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Meteor beliefs
E.F. Sawyer

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Front cover photo

A Leonid photographed by Koen Miskotte of the Netherlands. It was taken on 1999 November 18 at about 02^h08^m UT. A 10-minute exposure on ISO 200 Kodak Elite with a Canon T70 and a Canon FD f=50 mm, f/1.4 lens. Taken near the small town of Xalos, ∼40 km south of Valencia, Spain. Frame number 18_11_1999nr19. Koen's website is `http://home.planet.nl/~misko002/`.

Back over photo

Four June Boötids recorded by Sirko Molau with two video cameras in Seysdorf, Germany, within 20 minutes of each other. The first (bottom left) and last (top right) were recorded by a Mintron camera (Mincam1). The other two were recorded by the image-intensified camera AKM1. In the four hours around that interval, only one more June Boötid was recorded.

Future covers

Have you an interesting or spectacular meteor photograph that you think would look good on the cover of WGN? If so, please offer it to us. We can be contacted at `wgn@imo.net`; remember to put the word 'Meteor' in the subject line to get past the anti-spam filters.

Cover design

Rainer Arlt

Editorial — Meteorum in Sole Visa?

Chris Trayner

Those of us who observed the Transit of Venus have memories we will carry for a long time. In a meteor Journal one might expect to escape from tales of transits, but the recent one reminded me of other observations.

On 1864 October 1, Frederick Brodie observed what he thought might have been a meteor passing in front of the Sun. 'Suddenly a very brilliant body shot across part of the field of view, its light far surpassing in intensity that of the Sun's photosphere' (Brodie, 1864). He describes the event as having lasted 'about 3/10ths of a second' and sketched it (Figure 1). There are problems with his report: the orientation of the compass points is wrong for observing the sky, unless he used a sun or star diagonal, which he does not describe. (He describes using a wedge of dark glass, making it unlikely that he projected the image onto a screen.) The observations were apparently made from southern England, but described as 'October 1st, at about $22^{\mathrm{h}}30^{\mathrm{m}}$ GMT', when the Sun would have been below the horizon. All this, however, could be due to mistakes in copying or editing.

It is hard to assess the credibility of this report. To exceed the brightness of the Sun seems at first to imply an extremely bright bolide, as the Sun's apparent magnitude is -26.8. This is based on the illumination from the whole disc, however, and Brodie was examining only part of it. The brightness is less towards the limb of the Sun, and we are not told what part Brodie was observing, so it would be hard to put accurate constraints on the magnitude of the supposed meteor. If we naively assume an average figure, however, and take the entire $1' \times 4.5''$ reported area as that of the object, then the Sun's radiation over this area would be equivalent to about magnitude -17. A bolide 'far surpassing' this would be rare but not impossible.

More recent and careful studies have suggested that meteor-generated effects may be visible near the Sun. Archenhold (1984) lists several observations of ripples passing across solar haloes, possibly caused by shock waves from hypersonic bolides. Some of these observations have estimated the speed of propagation as being that of sound, supporting the hypothesis. Archenhold reports many of the observations as coinciding with daylight meteor showers, and suggests that further observations would be worthwhile.

When Jeremiah Horrocks made the first known observation of a Transit of Venus in 1639, he described them in a book with the Latin title of *Venus in Sole Visa* (Venus seen on the Sun). He was only able to observe part of the Transit, and could not measure the Earth–Sun distance with the accuracy he had wished. Presumably meteors pass near or across the Sun far more frequently than Venus; perhaps we should make an effort to observe them and see what they can tell us about daylight showers.

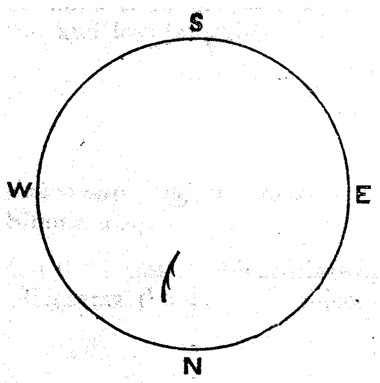

Figure 1 – Brodie's sketch of the 'Meteoric Appearance', from (Brodie, 1864). The object had a path of length 'about $1'$ of arc ; the breadth of the head about $4''$ or $5''$ of arc'. The field of view was $6'10''$ across.

References

Archenhold G. (1984). "Moving ripples in Solar haloes: are they caused by sound-waves from meteors?". *Quarterly Journal of the Royal Astronomical Society*, **25**, 122–125.

Brodie F. (1864). "Meteoric appearance on the Sun's surface". *Monthly Notices of the Royal Astronomical Society*, **25**, 21–22.

Special edition on imaging

Through pressure of time, this has had to be delayed. We hope to run it in the August or October WGN. Anyone who is interested in contributing is encouraged to contact the Editor.

Letter

On meteors ‘hurled from Vaynus, or Mars, or from Jupiter’s Moon’

from Alastair McBeath[1]

The more-or-less accidental ’meteorite and fireball’ issue of WGN (**32:2**, April 2004) provoked a few thoughts regarding meteors on a grander, Solar System, scale.

Chris Trayner’s editorial (pp. 39–40) in respect of late 19th-century beliefs about meteor/meteorite origins, picking up on a 1902 quote from my contribution with Andrei Gheorghe for the Meteor Beliefs Project (pp. 63–64), centred on the lines ‘a meteor hurled/ From Vaynus, or Mars, or from Jupiter’s Moon’. Current understanding of meteorites indicates we probably do have some meteorites on Earth from Mars, but not from Venus, despite the fact Venus passes relatively closer to Earth than Mars ever can ($\sim$ 0.26 au Venus-Earth; $\sim$ 0.36 au Earth-Mars). Venus of course is much larger than Mars ($\sim$ 12 000 km compared to $\sim$ 6 800 km, respective equatorial diameters), has a consequently greater escape velocity ($\sim$ 10 km/s Venus, $\sim$ 5 km/s Mars), and a much thicker atmosphere to protect it against impacts liable to extract suitable meteoritic candidate rocks in the first place. Coincidentally, there has been a debate concerning the potential for meteorites from Mars and Venus on-going on the Cambridge Conference Network e-mail list during the first half of 2004. This has suggested the matter is not quite as clear-cut and settled as one might expect[2].

Difficulties in transporting material from any of Jupiter’s Moons to Earth are still greater, not least because of the enormous influence Jupiter’s gravitational power wields on the Solar System between the orbits of Mars and Saturn especially. However, this same power has a massive effect on what comet, asteroid, and any associated meteor stream orbits, are moved into or out of the inner Solar System. Jupiter’s action on various existing meteor streams visible from Earth is well-known, and the complexities its repeated effects may have are nicely demonstrated by the Quadrantids. For all Peter Jenniskens’ optimism that he has ‘found’ the Quadrantid parent in the $\sim$ 2 km rock 2003EH$_1$ (WGN **32** : **1**, February 2004, pp. 7–10), uncertainties in the Quadrantid orbits, as well as those of 2003EH$_1$, along with the behaviour over time of other proposed ‘parents’, for instance comets 96P/Machholz, C/1490 Y1, or asteroid 1973 NA, and possibly linked meteor showers, such as the δ-Aquarids or daytime Arietids, mean this is only one more potential Quadrantid parent object, or fragment. All of these (plus an unknown number of additional possible Quadrantid ‘parents’ not yet identified, or even discovered) are, or have been, subject to repeated Jovian perturbations. So while not strictly ‘from Jupiter’s Moon’(s), Jupiter does determine some of the meteor activity we see from Earth.

