection of a dust trail in the orbit of an Earth-threatening long-period comet". *Astrophys. J.*, **479**, 441–447.

Lyytinen E. and Jenniskens P. (2003). "Meteor outbursts from long-period comet dust trails". *Icarus*, **162**, 443–452.

MacKenzie R. A. (1980). *Solar System Debris.* British Meteor Society, Dover.

Molau S. (2001). "The AKM video meteor network". In Warmbein B., editor, *Proc. Meteoroids 2001, Kiruna, Sweden, Aug. 2001*, pages 315–318.

Root E. (1976). "Unusual displays". *Meteor News, Journal of the AMS*, **36**, 13.

Sander W. (1943). "Sternschnuppenschwarm am 1942.x.5d". *Die Sterne*, **23**, 46–46.

Teichgraeber A. (1943). "Bemerkung zu dem Sternschnuppenschwarm 1942 x 5d". *Die Sterne*, **23**, 172.

The Summer Pegasids from IMO video data

Mihaela Triglav-Čekada [1] *and Rainer Arlt* [2]

A July Pegasid and Upsilon Pegasid search in the IMO video database (1993–2004) is presented. The July Pegasids are typically assumed to be active from July 7–13, and the Upsilon Pegasids were reported to be active from approximately end July to end August. Neither minor meteor shower produces ZHRs higher than 3 at the dates of their maxima. The present investigation is based on nearly 23 000 non-Perseid video meteors of July and August. It does not show a clear indication of the July Pegasid radiant, according to day-to-day radiant distributions of 2001–2004. The August data of 1998–2004 show no evidence of an Upsilon Pegasid radiant either. Both showers may be inactive for the scope of video and visual means.

Received 2005 October 2

1 Introduction

In the summer time, two meteor showers with the name of Pegasids can occasionally be found in the literature. First are the July Pegasids active only around July 7–13 (see e.g. Rendtel et al., 1995) and the second are the υ-Pegasids active from approximately July 23 to August 29 (e.g. Povenmire, 1998). Both showers have very fast meteors – V_∞ near 70 km/s for the July Pegasids and 50 km/s for the υ-Pegasids. Also both meteor showers lack in-depth research, and we cannot find many authors mentioning them at all. Do not confuse the July Pegasids with other Pegasid radiants mentioned in the literature (Cook, 1973; Neslušan, 2002; Svoreň et al. 2000) which are active in winter time and are not connected with the above mentioned meteor showers.

The July Pegasids are very fast meteors with V_∞ of 70 km/s, meaning that they have very distant aphelia. On the average, the ZHR of the July Pegasids is about 3. They have a maximum on July 11 ($\lambda_\odot = 108°$). Comet Bradfield (C/1979 Y1) is connected with them (cf. Rendtel et al., 1995). Recent research on the visual IMO database (Olech and Wiśniewski, 2002) confirmed their level of activity with ZHR $= 3.1 \pm 0.1$ on the day of the maximum.

The υ-Pegasids are mentioned only in the work of a single author, Harold Povenmire. First they were seen on August 8, 1975, as numerous meteors radiating from the square of Pegasus. Their activity is reported to vary in different years; the highest activity was seen on August 7–9, 1978, with a ZHR of approximately 20. In an average year, the ZHR of 3.5 is seen on the day of their maximum on August 8 ($\lambda_\odot = 134\overset{\circ}{.}5$). They are described as being fast, faint, yellow-white in color and lacking significant trails (Povenmire, 1998). Some fireballs were also associated with this shower, giving the approximate orbital elements of the stream and rejecting their hyperbolic nature which would be the key for their high velocity (Povenmire, 2001).

[1]Streliška 9, SI-1000 Ljubljana, Slovenia
Email: mtriglav@yahoo.com
[2]Friedenstraße 5, D-14109 Berlin, Germany
Email: rarlt@aip.de

IMO bibcode WGN-335-triglavcekada-pegasids
NASA-ADS bibcode 2005JIMO...33..129T

2 The data set

This radiant investigation of the July Pegasid and υ-Pegasid meteor showers is based on individual meteors recorded by video systems (with and without image-intensifiers). All the observations from July and August in the years 1993–2004 placed on the IMO video network database are used (Molau, 2005a,b), with the exception of the Perseids in August which have been filtered out (those meteors which MetRec associated with the Perseid radiant).

The meteor data of the following observers is used (Molau, 2005a), ordered by the amount of observing hours contributed to the network :

Sirko Molau, Jörg Strunk, Jürgen Rendtel, Orlando Benítez-Sanchez, Steve Quirk, Ilkka Yrjölä, Stane Slavec, Detlef Koschny, Mirko Nitschke, Stephen Evans, Javor Kac, Ulrich Sperberg, Stefan Ueberschaer, Robert McNaught, André Knöfel, Rosta Štork, Michael Gerding.

All the data were treated as single-station video observations in this analysis. The meteors were measured using the MetRec software by Molau (1999). The positional accuracy is of the order of few arc minutes. Time differences are known very precisely due to the constant rate of video frames, so the determination of the angular velocity should have an accuracy similar to that of the positions. During computation, the individual meteor positions are projected onto a common (average) line, and the velocity is computed as the weighted average over all pair-wise distances on this line. The length of a meteor part on a video frame with larger time difference gets a larger weight, so individual position errors should have little influence on the resulting velocity for meteors captured on a number of video frames (Molau, 2005b).

Figure 1 shows the distribution of meteor data per year and date. When looking at the sum of all observations day-to-day we reached the following conclusions:

- On average 200 meteors per day are captured until July 26; after that the average rises to 400 meteors per night (without Perseids).
- Since the year 2000 there has been complete day-to-day video coverage in August, since 2001 there has been also complete day-to-day video coverage in July, meaning that our research on July meteor showers is concentrated only on their activity in the last three years.

Table 1 – The observational statistics for the July–August period per year. The majority of Perseids in August have been filtered out already.

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Sum
N	37	44	0	288	737	162	1365	2718	4587	2571	5929	4507	22 945

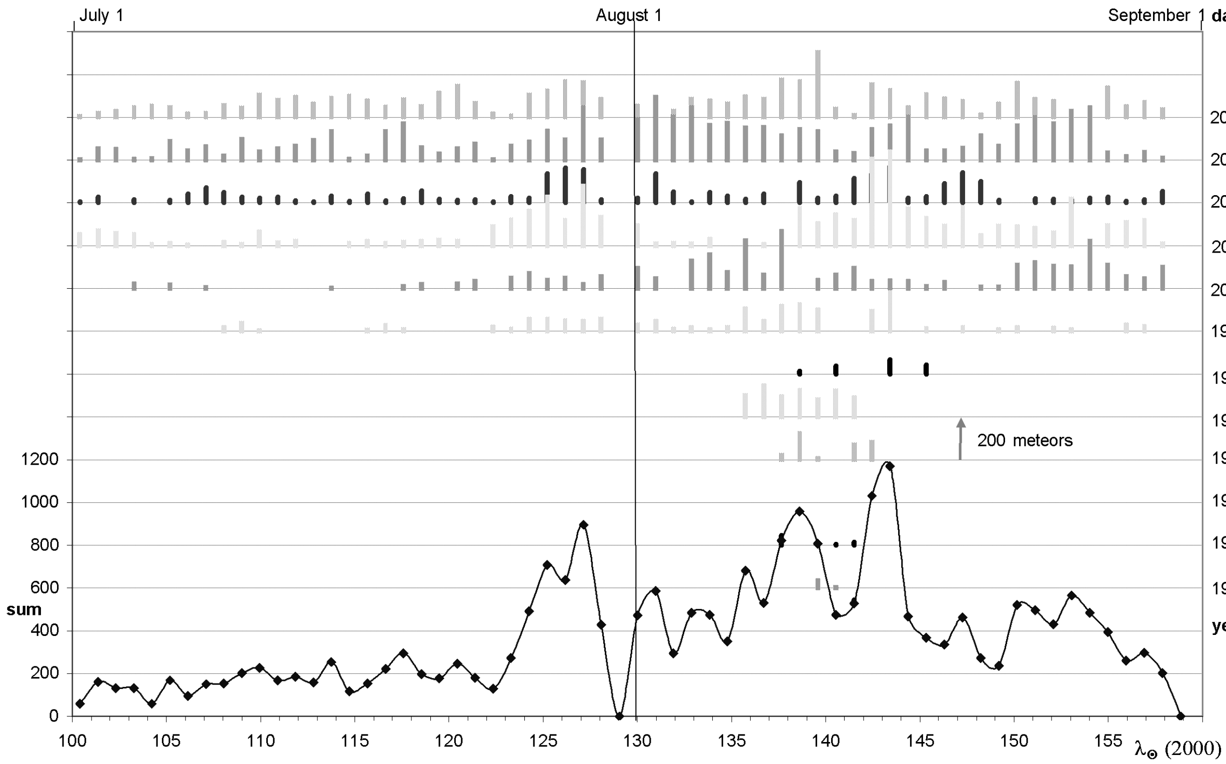

Figure 1 – Video observational statistics. The majority of Perseids in August have been filtered out from the 1993–2004 data (those already classified as Perseids by MetRec), the Perseids are left only in the July data as their contribution is negligible. The solar longitude is valid for equinox J2000.0, when 1 day is about 0°96 on average in the July–August period. The number of captured meteors each night in each year is presented as a bar. The lowest graph shows the sum (N) of all the meteors captured in one night in the 1993–2004 period. In 1995, no meteors were captured in these two months.

Altogether this data sample contains 22 945 meteors. The number of meteors captured per year in this time interval is given in Table 1.

3 Method

The radiant analysis presented in this paper was made with the program Radiant (Arlt, 1992, 2001). All the radiant plots are the result of the 'Probability functions' of the Radiant software. 'Probability functions' are more powerful representations of the radiant than simple backward prolongation of the meteor. If path and velocity are precisely known, each individual meteor has one point (actually two on a great circle in general) which is its radiant. Positional errors and uncertainties in the angular velocity smear this point into an area of varying probability to be the radiant of that meteor. The values in this probability area form a sort of two-dimensional Gaussian function (Arlt, 1992, 2001, 2003). For more detailed information about the 'probability functions' see Arlt (2003).

Unless otherwise mentioned the parameters used to construct the 'probability functions' are the ones shown in Table 2.

Table 2 – Values for the positional distance d, angular velocity ω, and their standard deviations of video observations as used in Radiant (Arlt, 2003). Values in between the distances and velocities listed are obtained by linear interpolation.

d	0°	5°	15°	30°	50°	70°	
$\sigma(d)$	0.5°	0.9°	1.3°	1.5°	1.7°	1.8°	
ω	2.5	7.5	12.5	17.5	22.5	27.5	>30
$\sigma(\omega)$	1.0	1.5	1.9	2.3	2.6	2.9	3.0

4 July Pegasids

4.1 The velocity of the July Pegasids

In order to get a starting V_∞ for Radiant calculations, the value stated in Rendtel et al. (1995) of $V_\infty = 70$ km/s was used. We also calculated the value of $V_\infty = 63$ km/s from the average orbital elements of the comet C/1979 Y1 also given in Table 4 (Rendtel et al., 1995).

As the values for V_∞ differ significantly, we used a broad velocity band from 54 to 70 km/s (54, 58, 62, 66, and 70 km/s) for the Radiant calculations. Visual observers thus observe high-speed meteors in terms of angular velocity.

Table 3 – Supplementary table for Figure 2 – the July Pegasid radiant plots. N is the number of all meteors from that interval and n is the number of meteors actually contributing to the radiant plot.

Date	$\lambda_\odot$ [°]	v_∞ [km/s]	N	n
July 05	103	66	611	209
July 10	108	66	1186	300
July 15	113	66	1497	408
July 20	118	62	1303	301

Table 4 – Average orbital elements of Comet C/1979 Y1 – the probable parent body of the July Pegasids.

Ω	ω	i	e	q	a	P
°	°	°	°	AU	AU	years
103.22	257.58	148.60	0.988	0.545	44	291

4.2 The radiant plots

The plots were made for 5° solar longitude intervals from July 1 ($\lambda_\odot = 103°$) to July 30 ($\lambda_\odot = 130°$). In each 5° solar longitude interval there were on average 1100 meteors collected and 250 contributed to the Radiant plots covering approximately 40° × 40° with a pixel size of 0.4°. As no distinct radiant could be found on those plots, the calculations were repeated for a larger pixel size of 0°.6 and 0°.8. In all these cases, the radiant plots change a lot when changing the V_∞ and no distinct radiant can be followed in three successive V_∞ radiant plots (see Figure 2). In Figure 3, one can see the distribution of meteors in the interval July 1–22 around the probable radiant position, which is in the center of the Radiant plot. The meteors are distributed almost evenly within the inner square which represents the area of the Radiant plot shown in the following graphs. A larger portion of them are, however, on the northern side from the center of calculation. If we get a radiant it might be shifted a little to the north from its correct position, because of the slightly uneven meteor distribution.

On the radiant plots for the intervals July 10, July 15, and July 20, very weak structures slightly south of the predicted radiant can be found. If we compare them with other obvious 'radiant artifacts' seen elsewhere on the same Radiant plots, we consider all of the structures spurious. Moreover, those 'July Pegasid' radiants do not show any realistic radiant motion through the sky. At best they move from north to south and not parallel to the ecliptic.

The July Pegasid meteor shower activity cannot be confirmed from the video observations of the years 2001–2004 (see Figure 1).

5 The υ-Pegasids

5.1 The velocity of the υ-Pegasids

Povenmire (1998) suggested a velocity of $V_\infty = 52$ km/s for the υ-Pegasids. When using the orbital elements mentioned in Table 5 and the predicted radiant position, a lower value of $V_\infty = 49$ km/s can be derived. Given such a medium entry velocity, it has been argued that the υ-Pegasid radiant may be an artifact from the intersections of Aquarids typically moving towards high declinations for a northern observer, and the Perseids typically moving towards lower western parts of the sky as seen by an observer facing south.

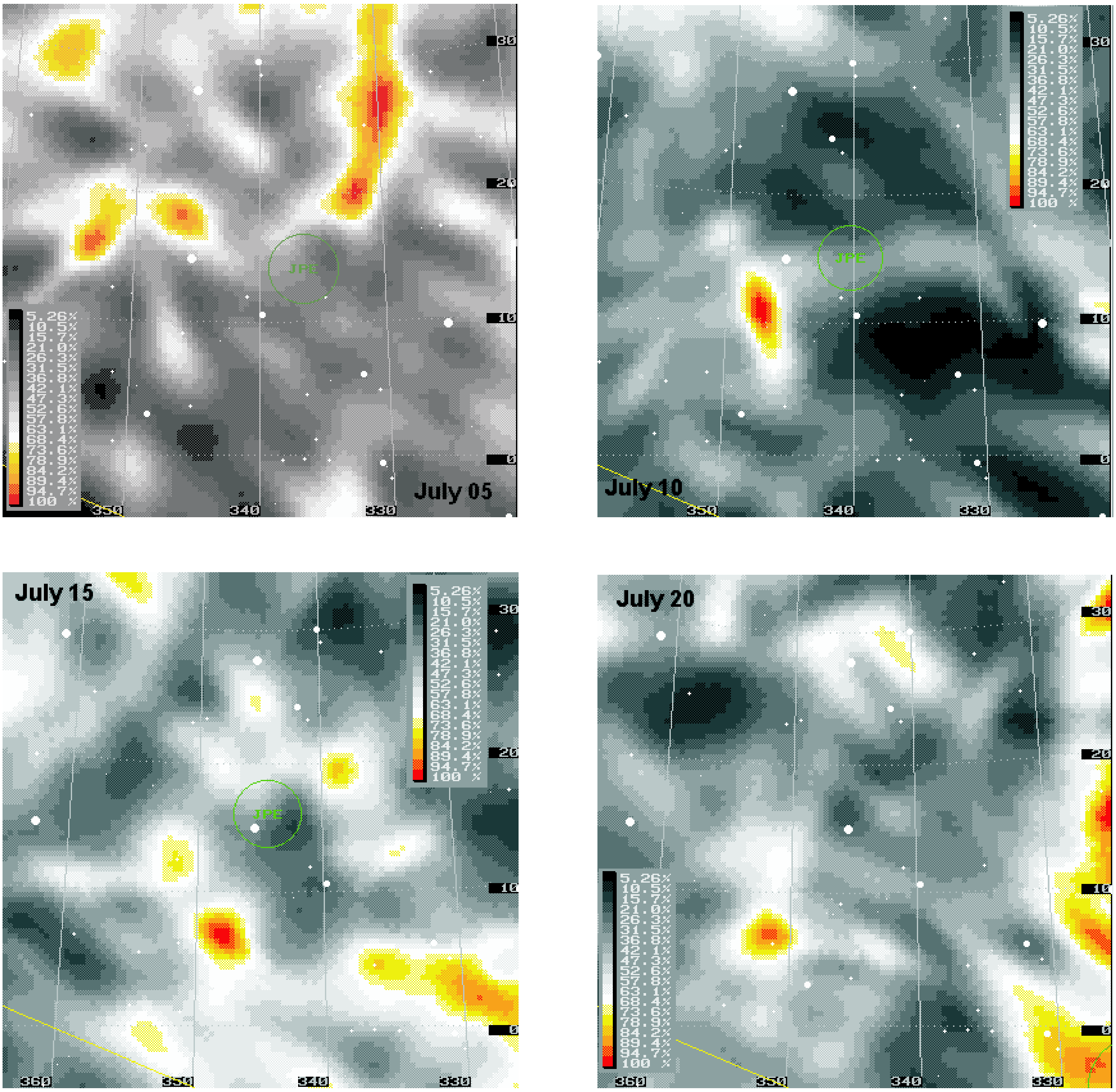

Figure 2 – The July Pegasid radiant plots – no radiant can be found. Top left: July 5; top right: July 10; bottom left: July 15; bottom right: July 20. See Table 4 for details.