What are the chances fireball EN291103B would pass so perfectly behind the outstretched limb of the antenna tower, as seen from the camera taking the photo, in WGN **32** : **2**, p. 45 (Figure 2, and outside back cover)? It seems quite an amazingly improbable event, but provided a most impressive image. Like many ‘asteroidal’ fireballs, its appearance was probably due to Jovian influence at some past stage. Further in-keeping with the general theme of these notes, since power pylons very similar to the transmitter tower - with two to six outspread arms - were sometimes called ‘Martians’ in my childhood, the photo looks to me like a ‘Martian’ grasping a fiery lance or spear. Meteors perceived as burning spears have a long pedigree certainly, as future Meteor Beliefs Project articles should demonstrate.

Lastly, still on the subject of ‘asteroidal’ fireballs, there are now at least six instrumentally-determined meteorite orbits, not just five, as suggested by Alexandra Terentjeva and Sergej Barabanov (WGN **32** : **2**, pp. 60–62, especially p. 60). The sixth is the Neuschwanstein meteorite fall of 2002 April 6–7, as I mention in my 2002 April-June SPAMS results article. [This will appear in the August WGN – *Ed.*] The Neuschwanstein and Příbram (1959 April 7) meteorites have very similar orbits, and it has been suggested the two may be part of a loose ‘fireball stream’, with a probable radiant in Coma Berenices (although a rate of two fireballs in 43 years is not altogether enticing for regular observations. . .). Concerning this potentially very low activity, it is interesting there are no close matches to the Neuschwanstein-Příbram ‘stream’ in Alexandra Terentjeva’s fireball stream list in WGN **17** : **6**, December 1989, pp. 242–245.

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[2] Unfortunately, the archived CCNet messages for 2004 are not yet available. It is anticipated these will become accessible later this year, but the details are not yet finalised.

VARNA 2004 IMC BULGARIA

International Meteor Conference

23 - 26 September

For the second time the International Meteor Conference will be held in Bulgaria and we are very happy to be the local organizers again. This time it will be in our 'Nicolaus Coperrnicus' Astronomical Observatory and Planetarium in the city of Varna.

'Nicolaus Copernicus' Astronomical Observatory and Planetarium

This is one of the first public astronomical observatories and planetaria in Bulgaria, operating since 1963. It has maintained regular contacts with the International Meteor Organization since 1988.

The weather

September here is normally warm and sunny, and the sea water temperature is above 20°C, so you can enjoy all this. But, just in case, bring your umbrella.

Currency

The monetary unit is the Bulgarian Lev. Since 1998 it has had a fixed rate of €1 = 1.96 Lev. Foreign currency can be exchanged for Levs and vice versa in banks and exchange offices. Information about the exchange rates for other currencies can be found on the web site of the Bulgarian National Bank:
`www.bnb.bg/bnb/rates.nsf/vWebRatesByMonthEN/$First`

Visas and invitations

Visitors from Western Europe and most of the East European countries, including all our neighbouring countries, don't need visas to come to Bulgaria. For people from the countries for which visas are necessary we will gladly send official invitations provided that they inform us about this in time. You can find out whether visas are needed for citizens of your country on the IMC website — see the bottom of this page.

The city of Varna

Varna is the third largest city in Bulgaria. It is located on the Black Sea shore and is sometimes called the sea capital of our country.

Chayka resort

The IMC will be held in the Chayka resort, ten kilometres to the north of Varna. The participants will be accommodated in the buildings of the Varna Free University (`http://www.VFU.bg`). There are a hotel, many lecture halls, well equipped technical equipment, access to the Internet and a nice view of the sea.

Participation fee

The participation fee for IMC 2004 is €100 for people who register before July 1 and €110 for those who register later. A prepayment of €50 should be sent with the registration form to the IMO Treasurer Ina Rendtel. The application form is on the following page.

Preliminary excursion to Byala

On September 23 in the afternoon, a preliminary excursion will be organized to the town of Byala, on the sea coast about 60 km south of Varna. In recent years an exposed geological stratum from 65 million years ago was found there, bearing traces of the mass extinction of living species that is supposed to have been caused by fall of a large meteorite. Those who arrive in Varna early enough can take part. It will cost an additional €5 to be paid on the day. If you wish to participate, you can stay one more night in the hotel before the conference without any problem. The traditional excursion (though not to Byala) is also included in the IMC schedule.

VARNA 2004
BULGARIA

International Meteor Conference
23 - 26 September

IMC Registration Form

You can also register online at `http://www.imo.net/imc2004/files/bulgaria.html`

To participate, fill in the form below and return it to Ina Rendtel as soon as possible, with at least the minimum pre-payment of € 50. If you are not yet certain whether to participate, keep reading the website above and register as soon as possible. Payment should be to Ina Rendtel by Giro (details inside the back cover) or as described for WGN subscriptions (see WGN 31:6, p. 170).

For travel information see the IMC website above.

Name ______________________________ Date of birth ______________

Address: ____

____

Phone ______________ Fax ______________ E-mail ______________

In intend to travel by ______ together with ______________________________

Additional requests

- I intend to stay in Bulgaria before or after IMC and require extra information.
- I wish to participate in the September 23 excursion to Byala
- I require travel information from __________ to Varna (see IMC website for frequent routes)
- I wish to give a lecture entitled ______________________________
  lasting ______ minutes; equipment required: ______________________________
- I wish to organise a workshop with the title ______________________________
- I wish to present a poster ______ metre wide by ______ metre high
- T-shirt size: O Small O Medium O Large O Extra-large

Contact with the Organizers

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E-mail: planetarium@triada.bg
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Website

`http://www.imo.net/imc2004/files/bulgaria.html`

Aquarid-Capricornid complex

Observational characteristics of meteor showers associated with the Aquarid-Capricornid complex

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

On the basis of the most recent (1997–2002) VMDB records, we provide an extended analysis of the meteor showers collectively called the Aquarid-Capricornid complex — the Southern and Northern δ-Aquarids, the α-Capricornids and the Southern and Northern ι-Aquarids. Our analysis covers two months (July–August) of meteor activity. We present a set of updated shower parameters, including visibility periods, population indices and activity levels. We also discuss a number of factors that may significantly alter final activity estimates obtained from visual observations. These are in particular the shower association, zenith attraction and the role of the zenith exponent.

Received 2004 June 25

1 Introduction

In the summer months of July and August, noticeable meteor activity is usually sighted in the Southern part of the celestial sphere. Due to the complex radiant structure in the Aquarius-Capricornus region, the five meteor showers, namely the Capricornids, the Northern and Southern δ-Aquarids, and the Northern and Southern ι-Aquarids are often treated as a unified Aquarid-Capricornid complex by observers.

Meteoroid streams producing these showers are not mutually related and posses rather different origins, however. To be precise, it has to be noted that none of these five meteoroid streams producing the aforementioned meteor showers have clearly identified parent objects. Hamid & Whipple (1963) suggested a link between the Quadrantids and the Southern δ-Aquarids, and McIntosh (1990) and later Jones & Jones (1993) identified Comet 96P/Machholz as a parent body of the meteoroid stream producing these two meteor showers. A refined search among meteoroid orbits confirmed this relationship and revealed that the Northern δ-Aquarids are also linked to the Comet-96P/Machholz-related meteoroid stream (Jopek et al., 1999).

However, the issue still remains open, as more recently Jenniskens (2004) found that another comet-like object, 2003 EH_1, has very similar orbit to that of the Quadrantid meteoroid stream. The Capricornids represent an ecliptical shower with a large characteristic spread of orbital elements of individual particles. Nevertheless, Comet 45P/Honda-Mrkos-Pajdušakova has been identified as the main but probably not a single parent body producing the Capricornid meteor shower (Neslušan 1999, Hasegawa 2001). Wright et al. (1957) derived radiant positions and orbits of Northern and Southern ι-Aquarids from photographic observations and interpreted these showers as two branches of a single ecliptical meteoroid stream. However, no apparent relationship between the ι-Aquarid meteoroid stream

Table 1 – Observational characteristics of the Aquarid-Capricornid complex meteor showers given by Jenniskens (1994), Rendtel et al., (1995), and Olech & Wiśniewski (2002). Most of the r-values are not derived in those publications, but compiled from other sources.