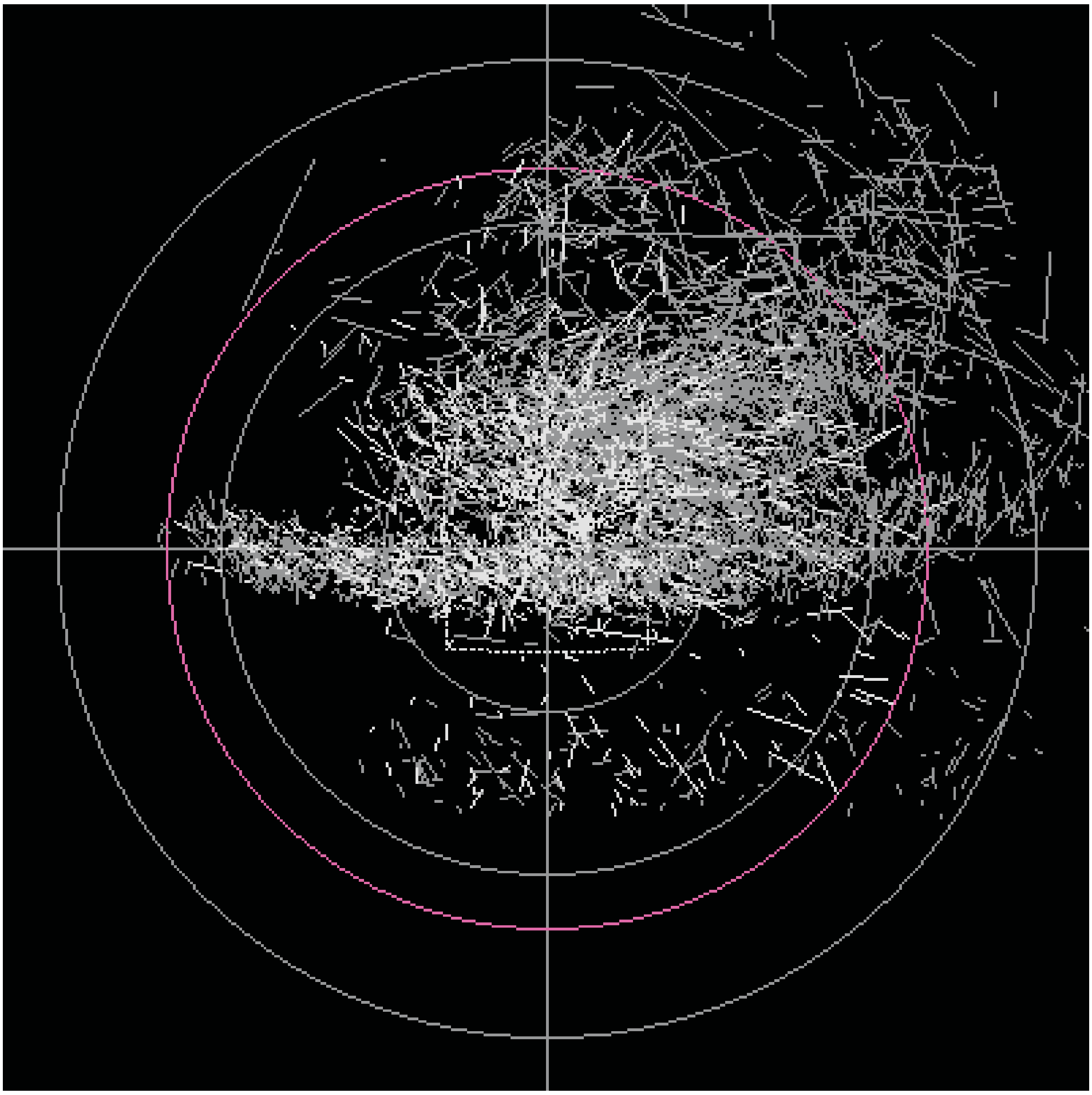

Figure 3 – The meteor distribution around the center of calculation at $\alpha = 340°$ and $\delta = 15°$, for the meteors of July 1–22.

Table 5 – The weighted mean orbital elements of the υ-Pegasid meteor shower (Povenmire, 2001).

Ω	ω	i	e	q
134.5°	303.4704°	79.33°	1.0	0.228 AU

5.2 The radiant plots

For the search for this radiant we again used 5° solar longitude intervals with velocities from 32 to 68 km/s (32, 38, 42, 48, 53, 58, 63 and 68 km/s) and 0.5° pixel size leading to a field of approximately 40° × 40°. The intervals around the possible date of the maximum from August 5 to August 20 were checked. No radiant could be found at the place suggested by visual records, which could be followed in two successive intervals. We therefore conclude that the υ-Pegasids were not active in the years from 1998 to 2004 (Figure 1). On the radiant plots made for the υ-Pegasid (see a sample in Figure 4) search, the radiant should emerge near the center of the distribution, where no distinct structure can actually be seen. In the southern part of the plot, an Aquarid source is found, probably representing the Northern δ-Aquarids.

6 Conclusion

In our previous paper (Triglav-Čekada and Arlt, 2005) we can see the example of the Taurid meteor showers, which are minor showers with a low ZHR of less than 5, and they are indeed found to be active in the radiant distributions. They do show well defined radiants which can be followed for a number of successive intervals. In the case of the July Pegasids, only very vague structures are found near the commonly reported position, but the existence of the shower *cannot be proven* with the analysis of video data of 2001–2004 when day-to-day observations in July are available.

The υ-Pegasids also *do not produce any radiant structure* which can be followed for at least two successive intervals. Since more video observations were gathered in August than in July, this statement was verified for day-to-day observations even for the seven-

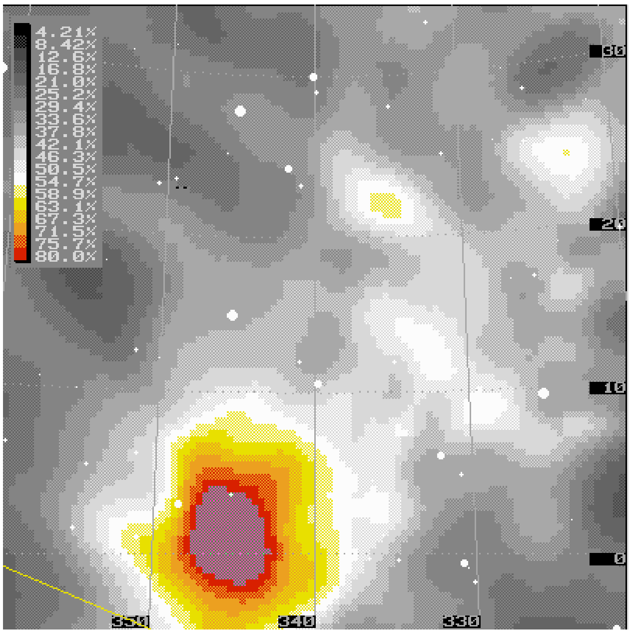

Figure 4 – The radiant plot made for 5° solar longitude interval with center on August 10 and $V_\infty = 48$ km/s, where υ-Pegasid radiant should be placed at the center of the display, but no υ-Pegasid radiant can be seen. Small structures seen on the display cannot be followed in other intervals. A total of 1010 meteors contributes to the radiant display, the majority forming the excluded Aquarid radiant source near the southern edge of radiant display.

year period of 1998–2004 which is longer than the July Pegasid sample.

Acknowledgments

This study would not have been possible without Sirko Molau's tremendous work in setting up and maintaining the IMO video network. We are most grateful for his efforts and also for providing the databases. We would also like to thank the video observers whose data contributed to this analysis. We are very grateful to Alastair McBeath, Robert Lunsford, and Jürgen Rendtel for their comments regarding this topic.

References

Arlt R. (1992). "The software RADIANT". *WGN*, **20**, 62–69.

Arlt R. (2001). "The RADIANT software – details and problems scrutinized". In *IMC Proceedings 2000*, pages 10–17. IMO, Potsdam, Germany.

Arlt R. (2003). "Radiant ephemeris for the Perseid meteor shower". *WGN*, **31:1**, 19–28.

Cook A. (1973). "A working list of meteor streams". In Hemenway C., Millman P., and Cook A., editors, *Evolutionary and Physical Properties of Meteoroids, Proceedings of IAU Colloq. 13, held in Albany, NY, 14-17 June 1971*, page 183. National Aeronautics and Space Administration SP 319.

Molau S. (1999). "The meteor detection software METREC". In *IMC Proceedings 1998*, pages 9–16. IMO, Potsdam, Germany.

Molau S. (2005a). "IMO video network database". `http://www.metrec.org/database.html`.

Molau S. (2005b). Personal communication.

Neslušan L. (2002). "The photographically observed meteors of (Pegasids?) associated with comet 18P/Perrine Mrkos". *Celest. Mech. and Dyn. Astr.*, **81:1–2**, 363–364. Partial reprint of Dynamics of Natural and Artificial Celestial Bodies, Proc. of the US/European Celest. Mech. Workshop.

Olech A. and Wiśniewski M. (2002). "An artificial meteors database as a test for the presence of weak showers". *Astronomy and Astrophysics*, **384**, 711–724.

Povenmire H. (1998). "The Upsilon Pegasid fireball: European network 190882A [and on same page] The Upsilon Pegasids meteor shower: History and observational characteristics". *Meteoritics & Planetary Science, Supplement*, **33**, A126.

Povenmire H. (2001). "The weighted means of the photographic Upsilon Pegasids orbital elements". *Meteoritics & Planetary Science, Supplement*, **36**, A165.

Rendtel J., Arlt R., and McBeath A. (1995). *Handbook for visual meteor observers*. IMO, Potsdam, Germany.

Svoreň J., Neslušan L., and Porubčan V. (2000). "A search for streams and associations in meteor databases. Method of indices.". *Planetary and Space Science*, **48**, 933–937.

Triglav-Čekada M. and Arlt R. (2005). "Radiant ephemeris of the Taurid meteor complex". *WGN*, **33:2**, 41–58.

History

Meteor Beliefs Project: Meteorite worship in the ancient Greek and Roman worlds

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

A selection of various objects believed to have fallen from the skies, and subsequently worshipped because of this, in the ancient Classical European world are examined and discussed, together with a common Greek term, *diopetes*, applied to some of these.

1 Introduction

In our examination of the wooden idol of the Greek goddess Pallas Athene, the Palladium, said to have anciently fallen from heaven, and kept as a token of security first at Troy, then later at Rome (McBeath & Gheorghe, 2004), we hoped to return to the topic of meteorite worship in the Classical world. That is what we have done here.

The Palladium can be seen as a prototype for much of the material we have included this time, since its origins in texts of the 7th century BC or before preceded all the datable reports covered here, except possibly one. As we saw in our earlier article too, 'palladia' was used as a term to describe other — if typically unspecified — objects believed to have landed from the sky. Curiously, none of the objects we have looked at for this paper were anciently identified as 'palladia', although we have chosen several of the most prominent supposedly sky-fallen items in doing so. However, some were described by the Greek term 'diopetes', literally things 'that fell from Zeus'. The supreme Greek deity Zeus/Dios was god of the sky, specifically the bright daytime sky, so the term can be comfortably interpreted as meaning an object that fell from the sky or the heavens. The Palladium was also sometimes described using this phrasing.

We have imposed a loose structure on this article by presenting our selected items in a rough chronological order, typically using the dates of the earliest texts we found them mentioned in, or the dates of the earliest author's lifetime, where no clearer evidence could be established. Figure 1 shows many of the places associated with those dealt with here, as well as the Palladium. Although our account is not intended as fully comprehensive for all the potential meteoritic objects mentioned by Classical sources, it is interesting to see where most of those we have tackled so far were concentrated.