ZHR_{max}	$\lambda_\odot^{max}$	B [1/°]	r	Ref.
SDA				
11.4 ± 1.2	$124.°9 \pm 0.°3$	0.09	3.3	1
23 ± 2	125	-	3.2	2
9.0 ± 0.2	$127.°1 \pm 0.°1$	0.07	-	3
NDA				
1.0 ± 0.2	$123.°4 \pm 1.°0$	0.06	3.3	1
3.5 ± 0.3	136°	-	3.4	2
2.6 ± 0.1	$130.°0 \pm 0.°3$	0.02	-	3
CAP				
2.2 ± 0.3	$121.°7 \pm 0.°9$	0.04	2.0	1
3.2 ± 0.2	127°	-	2.5	2
3.4 ± 0.1	$126.°2 \pm 0.°2$	0.04	-	3
SIA				
1.5 ± 0.3	$131.°0 \pm 1.°0$	0.07	3.3	1
2.0 ± 0.2	132°	-	2.9	2
2.5 ± 0.1	$126.°9 \pm 0.°3$	0.05	-	3
NIA				
2.2 ± 0.3	147°	-	3.2	2

Refs:
1 (Jenniskens, 1994)
2 (Rendtel et al., 1995)
3 (Olech & Wiśniewski, 2002)

and known small bodies of the Solar system has been disclosed up to date.

The annual activity of the meteor showers related with the Aquarid-Capricornid has attracted considerable attention of observers worldwide. Although there were no indications that any of these showers has produced exceptional activity in the past, the radiants of the Capricornids and the δ-Aquarids were identified in the second half of the nineteenth century by the pioneering meteor observers. With growing interest in meteor astronomy, a number of analytical investigations on Aquarid-Capricornid complex members have been carried out. An informative compilation of vari-

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ous observations and comprehensive review of historical records has been provided by Kronk (1988), in his Descriptive Catalog of Meteor Showers. Zvolánková (1992, 1993) studied Aquarid and Capricornid activity on the basis of Czechoslovak observations during 1945–1952. However, the limited number of single-site observations resulted in a large scatter of ZHR values and led to generally overestimated rates, thus preventing the obtaining of reliable activity profiles. Jenniskens (1994) in his overview paper of annual showers provided more detailed investigations using visual data collected by members of Dutch Meteor Society (DMS) and Meteor Section of Australian Planetary Observers (NAPO-MS) between the years 1981 and 1991.

Another comprehensive radiant study in the frame of the IMO Aquarid project was performed by Arlt et al. (1992), which showed the Southern δ-Aquarids to be weaker than the Northern counterpart because the observers contributing were chiefly located north of 40° N. Activity profiles of 1988–1995 were published in the IMO Handbook for visual meteor observers (Rendtel et al., 1995). More recently, Olech & Wiśniewski (2002) presented an extended analysis based on the observations of Polish Comets and Meteors Workshop (CMW) members in 1996–1999. These last three analyses provide rather different observational characteristics of showers of interest, giving a large scatter in the dates of maxima, periods of visibility and maximum rates as well; see Table 1. Moreover, Jenniskens (1994) noted large discrepancies in ZHRs for δ-Aquarids and Capricornids, in particular, as derived using observations from the Northern and Southern Hemispheres.

The aim of this work is to provide refined observational characteristics for all the members of the Aquarid-Capricornid complex using the newest and most comprehensive data from the Visual Meteor Data Base (VMDB) as collected in 1997–2002 by IMO observers around the globe. The VMDB set includes the CMW data.

2 Meteor data reduction and processing

Since the observations available were not homogeneous with respect to shower association, in the initial stage we applied the following data selection rules, which helped to classify the observations. First of all, observations reporting the Perseids only and some of other minor showers, which were not the subject of this study, were simply excluded; most of these referred to the Perseid maximum time ($\lambda_\odot$ = 137° to 141°). A large number of observers reported the Capricornids only with no indication of any of the Aquarids; these observations were not further included in the Aquarid datasets. However, this fact raises some doubt that numerous Aquarids might be misidentified. Further, following the above considerations, we have constructed all the Aquarid datasets.

Special care has been taken to treat the period of shower activity; for instance, if an observer reports meteors of a particular shower at $\lambda_\odot = 120°$, but there is no indication of them at $\lambda_\odot = 110°$ and $\lambda_\odot = 145°$ (within the activity period according to the IMO shower list), we simply added zeros for these dates in the rate files. This improvement allowed us to avoid overestimation of meteor rates at the very ends of the activity profiles. Then observers tend to report the shower only if they had seen a meteor from that radiant, but omit the shower if nothing was detected. In this way, we have built five separate datasets, as listed in Table 2.

Table 2 – Observational data for the Aquarid-Capricornid complex showers, collected in 1997–2002. Note that the time span listed does not necessarily refer to the shower's activity period. $N_{\rm rate}$ and $N_{\rm mag}$ are the numbers of meteors contributing to the rate and magnitude datasets, respectively.

Shw	Time span	$\lambda_\odot$ interval	$N_{\rm rate}$	$N_{\rm mag}$
SDA	Jul 05–Aug 23	103°–150°	6353	5848
NDA	Jul 13–Aug 28	110°–156°	4750	4549
CAP	Jul 03–Aug 19	100°–146°	7106	6227
SIA	Jul 18–Aug 21	115°–148°	1485	1407
NIA	Aug 09–Sep 02	136°–160°	1188	1366

First of all we have calculated the population index; the procedure involved a calculation of average differences $lm - m$, where lm is the limiting stellar magnitude and m is the magnitude of a meteor, and subsequent conversion into the population index. The full description of the method and conversion tables are given in (Arlt, 2003). The ZHR was computed by means of the standard equation

$$\mathrm{ZHR} = \frac{N}{T_{\rm eff}} \frac{r^{(6.5 - rmlm - \Delta \mathrm{lm})} F}{\sin^\gamma h_{\rm R}}, \qquad (1)$$

where Δlm was introduced by Koschack & Roggemans (1991). In the case of multiple observations, the ZHR can be rewritten as:

$$\overline{\mathrm{ZHR}} = \frac{1 + \sum\limits_i n_i}{\sum\limits_i \frac{T_{{\rm eff},i}}{C_i}}, \qquad (2)$$

where n_i is the individual number of shower meteors observed during a time period $T_{{\rm eff},i}$, and C_i is the total correction for a limiting magnitude lm, field obstruction factor F, and the radiant elevation $h_{\rm R}$:

$$C_i = \frac{r^{(6.5 - \mathrm{lm} - \Delta \mathrm{lm})} F}{\sin h_{\rm R}}, \qquad (3)$$

Here we applied a zenithal exponent of $\gamma = 1$ and individual perception coefficient $c_p = 1$. The population index used for the ZHR is computed from the magnitude distributions of this analysis — one value for each of the five meteor showers.

Because of low radiant elevation for most of European observers, somewhat relaxed data reduction, according to $C_i \leq 10$ instead of widely used $C_i \leq 5$, was applied. As a standard, ZHR-profiles were calculated using 1° bin size; in some rare cases the bin size has been increased to 2°, in order to avoid 'noise' that occurs as a consequence of a small number of observations.

The error margins were estimated as

$$\Delta \mathrm{ZHR} = \frac{\overline{\mathrm{ZHR}}}{\sqrt{1+\sum_i n_i}}, \quad (4)$$

For the data fit, we used a double-sided exponential function:

$$\mathrm{ZHR} = \mathrm{ZHR}_{\max} 10^{-B|\lambda_\odot - \lambda_\odot^{\max}|} \quad (5)$$

(Jenniskens, 1994), where B is the slope coefficient related to the full width at half maximum by FWHM $= 2\ \log 2/B$.