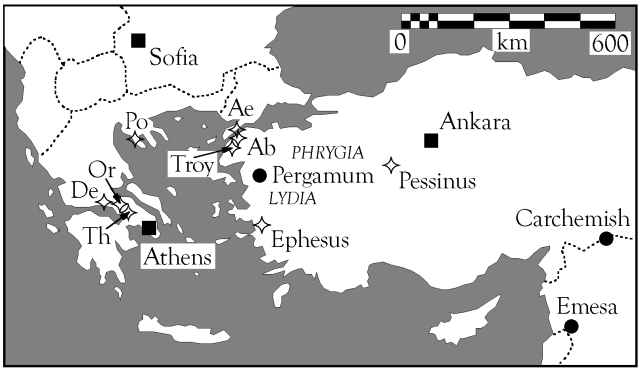

Figure 1 – A sketch map of parts of Anatolia, the Near East and the Balkans, showing the locations of objects believed anciently to have fallen from the sky, as discussed in this article (the open four-armed star symbols). Other places marked include selected modern capital cities (filled squares), relevant ancient cities (filled circles) and country names (given in italicised capitals), along with modern national borders. The abbreviations for fallen object locations are: Ab = Abydos; Ae = Aegospotami; De = Delphi; Or = Orchomenus; Po = Potidaea; and Th = Thebes.

2 Ancile

The *Ancile* was a magical shield, said to have fallen from heaven in the time of the legendary second King of Rome, Numa Pompilius. Numa's ruling dates were traditionally given as 715–673 BC, and as the shield came to him in 707 BC (according to Plutarch's *Life of Numa Pompilius*; Plutarch's dates were circa 46 to circa 120 AD; see (Clough, 1910a, p. 104)), this could be seen as predating the texts featuring the Palladium. However, none of the surviving works which described the Ancile in detail were earlier than the first century BC, so whether the Palladium and Ancile began in tales from the same or a similar origin in the 8th–7th centuries BC, or whether one may have predated the other with separate origins, we cannot say with confidence. The extant datable Greek texts and artworks suggest the Palladium may have precedence though.

There were three main versions of the story of the Ancile's arrival, in works by Dionysius of Halicarnassus (circa 55 to circa 7 BC), Ovid (43 BC to 17 AD), and Plutarch. Dionysius, in his *Roman Antiquities* II.71.1 (Cary, 1937, pp. 518–519), stated that it 'fell from heaven and was found in the palace of Numa, though no one had brought it thither and no buckler of that shape had ever before been known among the Italians; and that for both these reasons the Romans concluded that this buckler had been sent by the gods.' A 'buckler' was a small, usually circular, shield. As Dionysius wrote in Greek, it was not surprising he used 'diopetes' to describe this fall.

[1]12a Prior's Walk, Morpeth, Northumberland, NE61 2RF, England, UK. Email: meteor@popastro.com

[2]Bd. Tineretului 53, bl. 65, ap. 40, sect. 4, Bucureşti, Romania. Email: sarm@romwest.ro

IMO bibcode WGN-335-mcbeath-mbp16
NASA-ADS bibcode 2005JIMO...33..135M

Ovid's *Fasti* III. 361–392 gave his variant, under feasts for March 1, although this need not have equated with the date of any postulated original event. Just after sunrise, Numa stood with his arms raised, wearing a white hood, and called on the supreme god Jupiter to send him the boon Jupiter had earlier promised. 'Even while he spoke, the sun had already lifted his full orb above the horizon, and a loud crash rang out from the heaven's vault. Thrice did the god thunder from a cloudless sky, thrice did he hurl his bolts' (III.367–369; (Frazer, 1931, pp. 146–147)). 'At the zenith the sky began to yawn; the multitude and their leader lifted up their eyes. Lo, swaying gently in the light breeze, a shield fell down. The people sent up a shout that reached the stars' (III.371–374; *loc. cit.*). The thunder in a clear sky, and the sky 'yawning', were features that could have tallied with a meteoric or meteoritic event, adding realism to Ovid's account, albeit these may simply have been his own embellishments to the story.

The relevant section from Plutarch's *Life of Numa* ran: 'In the eighth year of the reign of Numa, a terrible pestilence, which traversed all Italy, ravaged likewise the city of Rome; and the citizens being in distress and despondent, a brazen target, they say, fell from heaven into the hands of Numa, who gave them this marvellous account of it: that Egeria and the Muses had assured him it was sent from heaven for the cure and safety of the city' (Clough, 1910a, p. 104). The pestilence ceased soon after. 'Target' had the same meaning as 'buckler', while Egeria was a water goddess, connected with prophecy, supposed to be Numa's consort and advisor (Price & Kearns, 2003, p. 184).

Dionysius' mention of the shield's unusual shape was reinforced by descriptions elsewhere, including in his own text, II.70.3, where he called it 'a Thracian buckler, which resembles a lozenge-shaped shield with its sides drawn in' (Cary, 1937, pp. 516–517). Varro (116–27 BC) also used this Thracian simile, in his *On the Latin Language* VII.43: 'The *ancilia* "shields" were named from their *ambecisus* "incision on both sides", because these arms were incised at right and left like those of the Thracians' (Kent, 1951, pp. 308–309). However, the only known special Thracian shield was the crescent-shaped *pelta*, with a marked concave indentation on one edge, the other being convex (see (Webber, 2001, especially p. 38 and various illustrations throughout)).

Ovid ignored the Thracian motif, and said simply that Numa 'called the shield *ancile*, because it was cut away (*recisum*) on all sides, and there was no angle that you could mark' (*Fasti* III.377–378; (Frazer, 1931, pp. 146–147)). Plutarch too settled for just a physical description: 'The targets were called Ancilia from their form; for they are not made round, nor like proper targets, of a complete circumference, but are cut out into a wavy line, the ends of which are rounded off and turned in at the thickest part towards each other; so that their shape is curvilinear, or, in Greek, *ancylon*' (*Life of Numa*; (Clough, 1910a, p. 105)). Plutarch went on to suggest several other reasons for the name, including *ancon*, 'elbow', as they were carried there; *anecathen*, 'from above'; *akesis*, 'cure of diseases'; *auchmon lysis*, because it ended a drought; or *anachesis*, 'relief from calamities'. As Cary (1937, p. 517, footnote 1) mentioned, the overall curving form has modernly been identified as a shield having a 'figure-of-eight' shape on a few ancient coins and inscribed gems, which is likely to be correct. This form of shield, though much larger, was shown in artworks as being used by the significantly earlier Mycenean Greeks, perhaps around the time proposed for the Trojan War, in the late second millennium BC. This might imply a loose 'Trojan' origin for both the Ancile and the Palladium, though this is merely speculation.

Rather like the Palladium too, the Ancile was believed a guarantor of Rome's security while it was preserved there. In order to protect it from traitors and thieves, Numa had eleven identical copies made, which, with the original, were borne by 12 dancing priests, the *Salii* (later the *Salii Palatini*, to distinguish them from other colleges of dancing priests, as their temple was on the Palatine Hill in Rome). The Salii priesthood was said to have been created by Numa, the name derived from the Latin *salire*, 'to leap and skip'. The priests were good-looking young free men, native Romans, whose fathers and mothers were still living. They processed in smart costumes and conical helmets, each bearing their ancile, a short sword and a spear or staff, in honour of the gods of war, during much of the month sacred to Mars (from March 1–24). They danced on their graceful, intricate, leaping, way to a flute, while clashing their swords and shields to help keep time, and sang hymns. Only one artificer could be found with skill enough to make the copies of the Ancile, Mamurius Veturius, who asked that in reward, his name should be chanted at the end of the special praise-song the Salii performed. Frazer (1931, p. 148, footnote a) suggested that Mamurius was probably a pseudonym for Mars. The importance of this supposedly heaven-sent Ancile was again strengthened by the stress placed on the activities of the priests, and the apparent uniqueness of the Ancile's shape. Celebrations involving the Ancile continued during the lifetimes of all our ancient authors cited in this section, though how long after the second century AD could not be established, unfortunately. (The general comments in this paragraph were derived from sources already cited in this section, especially Dionysius and Plutarch, who preserved notes on the costumes of the Salii in detail.)

3 Aegospotami

Perhaps the best-known of all the ancient supposedly sky-fallen objects, as well as the most plausibly meteoritic, was the large stone which fell at Aegospotami, on the north shore of the Dardanelles, on the modern Gallipoli Peninsula of European Turkey. It fell in 467 BC according to Pliny the Elder's *Natural History* (II.LIX.149; (Rackham, 1949, pp. 284–287); Pliny's dates were 23–79 AD), and was mentioned by Aristotle (384–322 BC). Aristotle, however, used it in part of his discussion on comets, because a bright comet was seen in the western sky after sunset at the same time as the fall happened, and he claimed years with frequent comets were 'notoriously dry and windy'. He stated the Aegospotami stone had merely been lifted by the comet-induced wind, to fall back again later (*Meteorologica* I.VII.27–34 (Lee, 1952, pp. 54–55)).

Pliny related the Greek tale that the fall of a rock 'from the sun' had been prophesied some days in advance by Anaxagoras of Clazomenae (500–428 BC), 'and that this occurred in the daytime in the Goat's River district of Thrace (the stone is still shown — it is of the size of a wagon-load and brown in colour)' (Rackham, *loc. cit.*). 'Goat's River' is of course a literal translation of 'Aegos Potami', while this part of European Turkey was anciently part of Thrace in Greece. Pliny expressed disbelief in the possibility that Anaxagoras could have really made such a prediction, though unlike Aristotle, he added, 'But it will not be doubted that stones do frequently fall.'

A little after Pliny, Plutarch gave a still more detailed discussion of the Aegospotami fall, in his *Life of Lysander* (here cited from (Clough, 1910b, pp. 123–124)). Plutarch commented that some believed the stone's fall was one of several portents foretelling Lysander's successful conclusion of his war with the Athenians, then being fought. 'For a stone of a great size did fall, according to the common belief, from heaven, at Ægos Potami, which is shown to this day, and held in great esteem by the Chersonites.' The Gallipoli Peninsula was anciently called Chersonesus.