3 Southern δ-Aquarids

The Southern δ-Aquarid meteor shower is the most active member of the complex producing steady meteor rates from year to year. Although in the northern hemisphere, where the majority of observers reside, its rates are diminished by low radiant elevations, in the southern hemisphere Southern δ-Aquarids have the status of a major shower. Because of rather different observing conditions, we decided to divide the dataset of the Southern δ-Aquarids into northern and southern hemisphere observations. (While the shower radiant for a large number of northern locations remains at low elevation throughout the night because of its negative declination, for observers in the southern hemisphere it lies almost overhead.) In that way, the rate dataset for the Southern δ-Aquarids comprised 5746 shower meteors observed in 1997–2002 from the northern hemisphere and 707 shower meteors observed in 1993–2002 from the southern hemisphere locations. As can be seen, the latter dataset was extended by the observations in 1993–1996 in order to ensure better coverage of the shower activity period within the investigated time interval of July 3–August 23 ($\lambda_\odot = 103°$ to $150°$).

The population index was calculated choosing the observations with lm ≥ 5.0 and thus included 5210 and 638 shower meteor magnitudes recorded by Northern and Southern hemisphere observers, respectively. The calculation procedure yielded respective values of the population index $r = 2.62 \pm 0.04$ and $r = 2.43 \pm 0.09$ that had been used in the calculation of the ZHR-profiles.

As a first approximation, we selected data records according to $C_i \leq 10$; see the profiles depicted in Figure 1(a) and Figure 2(a). When comparing these two profiles, a number of distinct features emerge: (i) ZHRs near the maximum obtained from the southern observations are larger by factor of 2 than those derived from the northern observations. It has to be mentioned that Jenniskens (1994) reported a converse ratio, which most likely was caused by the large zenith exponent value ($\gamma = 1.4$) used in his ZHR calculations. (ii) No apparent maximum, but rather a broad plateau follows from the southern observations, whereas the time of maximum could be easily distinguished from the northern observations. (iii) The northern profile shows an extended background with ZHR ≈ 2, which was found to be persistent regardless of the chosen limits of C_i. In order to check the origin and possible reasons of the above mentioned discrepancies, we made a second run of the ZHR-profile computation.

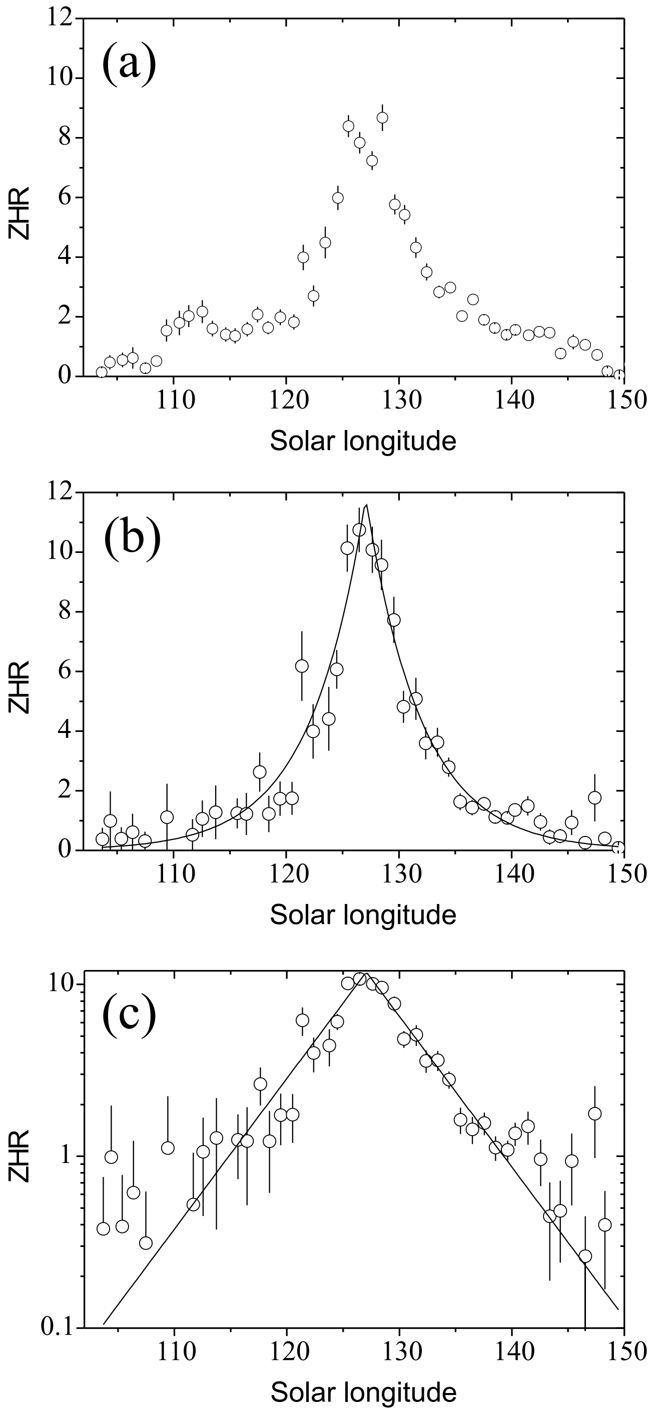

Figure 1 – Activity profiles of the Southern δ-Aquarids from Northern hemisphere observations in 1997–2002: (a) $C_i \leq 10$ and no limitation on radiant elevation, (b) $C_i \leq 10$ and $h_\mathrm{R} \geq 30°$, (c) Semilogarithmic plot; solid line shows double-sided exponential fit.

For northern observations we applied an additional data reduction on the radiant elevation $h_\mathrm{R} \geq 30°$. Although this limitation seemed to be stringent, since it reduced the number of observations notably, it resulted in an almost complete background subtraction, giving rise to a clean, symmetrical profile with a well-defined maximum $\mathrm{ZHR}_{\max} = 10.7 \pm 0.7$ at $\lambda_\odot = 126{\overset{\circ}{.}}5$, see Figures 1(b) and 1(c). Most probably, the appearance

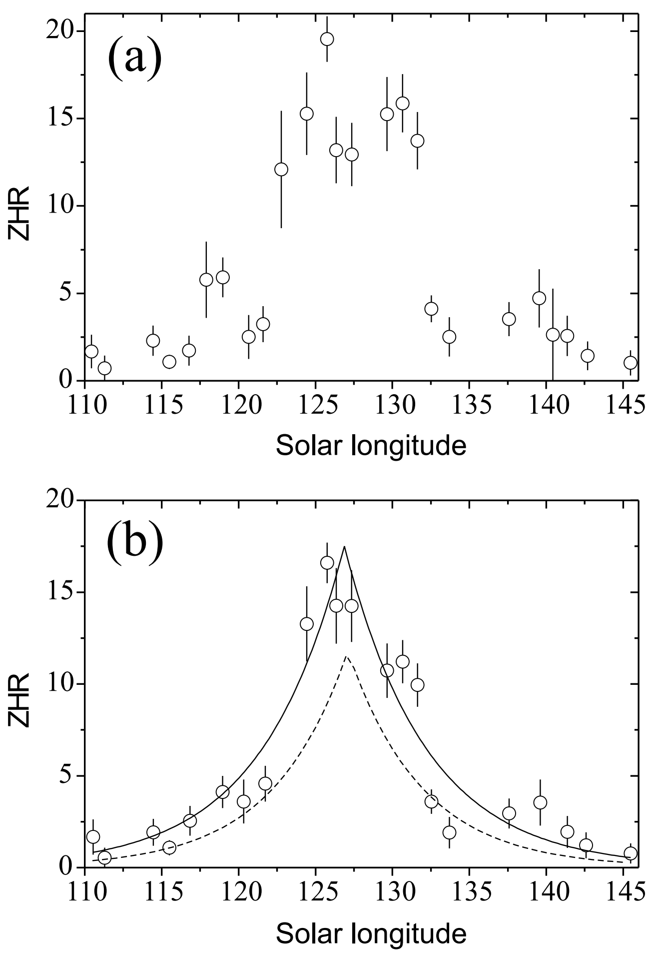

Figure 2 – Activity profile of the Southern δ-Aquarids from Southern hemisphere observations in 1993–2002. (a) uncorrected ZHRs, (b) rates corrected for the individual perception. The solid curve denotes the double-sided exponential fit, whereas the dashed curve is that derived from the northern hemisphere observations and is added for comparison.

of an extended background in this case is the result of incorrect shower association. Shower association could indeed be badly biased by the zenith attraction effect at low radiant elevation and high sporadic meteor activity from radiants clustered in the antihelion area (see discussion in Section 7).