Plutarch then described how Anaxagoras had predicted that a slip among the so-called fixed stars which caused any one to fall, would bring down the whole lot. Plutarch suggested Anaxagoras viewed the stars as heavy, like stones, that they shone by the upper atmosphere refracting round them, and that they were carried along only by the power of their motion, rotating about the Earth, to stop them from falling. Continuing his digression from biography, Plutarch next reported the more probable ideas of other thinkers:

> ... who say that falling stars are no effluxes, nor discharges of ethereal fire, extinguished almost at the instant of its igniting by the lower air; neither are they the sudden combustion and blazing up of a quantity of the lower air let loose in great abundance into the upper region; but the heavenly bodies, by a relaxation of the force of their circular movement, are carried by an irregular course, not in general into the inhabited part of the earth, but for the most part into the wide sea; which is the cause of their not being observed.

He continued by citing from a treatise on religion by Daimachus, a supporter of Anaxagoras' views some 300 years before Plutarch. Daimachus apparently referred to the comet, visible for 75 days before the stone fell, but described it as:

> ... a vast fiery body, as if it had been a flaming cloud, not resting, but carried about with several intricate and broken movements, so that the flaming pieces, which were broken off by this commotion and running about, were carried in all directions, shining as falling stars do.

Daimachus seemed to have assumed this comet (albeit part of his remarks could have equally referred to an aurora, perhaps in combination with a strong meteor shower) was the same as the stone which fell, although he proceeded that when the people overcame their fright at its landing, they found no sign of fire at all, and the stone, though large, seemed smaller than a stone from the comet should have been.

Plutarch concluded his notes by saying that if Daimachus was right, this would disprove the Aristotelian concept of the stone having been broken off a mountain-top, and whirled by strong winds until they slackened, and could no longer support the stone's weight. Hedging his bets rather, Plutarch's last comment was that this would be so unless the comet really had been of fire, and if so that its extinction was due to violent winds in the atmosphere, which could then have carried off the stone after all.

Sadly, although the Aegospotami object sounded very plausibly meteoritic (the size and colouring were reminiscent of the great 55-tonne Hoba, Namibia, iron meteorite, for example), along with all the other instances of fallen objects here, it has not survived to permit modern analyses.

4 Magna Mater

If the Aegospotami event was the Classical world's best-preserved meteorite fall report, the Magna Mater was the most detailed example of a probably meteoritic stone's worship from that world. The texts which suggested it fell from the sky were all relatively late however, and the most detailed description of the stone itself was in Arnobius' (circa 250 to circa 300 AD) *Case Against the Pagans*, VII.49 (McCracken, 1949b, pp. 536–537). He said it was:

> ... a certain stone of no great size, which could be carried in a man's hand without exerting any pressure on him, dusky black in color, uneven with some edges projecting, and which we all see today placed in that very image in lieu of a face, rough and uncut, giving to the image a countenance by no means life-like.

The implication was that the stone still survived in Arnobius' time, assuming he reported accurately that he had seen it, and that it formed only part of a larger image, probably a statue, of the goddess herself. Other Magna Mater statues were known, certainly. Pausanias (circa 120 to circa 180 AD) described a stone statue of her at the city of Patrae in Achaia (*Description of Greece* VII.XX.3 (Jones, 1933, pp. 284–287)), and another of gold with its face made of a hippopotamus's teeth instead of ivory at Proconnesus in Arcadia (*op. cit.* VIII.XLVI.4 (Jones, 1935, pp. 130–131)), indicating the faces of other images might well be made of a different material to the main figure too. Elsewhere, Arnobius called the stone merely 'a piece of flint' (VI.11 (McCracken, 1949b, p. 462)), though probably not in any strict geological sense.

Appian (circa 95 to circa 165 AD), in his often unreliable *Roman History*, presented what seemed to be a partial conflation with tales of the Aegospotami fall, in providing the earliest clear suggestion the Magna Mater stone was meteoritic. In the events for 204 BC, he wrote (VII.IX.56 (White, 1912, pp. 390–393)):

> As certain direful prodigies sent by Jupiter had appeared in Rome, the decemviri who consulted the Sibylline books said that something would soon fall from heaven at Pessinus in Phrygia (where the Mother of the Gods is worshipped by the Phrygians), which ought to be brought to Rome. Not long after, the news came that it had fallen, and the image of the Goddess was brought to Rome, and still to this day they keep holy to the Mother of the Gods the day on which it arrived.

Though Appian wrote in Greek (using 'Dios', which the translator, typical for his time, converted to 'Jupiter'), he used 'ouranos' in describing the sky-fall, not 'diopetes'. While the meaning is clear, 'ouranos' was more often used as meaning 'of the night sky', but this may be reading too much into an inexact text.

Somewhat later, Herodian's *History* (which covered 180–238 AD, again written in Greek) gave this description (I.11.1 (Whittaker, 1969, pp. 66–69)):

> The story is that the actual statue of the goddess fell from Zeus, but no one knows what it is made of or who the craftsman was and they say it is not of human workmanship at all. The account says that the statue fell from the sky a long time ago and was first found at a place in Phrygia (the name of the place is Pessinous, which gets its name from the fall of the statue out of the sky).

Herodian used both 'diopetes' and 'ouranos' in this passage, as accurately translated by Whittaker. Whittaker (*op. cit.*, p 68, footnote 1) noted that while 'pesein' is the Greek aorist infinitive for 'to fall', it was unlikely this was the origin of the name Pessinus/Pessinous, and even Herodian suggested two battles, one historical, one mythological, nearby, from where a 'fallen' etymology might have derived alternatively for the town's name.

Livy (59 BC to 17 AD), whose discussion of the Magna Mater and its Roman importance was the most valuable, described it only as a 'sacred stone' (XXIX.XI. 7 (Moore, 1949, pp. 246–249)). In Livy too was a more useful commentary on why the object was sought, compared to Appian's. In 205 BC, the Romans were occupied in difficult fighting with Hannibal's army in Italy, but there were portents too (Livy, XXIX.X.4–5 (*op.cit.*, pp. 244–245)):

> At that time religious scruples had suddenly assailed the citizens because in the Sibylline books, which were consulted on account of the frequent showers of stones that year, an oracle was found that, if ever a foreign foe should invade the land of Italy, he could be driven out of Italy and defeated if the Idaean Mother should be brought from Pessinus to Rome.

The Sibylline books were guarded and consulted only by the *decemviri*, later the *quindecimviri sacris faciundis*, one of four major colleges of the Roman priesthood, elected from the noblest families (see (Price & Kearns, 2003, p. 464)). The books themselves were Greek oracles, supposedly dating to the time of the traditional last King of Rome, Tarquinus Superbus, 534–510 BC. They were consulted when the Senate requested it, in response to any observed prodigies or portents. The 'Idaean Mother' was of course the 'Great Mother' or Magna Mater, whose full Roman title was the *Mater Deum Magna Idaea*. She was also known as the Mother of the Gods, as we saw before, as well as the Berecynthian Mother, or Mother Dindymene. The three names 'Idaean', 'Berecynthian' and 'Dindymene' all derived from ancient mountain names in Asia Minor (modern Turkey). She was called Cybele too.

Livy continued that further omens independently returned from the famous shrine of Pythian Apollo at Delphi in Greece, confirmed the Sibylline prophecy. Much the same information was given in other sources, including Herodian and Arnobius.

According to Livy (XXIX.XI.1–8), ambassadors went from Rome first to Delphi, where they discovered the Magna Mater should be sought of King Attalus in Phrygia, and that after they had returned with it, it should be welcomed by the best man of Rome. Travelling on to Pergamum in Phrygia, they met King Attalus, who was happy to give them the sacred stone from Pessinus. Ovid (*Fasti* IV.265–272 (Frazer, 1931, pp. 208–209)) had a variant of this in which Attalus initially refused their request, but after an earthquake, and the goddess speaking to him in her shrine at Pessinus, in fear he handed her over, saying it was acceptable as Rome traced its ancestry to Phrygia. Herodian (I.11.3) had the statue given up without question because of the Roman connection with the Phrygian Aeneas (he was said to have brought the Palladium and other Trojan idols to Rome, as noted in (McBeath & Gheorghe, 2004)).

Once received, the Magna Mater was brought over land, and then by sea, back to Italy, arriving at Rome in the spring of 204 BC. Livy (XXIX.XIV.3–5 (Moore, 1949, pp. 258–259)) listed a series of portents reported prior to the stone's arrival, including:

> ... that two suns had been seen, and that at night there had been light for a time; and that at Setia a meteor had been seen shooting from east

to west; that at Tarracina a city-gate had been struck by lightning, at Anagnia a gate and also the wall at many points; that in the temple of Juno Sospita at Lanuvium a noise was heard with a dreadful crash. To expiate these there was a single day of prayer, and on account of the shower of stones nine days of rites were observed. In addition they deliberated on the reception of the Idaean Mother ...

All the named places were in the province of Latium, around and to the south-east of Rome. Tarracina was the most distant, on the coast some 90 km south-east of Rome. Which of the various showers of stones was intended was not clear, nor was there evidence to show if any of these were meteoritic, meteorological or geological in origin. The nine days of rites following a stone-shower was standard Roman practice from the 7th century BC, and Livy commented on such an occurrence numerous times.

Publius Cornelius Scipio Nasica was the young man chosen to receive the Magna Mater, and went to Ostia, the port at the mouth of the River Tiber downstream of Rome, with all of Rome's matrons, to do so. He brought the stone to land, and then the matrons passed it from hand to hand till it reached the Temple of Victory on the Palatine Hill in Rome, no mean feat, as the distance was some 30 km. The stone was placed in the Temple on 204 BC April 12, a day declared holy, and on which a festival of games called the 'Megalesia' was held afterwards, though the date of the celebration was moved later to April 4 (Livy, XXIX.XIV.6–14). The Megalesia was said by Varro (*On the Latin Language* VI.15 (Kent, 1951, pp. 188–189)) to have derived from the name of the temple of the Great Mother goddess at Pergama, from where she was brought to Rome, the 'Megalesion'. The Greek 'megale' was equivalent to the Latin 'magna', 'great'. Pergama or Pergamum was usually said elsewhere to be Attalus' capital. Varro was presumably wrong in suggesting the stone was kept in the temple there, as all other near-contemporary sources gave the Megalesion's location as Pessinus.