The situation with the southern dataset was quite different: it contained a small number of observations at high radiant elevation provided by a small number of observers. Therefore, we found it reasonable to apply the individual perception coefficients c_p, which were derived from the number of observed sporadic meteors:

$$c_p = \frac{\mathrm{HR_{ind}}}{\overline{\mathrm{HR}}_{\mathrm{spo}}} = r^{\Delta \mathrm{lm}}, \tag{6}$$

where $\mathrm{HR_{ind}}$ and $\overline{\mathrm{HR}}_{\mathrm{spo}}$ denote individual and average sporadic rates, respectively. Following the recent analysis of Arlt & Buchmann (2002), we have adopted an average sporadic rate of $\overline{\mathrm{HR}}_{\mathrm{spo}} = 12.5$ and $r = 3.0$. Then the individual perception coefficient was converted into a correction for the limiting magnitude Δlm:

$$\Delta \mathrm{lm} = \frac{\log(c_\mathrm{p})}{\log(r)}, \tag{7}$$

With these corrections applied to (eqn. 3) and then to (eqn. 2), we obtained a much smoother ZHR-profile as shown in Figure 2(b). The double-sided exponential fit yielded a set of characteristic values: $\mathrm{ZHR_{max}} = 17.5 \pm 1.3$, $\lambda_\odot^{\max} = 126\overset{\circ}{.}9 \pm 0\overset{\circ}{.}3$ and $B = 0.08$ which are in good agreement with those obtained from northern-hemisphere observations, except the value of $\mathrm{ZHR_{max}}$, which was still higher for southern-hemisphere observations. We also checked the effect of individual perception on the population index; however, the corrected one, $r = 2.31 \pm 0.07$, was found to be even less consistent with that derived from the northern-hemisphere observations. Bearing in mind that simple considerations of atmospheric extinction (if not accounted for) for magnitude estimates of meteors having large zenithal distance will lead to the opposite effect, we have no explanation for this difference in the meantime.

4 Northern δ-Aquarids

Despite its low overall activity, the Northern δ-Aquarids is a minor shower visually detectable. The analyses available provide a large scatter of Northern δ-Aquarid maximum times, from July 25, $\lambda_\odot = 123°$ (Jenniskens, 1994) to as late as August 13, $\lambda_\odot = 140°$ (Kronk, 1988). Maximum rates given in the literature are also very different, and vary from 1 to 4, see Table 1. In the case of the Northern δ-Aquarids, as well as in the cases of the rest of the showers analyzed in this study, we did not split the observational data into Northern and Southern observations, as the latter provided insufficient data to build a reliable activity profile. Therefore, the single dataset for the Northern δ-Aquarids included 4750 meteors in the rate file and 4471 meteors in the magnitude file. The calculated population index was very similar to that of the Southern δ-Aquarids, i.e. $r = 2.66 \pm 0.05$ for sky conditions of $\mathrm{lm} \geq 5.0$. Two ZHR-profiles are shown in Figure 3. We found that observations limited to higher radiant elevation ($h_\mathrm{R} \geq 30°$) produced a smoother activity profile, while the activity level was not altered much. Apart from the shower maximum with $\mathrm{ZHR} = 2.5 \pm 0.2$ at $\lambda_\odot = 132\overset{\circ}{.}5$ there are two distinct additional peaks, the strong one with $\mathrm{ZHR} = 3.0 \pm 0.2$ at $\lambda_\odot = 126°$ to $127°$ and another weaker one with $\mathrm{ZHR} = 1.8 \pm 0.2$ at $\lambda_\odot = 150\overset{\circ}{.}5$. The time of a first peak clearly coincided with the maximum of the Southern δ-Aquarids, therefore most probably being a signature of incorrect shower association, whereas the second one most probably has to be linked to alleged maximum time of the Northern ι-Aquarids, as listed in the Table 1. In the fitting procedure we have omitted these two peaks and closest neighboring data points, and so obtained the following shower parameters, $\lambda_\odot^{\max} = 131\overset{\circ}{.}8$, $\mathrm{ZHR} = 2.6 \pm 0.1$ and $B = 0.03$.

5 Capricornids

The Capricornid meteor shower is a typical representative of ecliptical showers, being rich in bright meteors and fireballs. Capricornid meteors were reported by most of the observers and comprised the largest rate dataset consisting of 7106 meteors. We derived the pop-

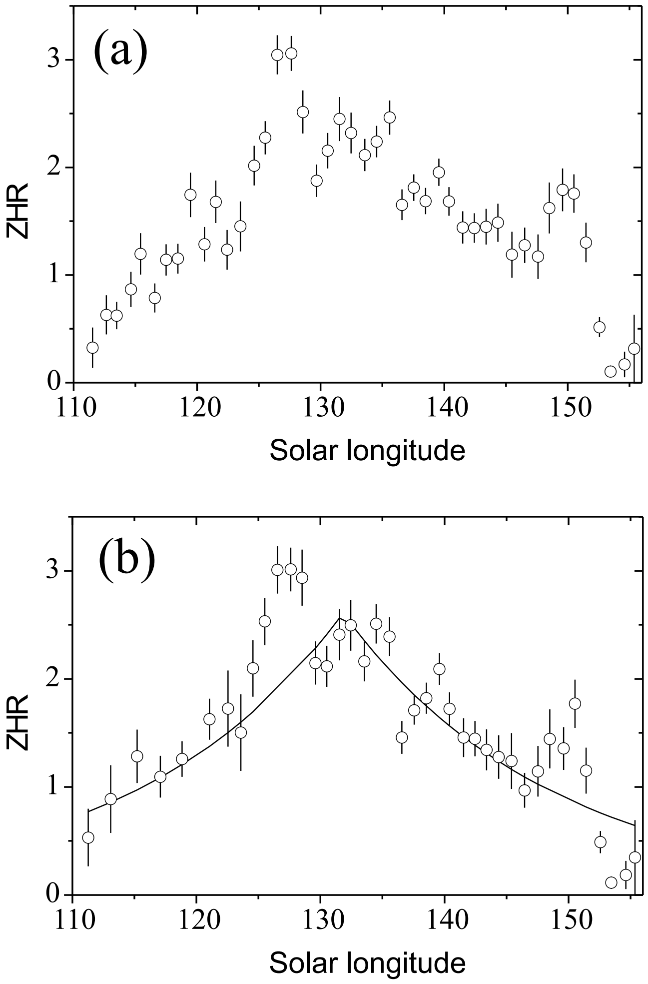

Figure 3 – Activity profiles of the Northern δ-Aquarids from observations in 1997–2002: (a) $C_i \leq 10$ and no limitation on the radiant elevation, (b) $C_i \leq 10$ and $h_R \geq 30°$. The double-sided exponential fit is shown by a solid line.

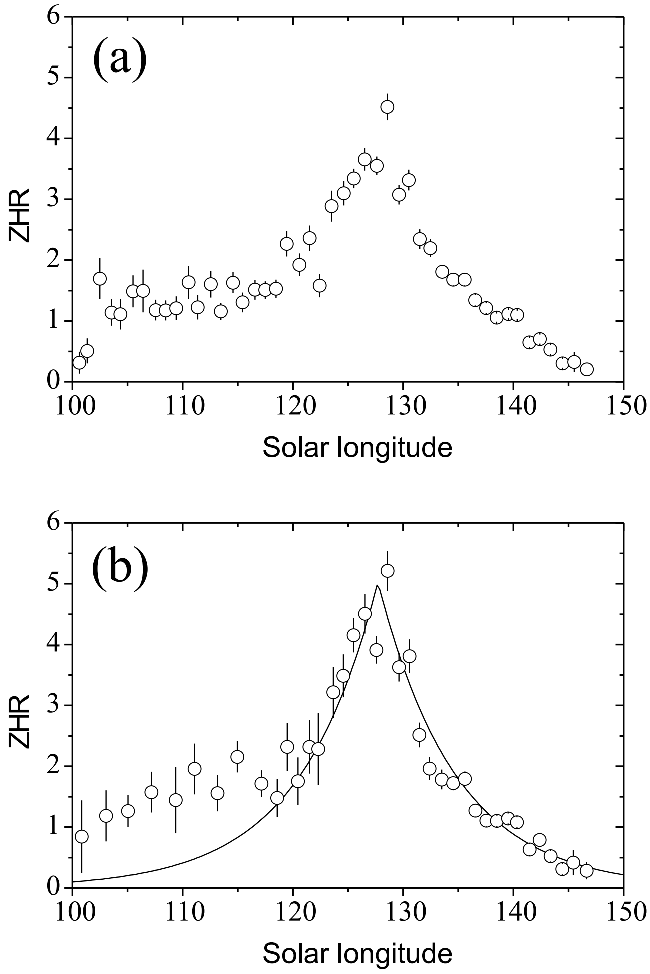

Figure 4 – Activity profile of the Capricornids from observations in 1997–2002. (a) $C_i \leq 10$ and no limitation on the radiant elevation, (b) $C_i \leq 10$ and $h_R \geq 30°$. The double-sided exponential fit is shown by a solid line.

ulation index of $r = 2.31 \pm 0.03$, a value comparable to the most noticeable ecliptical meteor shower — the Taurids in November.

The ZHR-profile of the Capricornids is plotted in Figure 4. A characteristic feature of the profile is an extended background with ZHR $\sim$ 1.5–2 in the solar longitude range of $\lambda_\odot = 110°$ to $120°$, which could not be simply suppressed by varying data selection parameters (C_i and h_R). Yet the effect appears to be a structural feature, related to the origin of the meteoroid stream. It is widely recognized that the structure of the ecliptical meteoroid streams is rather complex as a result of planetary perturbations which have highest probability of occurrence for low-inclination streams. In our case, this background represents a constant level of ecliptical activity up to $\lambda_\odot = 120°$, which is nicely continued by the Northern ι-Aquarids in the second half of August (see Section 6). In what follows, Capricornids are an embedded distinct shower within a much shorter period of time, July 23 – August 13 ($\lambda_\odot = 120° - 140°$), than is suggested by observational data shown in Figure 4.

In the fitting procedure we have chosen a $\lambda_\odot$ interval of 120° to 150°, where an exponential activity character is expected. A double-sided exponent fitted the activity profile fairy well, especially its descending part, and yielded the following numbers: $\text{ZHR}_{\text{max}} = 5.0 \pm 0.2$, $\lambda_\odot^{\text{max}} = 127\overset{\circ}{.}7 \pm 0\overset{\circ}{.}2$ and $B = 0.06$. It must be noted that the value of ZHR_{max} is slightly higher than that listed in the literature, see Table 1.

More precise analysis revealed another interesting finding which concerned the variation of ZHR_{max} with the chosen value of h_R in the data reduction procedure. An example can be seen when Figures 4(a) and (b) are compared. We found that higher ZHR_{max} values refer to higher radiant elevations, and this finding points to a clear signature of $\gamma > 1$; however, poor data distribution versus radiant elevation angle did not disclose any obvious trend.

6 Southern and Northern ι-Aquarids

The Southern ι-Aquarid meteor shower is badly disposed for Northern hemisphere observers, and due to its low activity less than 50% of observers contributing to Aquarid datasets distinguish this shower from the sporadic background. From 1485 shower meteors reported in 1997–2002 we have constructed a ZHR-profile, see Figure 5. Again, as in the case of the Northern δ-

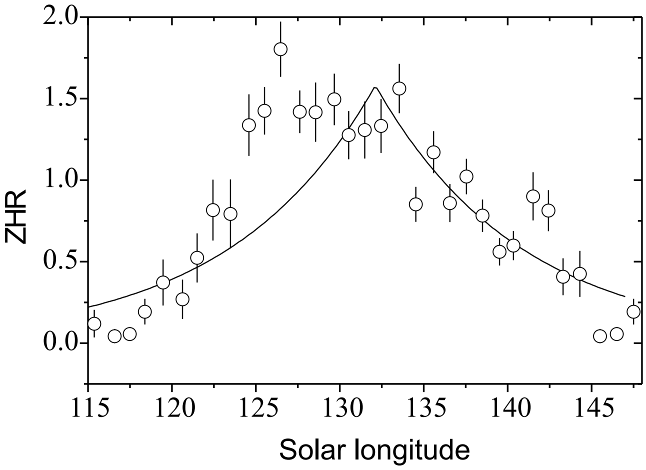

Figure 5 – Activity profile of the Southern ι-Aquarids from observations in 1997-2002. The double-sided exponential fit is shown by a solid line.

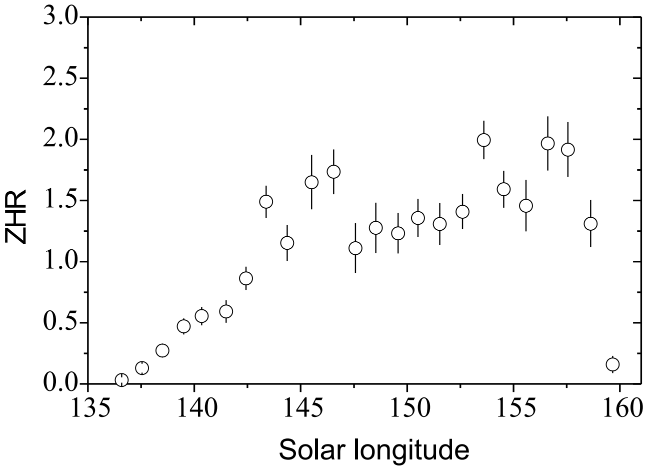

Figure 6 – Activity profile of the Northern ι-Aquarids from observations in 1997–2002.

Aquarids, the ZHR-profile of the Southern ι-Aquarids is distorted by the onset of the Southern δ-Aquarid activity around their maximum time ($\lambda_\odot = 126°$). Then it is not easy to define correctly the maximum time. With data around $\lambda_\odot = 126°$ excluded, the fit yielded $\lambda_\odot^{\max} = 132{.}^\circ1 \pm 0{.}^\circ5$ with ZHR = 1.6±0.1 and $B = 0.05$.

Because of very low activity, these values are very approximate only. The activity curve denotes a rather long period of visibility, however reliable detection ($ZHR > 1$) of shower meteors by visible means is possible just within two-week period of July 28-August 9 ($\lambda_\odot = 125$–136).

Nothing much has been found with regard to Northern ι-Aquarid activity. The ZHR-profile is shown in Figure 6. It exhibits just a broad plateau with ZHR = 1.2–2.0 within a solar longitude interval of $\lambda_\odot = 143°$ to 158° and does not point to an alleged maximum at $\lambda_\odot = 150°$ (Rendtel et al., 1995).