Other versions of the Magna Mater's arrival were somewhat different to Livy's, in which P. Cornelius Scipio was sidelined in favour of another character, Claudia Quinta. C. Quinta was the only matron to be named by Livy, who said simply that her participation indicated her chastity, which had been in some doubt. The gist of the tale based on Appian (VII.IX.56), Ovid (*Fasti* IV.291–330) and Herodian (I.11.3–5), was that the beautiful and chaste Claudia Quinta had been wrongly accused of adultery (Herodian seemed to suggest, in a possibly corrupted passage, that she was a priestess of Vesta, and thus supposed to be a virgin). As the ship bearing the Magna Mater entered the mouth of the Tiber, it ran onto a sandbar, where it stuck fast. In order to prove her innocence, Claudia Quinta looped her waistband over the ship's prow and prayed aloud to the goddess that only if she was still chaste should the vessel be freed. The ship miraculously moved off the sandbar as soon as she applied light pressure to the tow, and thus was she proven not guilty. Only Cicero (*The Response of the Soothsayers*, 56 AD, XIII.27 (Watts, 1923, pp. 350–351)) had the Magna Mater's arrival greeted equally by the best of men, Publius Scipio, and the chastest of matrons, Quinta Claudia.

From the description in Ovid's *Fasti* (IV.247–372), it is likely that many of the activities surrounding the collection, journey and arrival at Rome of the Magna Mater were recounted, at least partly by actors, during the annual Megalesia festival. The festival and games opened the year, with events suggested by various of our cited sources here running from March 15 to April 4. The more important elements clustered around the vernal equinox, including a major procession bringing a pine tree to the temple in honour of Cybele's youthful lover Attis on March 22, the *Hilaria* — a day of joy, feasting and visiting others — on March 24, and the *Lavatio*, the ritual washing of the Magna Mater stone at the confluence of the rivers Almo and Tiber around 3 km downstream of Rome, on March 27. A useful synopsis of these celebrations, including references, is in (Price & Kearns, 2003, pp. 139–140, 'Cybele'). Ovid (*Fasti* IV.357–360) noted the games had precedence over all others, as the goddess had given birth to the gods. We note there was an apparent overlap between the celebration dates regarding the Ancile and the Magna Mater, perhaps reinforcing the protective powers of both at a religiously 'dangerous' liminal time, where one year ended and the next began.

The whole period of the festival was an important one, but its non-Roman origins and nature were never forgotten, indeed were strongly emphasized, as only Phrygian priests could serve the Magna Mater and participate fully in her processions and rites. These priests, called 'Galli', apparently after the River Gallus at Pessinus, like the Mother's lover Attis, practised self-castration, thus setting themselves apart from society generally. The rites were wild, orgiastic and noisy, as several authors attest, and the priests often dressed and behaved effeminately. Thus, there was plenty for the early Christian writers — such as Arnobius — to take exception with, and criticize (e.g. Arnobius V.5–7 and 11). The significance of Phrygia stemmed from the anciently-held belief that the Phrygians possessed the oldest of the civilizations, predating the Egyptians. This can be traced in texts from, for example, Herodotus' (circa 480 to circa 425 BC) *Histories* II.2 to Claudian's (circa 370 to circa 404 AD) *Against Eutropius* II.251–254 (Platnauer, 1922, pp. 202–203).

Although much survives concerning the mythology of Cybele and Attis, some of which is contradictory, or at least unclear, there is no indication that Cybele/ Magna Mater was ever associated with a meteorite or any other sky-fallen object prior to the Roman adoption of her cult. Her associated objects were typically a pair of lions, and a crown like a city wall, indicating her control of nature as a (primarily) fertility deity, and her defensive activities in protecting against (but also sometimes sending) disease, and giving oracles. Her alternative mountainous names tied her in with nature control - the wild, wooded mountains and hills ('Ida' means literally 'the wooded hill', for instance). Earlier forms of her name in Anatolia, including the Phrygian 'Kubileya', and the Lydian 'Kybebe', suggest a link with the earlier 'Kubaba', which latter goddess was first attested at Carchemish in Syria, although a possibly related, still earlier, but male, deity-like monster Huwawa/Humbaba (pronounced with a heavily-aspirated initial 'H') was known in ancient Mesopotamia long before. Huwawa was guardian of the mountainous 'Pine Forest', a semi-mythical land, probably composed of elements found in the mountains east and north of Mesopotamia. Various relevant entries in (Price & Kearns, 2003), and (McBeath, 1999, Chapter 7) for Huwawa, can provide research pointers for those interested in pursuing this further.

As for the subsequent history of the Magna Mater stone at Rome, in 191 BC, it was moved from the Temple of Victory to the newly-built and dedicated Temple of the Great Idaean Mother (Livy, XXXVI.XXXVI.3–5 (Sage, 1935, pp. 260–263)), also on the Palatine. The statue was still there in 43 BC, when among a long list of portents, it was said to have turned to face west of its own accord (Dio Cassius (circa 150–235 AD), *Roman History*, XLVI.33.3 (Cary & Foster, 1917, pp. 64–65)), and in 38 BC it was taken to the deep sea off the Tiber to be purified in response to an omen (*op. cit.* XLVIII.43.4–6 (*op. cit.*, pp. 310–313)). The temple itself burnt down at least twice, in 111 BC and again in 3 AD, accidents which the stone must have survived, although only the fact that a statue of Claudia Quinta, which stood in the vestibule, emerged unscathed was recorded (Valerius Maximus' *Memorable Doings and Sayings* of circa 30 AD, I.8.11 (Bailey, 2000, pp. 114–115)). Dates for other authors show it was probably present until the late third century AD at least, and possibly later, but Arnobius was apparently the most recent writer to mention having seen it, perhaps as late as 300 AD. Almost a century later, Claudian (*The War Against Gildo* I.117–123; (Platnauer, 1922, pp. 106–107)), referred in passing to Cybele, who had been brought from Mount Ida to Rome, in the present tense, in relation to events of 397–398 AD, which implied the stone was still at Rome in his time. Like the Palladium, it most probably did not survive the sack of Rome in 410 AD by the Goths, assuming either survived the anti-pagan purges of the Christian Emperor Theodosius I in 391–392 AD. Claudian seemed to indicate that at least the Magna Mater did.

5 Anchises' 'Holy Star'

Anchises was the father of Aeneas, whom we met briefly above, but also earlier in relation to the Palladium (McBeath & Gheorghe, 2004), and as presented by Dante (Gheorghe *et al.*, 2005). Aeneas' mother was the goddess Aphrodite, and he was conceived on Mount Ida (obviously a popular place — or perhaps more accurately, place-name, owing to its generic meaning, as outlined in relation to the Magna Mater above), by Troy. In Virgil's (70–19 BC) *Aeneid* II.680–691, in a section where Aeneas had been trying to persuade his elderly father to escape the coming sack of Troy to safety, Anchises called on Jupiter for a sign to confirm another portent, a tongue of harmless flame which had suddenly sprung up on the head of a young boy, Iulus. Lines 692–704 (Fairclough, 1935, pp. 340–341), spoken by Aeneas, ran:

> Scarcely had the aged man thus spoken, when with a sudden crash it thundered on the left and a star shot from heaven, gliding through the shadows, and drawing a fiery trail amid a flood of light. We watch it glide over the palace-roof and bury in Ida's forest the splendour that marked its path; then the long-drawn furrow shines, and far and wide all about reeks with sulphur. On this, indeed, my father was vanquished and, rising erect, salutes the gods, and worships the holy star. 'Now, now there is no delay; I follow, and where ye lead, there am I! Gods of my fathers! save my house, save my grandson. Yours is this omen, and under your protection stands Troy. Yea, I yield, and refuse not, my son, to go in thy company.'

This passage led directly into the most famous aspect of the Aeneas-Anchises story, depicted in many artworks from the 6th century BC onwards, apart from in texts like Virgil's, a byword for the archetype of the faithful, dutiful, loving son, where Aeneas carried his father Anchises on his shoulders to safety from Troy. The fact that Virgil's retelling used a distinctively meteoritic event — however inaccurate scientifically the concept of the 'glowing meteor landing just beyond the wall' motif may be — is significant in terms of meteorite worship studies. That it occurred in connection with both Troy and Mount Ida may suggest that many of the Anatolian objects worshipped as objects dropped from the sky, perhaps including the Aegospotami fall, might have had a single origin, the tale subsequently attached to a variety of different objects, much as the later Christian 'true relics' proliferated in medieval times. In this case, the very positive nature of the omen was demonstrated by the sign occurring to the observer's left. Elsewhere, signs to the right were said to be favourable instead (e.g. in the *Iliad*).

6 Pliny's fallen stones

In the same section of his *Natural History* as he detailed the Aegospotami fall, Pliny cited three examples of other stones that had fallen from the sky (II.LIX.149–150 (Rackham, 1949, pp. 286–287)):

> A stone is worshipped for this reason even at the present day in the exercising ground at Abydos - one of moderate size, it is true, but which the same Anaxagoras is said to have prophesied as going to fall in the middle of the country. There is also one that is worshipped at Cassandria, the place that has been given the name of Potidaea, and where a colony was settled on account of this occurrence. I myself saw one that had recently come down in the territory of the Vocontii.

Whether the tale of Anaxagoras' meteorite-prediction powers had simply been transposed from Aegospotami — just across the Dardanelles strait from Abydos, if the identification is correct — or whether perhaps the Aegospotami and Abydos falls happened as part of a meteorite shower in this general region, is unknown. 'Potidaea' (assumed here as being the one in Greece) may derive from the Greek 'daiomai', 'to burn', according to Rackham's footnotes (*loc. cit.*), perhaps as 'Burnt' or 'Burning River'. The Vocontii lived in an uncertain area of southern Gaul (modern France), probably somewhere in the modern Languedoc-Provence regions.

7 Temple of Diana at Ephesus

One of the seven wonders of the ancient world, Pliny (*Natural History* XXXVI.XXI.95–97 (Eichholz, 1962, pp. 74–77)) gave a detailed physical description of this temple, its size and how it took 120 years to build, very carefully set up on marshy soil to be protected from earthquakes and subsidence. Unfortunately, Pliny stopped short of providing further information, saying merely that 'other embellishments of the building are enough to fill many volumes'. This means he did not provide a discussion of the potential meteorite worshipped here, of which sky-fallen origin only a brief mention survives in the biblical *Acts of the Apostles* 19 : 35–36 (dated to circa 70 AD; here cited from (Wansbrough, 1994, p. 1833)). In this section, the 'town clerk' of Ephesus was trying to quell a riot by the silversmiths, who believed their livelihood — making silver miniature shrines of Diana for sale to pilgrims — was threatened by Paul's preaching that gods made by hand were not gods at all. He began his speech thus:

> Citizens of Ephesus! Is there anybody who does not know that the city of the Ephesians is the guardian of the temple of great Diana and of her statue that fell from heaven? Nobody can contradict this and there is no need for you to get excited or do anything rash.

Other translations of this part of the Bible (see for example (Kohlenberger, 1995, pp. 734–735)) changed 'statue' to 'image' or 'sacred stone', and sometimes gave Diana her Greek equivalent name, Artemis, as she was called in the earliest Greek text. The Greek text also used the phrasing 'diopetes', so the connection with other ancient plausibly meteoritic objects was confirmed.

Pausanias' *Description of Greece* IV.XXXI.8 (Jones & Ormerod, 1926, pp. 344–345) described the sanctuary of Ephesian Artemis as extremely ancient, and that tradition held the Amazons had originally set up the worship of the goddess there, something other authors confirmed (for example, lines 237–258 of Callimachus' 'Hymn to Artemis' from the 3rd century BC). He later amended this idea (VII.II.6–8; (Jones, 1933, pp. 174–177)), giving a still more ancient origin, so the shrine was then said to have been founded by 'Coresus, an aboriginal, and Ephesus, who is thought to have been a son of the river Caÿster'. Mythical eponymous founders abounded in ancient texts, but the 'aboriginal Coresus' may have been a folk-memory of the Lydian King Croesus/Kroisos, who conquered Ephesus and then helped fund the rebuilding of a new temple to Artemis Ephesia there in the early 6th century BC. Kroisos' involvement thus was attested by inscriptions in the earliest temple found during excavations by archaeological teams from the British Museum in the late 19th and early 20th centuries. A whole series of impressive temples were built and rebuilt on the site subsequently.

Artemis Ephesia seemed to have been a pre-Greek Anatolian fertility deity, possibly similar to Cybele, if not partly conflated with her, as some depictions showed her in a similar mural crown. Some of these crowns were up to three tiers high, and seemed exceptionally unwieldy, tapering outwards towards the top like a candlestick. One surviving example of such statuary, modernly called 'The Great Artemis' as she is 2.9 m tall (a figure apparently also shown on some coins), wore towering headgear around one-quarter the size of the entire carving.

Although the original sky-fallen image was not recovered from the temple excavations, later copies of the statue from the 1st and 2nd centuries AD, and presumed to be similar, made of stone, metal and clay carved in the round, or depicted on coins (the earliest showing this goddess were dated to 88–84 BC (Anonymous, 1959, p. 79 and Plate 44.9 reverse)), were found elsewhere at Ephesus. These showed a fairly young, female, humanoid figure, standing erect with her arms bent and held forward, as if to hold loosely something staff-like vertically in each hand. Coin depictions suggest chains, ropes or leashes descended either from her hands or wrists, sometimes to two animals, most likely stags, but possibly horses, standing by her sides. She wore a narrow, tapering, mummy-like robe on her lower body and legs, with only her feet showing, which robe was often decorated with two or three vertical rows of full-relief half-animals all facing forwards, while her upper torso was draped with a series of ovoid objects, often in two or three horizontal rows. These have been interpreted as multiple breasts, eggs, fruits, bags of votive offerings, bull or human testicles (Strabo's - circa 63 BC to circa 21 AD - *Geography* XIV.I.23 mentioned that like Cybele, Artemis Ephesia was served by eunuch priests, the Megabyzi). It has also been suggested that if the statue, or part of it, was originally a meteorite, these rounded protrusions might have been regmaglypts on its surface.

On some still-extant statues, a band showing zodiacal figures was carved in light relief around the goddess's neck, as if part of her robe, which might have conferred an astral component too. Other carvings on the figure's robe sometimes included full-relief mythical winged half-animals, all facing forward, often with several more carved into a large halo to either side of the goddess's face. Frequently these creatures were lions, bulls and goats/antelopes/deer. More lions leaped up the outside of her arms, while on the sides of her legs were bas-reliefs of animals, winged beasts, winged humanoids, flowers and bees.

The late date for the statues which have survived, modified back in time by the earliest coins showing this figure, may suggest this form of Artemis was relatively late too. Earlier coins from Ephesus going back prior to circa 88 BC into the second half of the 5th century BC (Anonymous, 1959) showed only a bee or a stag instead, both still symbols of Artemis and also — especially the bee — Ephesus. This negative evidence is inconclusive however, since it may simply have represented an earlier prohibition on making images of the goddess, or because the statue was not on public view. While he did not describe it, Xenophon (*The Anabasis of Cyrus* V.III.5–13; (Brownson & Todd, 1922, pp. 114–119)) mentioned the image of the Ephesian Artemis as if it had a sufficiently distinctive form without need to be detailed further, when writing of events he took part in around 400 BC. In the same place, he stated that the keeper of sacred things at the Ephesian temple was called Megabyzus, used as if it were a personal name. It may be that after his time, the name became attached to the whole class of priests, or it may be the leader of the priests enjoyed this more personalised title generally. There is nothing in any of this to say if the statue was believed to have fallen from the sky before the biblical 1st century AD text.

Images of the Ephesian Artemis, including statues, statuettes and coins, can be seen on a number of websites, but `www.ntimages.com/Ephesus-museum.htm` and `www.holylandphotos.org` were especially useful for the largest and best-preserved ones.

8 Four fallen objects in Pausanias

Pausanias' first Book of his *Description of Greece* concerned Attica, the region of mainland Greece surrounding Athens — 'Both the city and the whole of the land are alike sacred to Athena' (I.XXVI.6; (Jones, 1918, pp. 136–137)). The holiest image of Athena at Athens was said to be of very great antiquity, and was set upon the Acropolis when it was still called just the 'Polis' (= 'City'). 'A legend concerning it says that it fell from heaven; whether this is true or not I shall not discuss' (*loc. cit.*).

While a frustratingly brief statement, this was quite typical of other of Pausanias' comments, where he sometimes stated he knew more than he would give in his text. He phrased the fall with 'ouranos' not 'diopetes', incidentally. His other possibly meteoritic objects were equally tersely detailed, though none quite so unhelpfully as this.

In his description of Thebes in Boeotia, Pausanias referred to an object which had fallen from the skies at the same time as Zeus scared his mortal lover Semele to death with a thunderbolt. The tragic story of the Theban Semele, and how her and Zeus' unborn son, the future deity Dionysus, survived her death, can be found in Apollodorus' *Library* III.IV.3 (Frazer, 1921, pp. 316–321). In brief, Zeus promised Semele he would do whatever she asked of him. Tricked by Zeus' jealous spouse Hera, Semele asked that he show her his true form. As Hera planned, Semele was terrified at his awesome approach, and died of fright as Zeus launched a thunderbolt. Pausanias' additional remarks are from Book IX.XII.4 (Jones, 1935, pp. 222–225):

> There is also a story that along with the thunderbolt hurled at the bridal-chamber of Semele there fell a log from heaven. They say that Polydorus adorned this log with bronze and called it Dionysus Cadmus.

Cadmus was the legendary founder of Thebes, whose tale was recounted by Pausanias in the paragraphs just before the Semele story. Pausanias indicated the log was still preserved in a temple with a bronze image of the god Dionysus in his time.

Later in Book IX, Pausanias discussed Orchomenus, also in Boeotia, where among other shrines and temples, there was a sanctuary of Dionysus too:

> ... but the oldest is one of the Graces. They worship the stones most, and say that they fell for Eteocles out of heaven. The artistic images were dedicated in my time, and they too are of stone.
> *(IX.XXXVIII.1 (Jones, 1935, pp.* 340–341*).)*

Eteocles was one of two of Oedipus' sons who ruled in Thebes, alternating with his brother Polynices. Eventually they fell out, leading to the events in the famous 'Seven Against Thebes' myth, in which the brothers slew one another. See Apollodorus III.V.8–VI.8 (Frazer, 1921, pp. 348–369).

Although not specifically stated as falling from the skies, there was another worshipped stone of celestial origin (as it fell from a sky deity) given in Pausanias' coverage of Delphi, near the well-known Temple of Apollo we met earlier in regard to the Magna Mater. Outside the great temple, to its left, was an enclosure with the tomb of Achilles' son, Neoptolemus:

> Ascending from the tomb you come to a stone of no large size. Over it every day they pour olive oil, and at each feast they place on it unworked wool. There is also an opinion about this stone, that it was given to Cronus instead of his child, and that Cronus vomited it up again.
> *(X.XXIV.6 (Jones, 1935, pp.* 510–511*).)*

This is of particular interest as the stone was given in myth by the great mother goddess Rhea to her spouse Cronus, who had taken to eating his newborn children, to swallow in place of his son Zeus, so Zeus would survive. The baby Zeus was protected by a band of warriors, the Curetes, who clashed their weapons and shields to drown out the infant's cries, so Cronus would not hear him. Several ancient authors, including Ovid (*Fasti* IV.193–214), Lucretius (*The Poem on Nature* II.597–645 (Trevelyan, 1937, pp. 64–66)) and Arnobius (*Case Against the Pagans* III.32 and 41 (McCracken, 1949a, pp. 217 and 224)), indicated that Rhea and Cybele were the same, and that the noisy, active Phrygian priests of the Magna Mater were thought to be acting out the part of the Curetes. The young Zeus was said to have been reared in a mountain cave on Crete, possibly on Mount Dicte or Mount Ida (yet another one), though even where Mount Dicte was preferred, sometimes one of his nurses was named Ida. See Apollodorus' *Library* I.I.5–II.1, and especially Frazer's discussion (1921, pp. 6–9). The re-use of Ida seems to have reinforced the Magna Mater/Cybele connection in this respect, possibly in error. Regarding the Curetes, we note too that Dionysius of Halicarnassus (*Roman Antiquities* II.70.4–5 (Cary, 1937, pp. 516–519)) suggested the Curetes and Salii, the dancing priests who bore the ancilia, whom we met earlier, were also the same, because both made noise by clashing their arms together.