7 Zenith attraction and shower association

As briefly discussed in previous Sections, precise knowledge of radiant positions is of high importance for shower association. Useful hints and related issues for visual observers are given in the IMO Handbook (Rendtel et al., 1995) and more recently by Lunsford & Arlt (2003). In this Section we show that the effect of zenith attraction cannot be neglected in the case of Aquarid-Capricornid complex meteor showers. Because of the Earth's gravitation, the apparent radiant position is shifted towards the zenith as compared with the position of the true one, the effect known as the zenith attraction; see (Richardson, 1999) for details. In simple terms it is expressed as

$$z_R = \frac{z_t}{2} + \arcsin\left[\frac{v_g}{w}\sin\left(\frac{z_t}{2}\right)\right];\, w^2 = {v_g}^2 + 123.06, \quad (8)$$

where z_R and z_t are the zenith angles of the apparent and the true radiants, respectively, v_g is the geocentric meteor velocity at infinity in km/s. Note that radiant elevation is $h_R = 90° - z_R$. The effect of zenith attraction becomes more pronounced for the low radiant elevation and for the low velocity meteors, which is exactly the case of the meteor showers investigated here. To illustrate this, in Figure 7(a) we plotted radiant elevation as a function of local time for observers located at geographical latitude $50°N$. In Figure 7(b) we plotted the difference $\Delta h = h_R - h_t$ versus the radiant elevation h_R for the five meteor showers analyzed in this study. In data processing of meteors recorded by imaging (photographic and video) techniques, the zenith attraction could be easily accounted for, whereas the visual observer has to work the correction out for each individual meteor in the plot after the observation. The less accurate under-the-sky association of meteors with radiants is thus even poorer when zenith attraction comes into play. Gural (2000) has shown that the radiant point is systematically shifted in the azimuthal direction also, depending on the sighting direction, therefore the apparent radiant seems to be blurred. Without going into deep details, it is thus clear that above effects might play a relevant role with five closely located radiants active at the same time, and instant shower association becomes a non-trivial task. Furthermore, all the radiants are located in the vicinity of the antihelion area, which is intrinsically rich in sporadic meteor radiants, producing notable activity as well (Jones & Brown, 1993).

It must be noted that we have neglected the effect of zenith attraction in the calculation of ZHR, since for $h_R > 30°$ the correction Δh_R becomes comparable with actual radiant sizes, as given by Olech & Wiśniewski (2002).

8 Conclusions

The summary of refined observational characteristics for Aquarid-Capricornid complex meteor showers, as derived from the VMDB observations in 1997–2002, is presented in Table 3. First of all, we found that the population indices derived for all the showers of interest are systematically lower than those given in the literature (Jenniskens, 1994; Rendtel et al., 1995, Table 1). The difference for the δ-Aquarids is as large as 0.5, thus be-

Table 3 – Summary of Aquarid-Capricornid complex related meteor showers characteristics as derived from IMO observations in 1997–2002.

Shower	Visibility	Max date	$\lambda_{\odot}^{\max}$	$\mathrm{ZHR}_{\max}$	B [1/°]	r
SDA[a]	Jul 19–Aug 14	Jul 31	$127\overset{\circ}{.}1 \pm 0\overset{\circ}{.}3$	11.8 ± 0.5	0.09	2.62 ± 0.04
SDA[b]	Jul 14–Aug 17	Jul 31	$126\overset{\circ}{.}9 \pm 0\overset{\circ}{.}3$	17.5 ± 1.3	0.08	2.31 ± 0.07
NDA	Jul 21–Aug 23	Aug 4	$131\overset{\circ}{.}8 \pm 0\overset{\circ}{.}5$	2.6 ± 0.1	0.03	2.66 ± 0.05
CAP	Jul 4–Aug 14	Jul 31	$127\overset{\circ}{.}7 \pm 0\overset{\circ}{.}2$	5.0 ± 0.2	0.06	2.31 ± 0.03
SIA	Jul 28–Aug 9	Aug 5	$132\overset{\circ}{.}1 \pm 0\overset{\circ}{.}5$	1.6 ± 0.1	0.05	2.67 ± 0.08
NIA	Aug 17–Sep 1	–	–	~ 2	–	2.62 ± 0.07

[a] Derived from the Northern Hemisphere observations.
[b] Derived from the Southern Hemisphere observations.

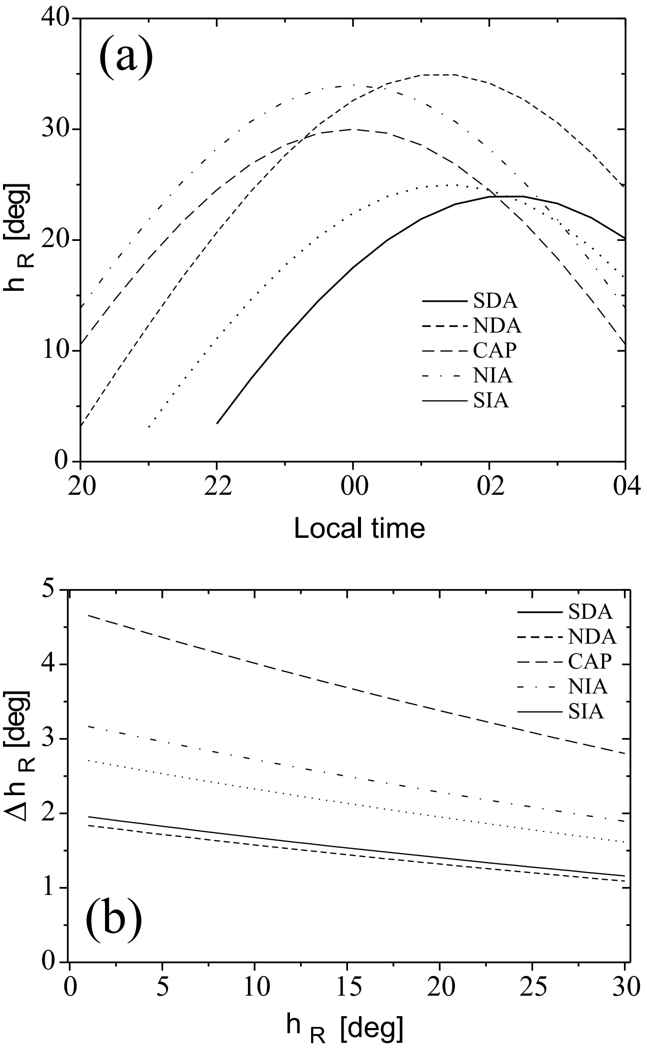

Figure 7 – (a) Radiant elevation for observers located at geographical latitude 50°N. Radiant positions at shower maxima as given by Arlt et al., (1990) are considered. (b) Radiant height correction Δh_R for zenith attraction versus radiant elevation h_R for Capricornids ($v_g = 25$ km/s), Southern δ-Aquarids ($v_g = 41$ km/s), Northern δ-Aquarids ($v_g = 42$ km/s), Southern ι-Aquarids ($v_g = 34$ km/s) and Northern ι-Aquarids ($v_g = 31$ km/s).

ing critical for the determination of the overall activity level. Since our analysis covers just a short time period (6 years), the possibility of long-term variations of the population index could not be ruled out.

Refined values of $\lambda_{\odot}^{max}$, ZHR_{max} and B for Southern and Northern δ-Aquarids, Capricornids and Southern ι-Aquarids were derived from the double-exponential fit (eqn. 5). Visibility periods (for $ZHR \geq 1$) were established again from the best fit, except that of the Capricornids, which was extracted directly from the activity profile because of the extended background. The activity profile of the Northern ι-Aquarids allowed just the derivation of approximate value of ZHR_{max} with no apparent maximum date.