Pausanias mentioned various statues and sanctuaries to Aphrodite Ouranias, 'Heavenly Aphrodite' (e.g. VI.XX.6 — a sanctuary — and VI.XXV.1 — an ivory and gold statue), but in describing three very old statues of Aphrodite at Thebes, one of which was called 'Heavenly', made it clear that this epithet signified her as representing 'a love pure and free from bodily lust' (IX.XVI.3–4; (Jones, 1935, pp. 240–241)), so not having any relevance to the current discussion. Aphrodite was a Greek name for the planet Venus in addition.

9 The black stone of Elagabalus

Our last choice was a borderline case for inclusion here, but it has some aspects of interest. Book V of Herodian's *History* (Whittaker, 1970) provided the relevant details. 'Elagabalus' was the Phoenician local name for the Sun God at Emesa, and later the assumed name of the deity's priest, who became emperor of Rome as Marcus Aurelius Antoninus, according to Herodian, from 218–222 AD (when he was assassinated by the Praetorian Guard). There were clear similarities between the dress and behaviour of the priests of Elagabalus and the Galli who served the Magna Mater, partly why the emperor was so ill-favoured by his supposed bodyguards.

There was a large, richly appointed, temple to Elagabalus at Emesa, which contained no man-made statue of the deity:

> ... but there was an enormous stone, rounded at the base and coming to a point on the top, conical in shape and black. This stone is worshipped as though it were sent from heaven; on it there are some small projecting pieces and markings that are pointed out, which the people would like to believe are a rough picture of the sun, because this is how they see them.
>
> *(V.3.5 (Whittaker, 1970, pp.* 18–21*).)*

The stone was taken to Rome by the priest-emperor Elagabalus/Antoninus, where he built it a large new temple, and paraded it in a chariot in celebration, while he ran backwards in front of the chariot (again something that failed to endear him to the city's officials). Given his short reign, this parade may have been only a single event.

Herodian's description of the stone 'as though it were sent from heaven' used the Greek phrasing 'diopetes' once more. The black, conical, lightly pitted surface of the stone sounded surprisingly more meteoritic than many of the other objects we have examined here, the 'small projecting pieces and markings' in no especial pattern perhaps being regmaglypts, if so. As coins attested (e.g. Plate 49.32 and p. 89 of (Anonymous, 1959), showing a coin from Emesa dated to 215 or 216 AD), the shape of the object seemed to have been like a 'D' laid on its flat side, with a rounded top, not the steeple-shaped form the 'pointed cone' phrasing might have suggested. Remembering the Aegospotami stone was suggested as having fallen from the Sun, we wondered if that possible meteorite-solar link was again in play with Elagabalus.

10 Conclusion

While it is impossible to know if any of these anciently-believed sky-descended objects were genuine meteorites, as none are still available for examination, they do demonstrate the acceptance that various things might fall from the heavens. It is equally clear that anything which did so fall (or which was thought to have done so) should be treated with reverence, as if it came from the gods themselves. Or perhaps from the supreme god Zeus himself, taking 'diopetes' in its most literal sense.

Acknowledgements

We are grateful to Julie Yellowley and her assistant Adele Arkley, both of the Northumberland County Library Service in England, for considerable assistance, particularly in tracing images and information on the Ephesian Artemis.

References

Anonymous (1959). *A Guide to the Principal Coins of the Greeks, from circ. 700 B. C. to A. D. 270, Based on the Work of Barclay V. Head (Revised edition).* Trustees of the British Museum.

Bailey D. R. S., translator (2000). *Valerius Maximus, Memorable Doings and Sayings, Volume I.* Harvard University Press (Loeb Classical Library imprint).

Brownson C. L. and Todd O. J., translators (1922). *Xenophon: Anabasis, Books IV-VII and Symposium and Apology.* William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Cary E., translator (1937). *The Roman Antiquities of Dionysius of Halicarnassus in Seven Volumes, I.* William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Cary E. and Foster H. B., translators (1917). *Dio's Roman History.* William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Clough A. H., editor (1910a). *Plutarch's Lives in Three Volumes: Volume One.* Dent (Everyman's Library imprint).

Clough A. H., editor (1910b). *Plutarch's Lives in Three Volumes: Volume Two*. Dent (Everyman's Library imprint).

Eichholz D. E., translator (1962). *Pliny Natural History in Ten Volumes: Volume X, Books XXXVI-XXXVII*. Harvard University Press (Loeb Classical Library imprint).

Fairclough H. R., translator (1935). *Virgil in Two Volumes: I Eclogues, Georgics, Aeneid I-VI (revised edition)*. William Heinemann Ltd & Harvard University Press (Loeb Classical Library imprint).

Frazer J. G., translator (1921). *Apollodorus, The Library, Volume I*. Harvard University Press (Loeb Classical Library imprint).

Frazer J. G., translator (1931). *Ovid in Six Volumes: V Fasti*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Gheorghe A. D., McBeath A., and Taibi R. (2005). "Meteor Beliefs Project: Meteors as symbols of love". *WGN*, **33:1**, 30–32.

Jones W. H. S., translator (1918). *Pausanias: Description of Greece, Volume I*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Jones W. H. S., translator (1933). *Pausanias: Description of Greece, Volume III*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Jones W. H. S., translator (1935). *Pausanias: Description of Greece, Volume IV*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Jones W. H. S. and Ormerod H. A., translators (1926). *Pausanias: Description of Greece, Volume II*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Kent R. G., translator (1951). *Varro: On the Latin Language, Books V-VII (revised edition)*. Harvard University Press (Loeb Classical Library imprint).

Kohlenberger III J. R., editor (1995). *The Precise Parallel New Testament: Greek Text, King James Version, Rheims New Testament, Amplified Bible, New International Version, New Revised Standard Version, New American Bible, New American Standard Bible*. Oxford University Press.

Lee H. D. P., translator (1952). *Aristotle in Twenty-Three Volumes: VII Meteorologica*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

McBeath A. (1997). "Stones from heaven: Some meteoric fossil folklore". *WGN*, **25:3**, 128–130.

McBeath A. (1999). *Tiamat's Brood: An Investigation into the Dragons of Ancient Mesopotamia*. Dragon's Head Press.

McBeath A. and Gheorghe A. D. (2004). "Meteor Beliefs Project: The Palladium in ancient and early medieval sources". *WGN*, **32:4**, 117–121.

McCracken G. E., translator (1949a). *Arnobius of Sicca: The Case Against the Pagans - Volume One*. Newman Press & Longmans, Green and Co.

McCracken G. E., translator (1949b). *Arnobius of Sicca: The Case Against the Pagans - Volume Two*. Newman Press & Longmans, Green and Co.

Moore F. G., translator (1949). *Livy in Fourteen Volumes: VIII, Books XXVIII-XXX*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Platnauer M., translator (1922). *Claudian, in Two Volumes: I*. William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Price S. and Kearns E., editors (2003). *The Oxford Dictionary of Classical Myth and Religion*. Oxford University Press.

Rackham H., translator (1949). *Pliny Natural History I: Preface and Books 1-2 (revised edition)*. Harvard University Press (Loeb Classical Library imprint).

Sage E. T., translator (1935). *Livy in Fourteen Volumes: X, Books XXV-XXXVII*. Harvard University Press & William Heinemann Ltd. (Loeb Classical Library imprint).

Trevelyan R. C., translator (1937). *Lucretius De Rerum Natura*. Cambridge University Press.

Wansbrough H., editor (1994). *The New Jerusalem Bible: Study Edition*. Denton, Longman & Todd.

Watts N. H., translator (1923). *Cicero: The Speeches*. William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Webber C. (2001). *The Thracians, 700 BC – AD 46*. Osprey Publishing (Men-at-Arms 360).

White H., translator (1912). *Appian's Roman History, in Four Volumes: I*. William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Whittaker C. R., translator (1969). *Herodian in Two Volumes: I, Books I-IV*. William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

Whittaker C. R., translator (1970). *Herodian in Two Volumes: II, Books V-VIII*. William Heinemann Ltd. & Harvard University Press (Loeb Classical Library imprint).

The International Meteor Organization

web site http://www.imo.net

Council

Commission Directors

WGN

IMO Sales

Available from the Treasurer	€	$
Proceedings of the International Meteor Conference		
1990–1996	5	6
1997	Out of print	
1998–2000, 2002–2003	6	7
2001 — on CD only	5	6
2004	8	10
Back issues of WGN		
Vols. 19–22 (1991–1994) per complete volume	10	12
Vols. 23–29 (1995–2001) per complete volume	18	22
Vol. 30 (2002) per complete volume	20	24
WGN Observational Report Series		
Vols. 1–5 (1988–1992), 7–8 (1994–1995) Visual Observations, per volume	8	10
Vol. 6 (1993) Visual Observations and Electrophonic Fireball Catalogue	8	10
Vols. 9–14 (1996–2002) Visual Observations, per volume	10	12
Other publications		
Photographic Meteor Database (1986)	4	5
Photographic Astrometry + diskette	7	8

A Taurid fireball photographed through thin cloud by Koen Miskotte.
The Pleiades are visible at the top right.