The Southern δ-Aquarids are the strongest shower, however typical hourly rates at the maximum do not exceed 15. Since we found somewhat different activity levels as derived from the Northern and Southern Hemisphere observations, we present two characteristic value sets in the summary table. Activity levels of the Northern δ-Aquarids and the Capricornids were found to be fairly consistent with those given in the literature, with some of minor corrections. Both Southern and Northern ι-Aquarid showers have been found to be relatively weak ($ZHR_{max} < 2$), just slightly above the visual detection limit.

An interesting finding addresses the dependence of ZHR on the radiant elevation h_R. For Southern ι-Aquarids, Southern δ-Aquarids and Capricornids we have found that systematically higher ZHRs refer to higher radiant elevation, thus being a clear signature that a zenithal exponent value higher than $\gamma = 1$ has to be applied. Although this effect has been investigated in the case of major showers (Zvolánková, 1983; Bellot Rubio, 1995; Arlt & Buchmann, 2002), the issue still remains open as existing methods do not allow sufficient accuracy to be achieved.

We also found that incorrect shower association might constitute a serious drawback in derivation of shower characteristics. Typical examples are the ZHR-profiles of the Northern δ-Aquarids and Southern ι-Aquarids, where onset of Southern δ-Aquarids activity is reflected through false maxima around $\lambda_{\odot} = 126$. This finding points out that a considerable number of Southern δ-Aquarid meteors might be misidentified at the expense of their own activity level. Moreover, in the case of Southern δ-Aquarids, incorrect shower association has been found responsible for the extended background in the activity profile. And finally, the difference in rates of δ-Aquarids as derived from Northern and Southern hemisphere observations can be attributed to a complex issue of shower association and zenith exponent effects.

As a final remark, we want to stress that it does not mean that observations at low radiant altitudes are wrong or not useful, we just intend to direct observers' attention to the fact that zenith attraction indeed might play a relevant role in shower association, and therefore has to be carefully taken into account.

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Radiant distributions of the Capricornid-Aquarid complex

Yoshihiko Shigeno [1, 2] *and Tomoko Shigeno* [1, 3]

Double-station TV meteor observations were carried out in Australia for 9 days from the end of July until early August. We observed 492 double-station meteors. Five meteor streams are known to be found around Capricorn and Aquarius during this period. The observation results, however, were concentrated in the Alpha Capricornids and the Southern Delta Aquarids. The other results were widely scattered and could not be classified. They are better introduced as meteor streams with widely scattered radiants, not classified into smaller subdivisions.

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1 Introduction

It is well known that the Alpha Capricornids, Southern Iota Aquarids, Northern Delta Aquarids, Southern Delta Aquarids, and Pisces Australids appear from late July to early August. Kronk attributes the discovery of these meteor streams to visual observation in the latter half of the 19th century (Kronk, 1988, p. 121 et seq.). When double-station photographic observation started, more detailed observation results were reported (McCrosky & Posen, 1961; Cook, 1971; Lindblad, 1987). In recent years, more detailed analysis has been attempted by using many visual observations (Arlt et al., 1992). There is much visual observation of many meteors, but the precision is not high enough. Photographic observation has high precision, but the number of meteors has been limited. Therefore, there have not been enough observation results up until now. We thus carried out double-station TV meteor observation in Australia at the end of July in 1998 (Shigeno et al.,1999). We did this in order to observe many meteors with higher precision. The results showed that not enough research had been done on these meteor streams. Therefore, we carried out double-station TV meteor observation again at the beginning of August 2002 and analyzed the data.

2 Observations

We carried out double-station TV meteor observations twice in Queensland; in Atherton and Hughenden in 1998 July, and in Roma and Hughenden in 2002 August (see bottom of Table 1). All baselines were approximately 45 km. We used an image intensifier with a CCD (Shigeno et al.,1997). The lenses which imaged the sky onto the image intensifier were f=85 mm $f/1.2$, f=85 mm $f/1.4$, and f=50 mm $f/1.2$. The field of view was approximately $10° \times 8°$, and the limiting stellar magnitude approximately 10.5. The average measurement error was approximately $100''$, and the average error of the radiant location approximately 0.6°. Approximately 25 meteors were observed in one hour.

3 Alpha Capricornids

The radiants are diffuse and the mathematical analysis results differ according to how far out meteors are included. This time only the concentrated areas were used for the mathematical analysis. Table 1 show the daily average and other published observations for comparison. and the motions of the radiant. The divergence from the comparison data is very obvious.

4 Southern Delta Aquarids

It is easy to do the math as the concentrated parts of the radiants are clear. Table 2 shows the daily average and comparison data for the observations this time. It also displays the radiant's motions. They match the comparison data well.

5 Other meteor streams

A radiant distribution chart was made of the area around Aquarius from the end of July to early August. Figure 1 shows McCrosky & Posen's radiants at the end of July, and Figure 2 shows our radiants at the end of July. Radiant forecast locations (Rendtel et al., 1995) by the IMO for each location are marked with circles. Figure 3 shows McCrosky & Posen's radiants in early August, and Figure 4 shows our radiants in early August. The areas around Capricorn and Aquarius have many scattered radiants. We could only do the math for the Alpha Capricornids and the Southern Delta Aquarids because the other areas did not have any concentrated parts.

6 Conclusion

During 9 days from late July to early August, 492 double-station meteors were observed. The results shown in the radiant chart (Figures 2 and 4) are laid out so they are easy to see. Only two of these five meteor streams appear to exist independently. The Alpha Capricornids and Southern Delta Aquarids have concentrated parts, but the other meteor streams only have widely scattered radiants. Kronk (1988, p.128) reports Hoffmeister as saying in 1948 that activity tended to be strong in a 20-degree diameter area centred on the Southern Delta Aquarid radiant. In addition, Kronk pointed out that this was an observation from the Northern Hemisphere, and that the observation was wrong due to the large errors. Our observation results, however, show that Hoffmeister was right. We believed in the five meteor streams written in various works, and carried out observations from the Northern Hemisphere for many years. However, the only meteor streams we could classify were the Alpha Capricornids and Southern Delta Aquarids. These meteor streams are the Capricornid-Aquarid complex. Our results call into question whether any more detailed classification is justified.

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Table 1 – Daily Average and Standard Deviation of the Alpha Capricornids. (Equinox 2000.0) The upper line of each pair gives the averages and the lower line gives the scatter in the data in standard deviation and does not indicate the errors in the averages. The standard deviations σ are those of the value immediately to the left. V_G is the geocentric velocity. H_b and H_e are beginning and ending heights respectively.

		Corrected radiant															
Date (UT) Y/M/D	$\lambda_\odot$ °	RA α °	σ °	Dec δ °	σ °	V_G km/s	σ km/s	a AU	e —	q AU	ω °	Ω °	i °	H_b km	H_e km	Abs mag	No. of mets
1998/07/31.62	128.23	305.8	0.3	−8.1	0.7	21.2	1.0	2.33	0.735	0.617	265.8	128.2	7.6	99.1	87.1	4.9	5
0.02	0.02	1.1	—	0.6	—	0.6	—	—	0.023	0.012	2.0	0.0	0.5	4.0	3.0	0.6	
1998/08/01.65	129.21	305.7	0.4	−6.4	1.3	20.3	0.8	2.16	0.704	0.639	264.0	129.2	8.3	98.1	85–	4.5	3
0.04	0.04	0.3	—	0.4	—	0.6	—	—	0.022	0.007	0.5	0.0	0.1	1.6	—	1.4	
2002/08/03.61	131.06	305.4	0.4	−7.6	0.8	18.4	1.0	2.12	0.683	0.673	260.2	131.0	7.0	99.2	89.5	5.6	2
0.04	0.04	0.8	—	0.1	—	1.7	—	—	0.044	0.022	1.3	0.0	0.5	—	0.4	0.4	
2002/08/04.68	132.08	309.0	0.4	−8.1	0.7	19.5	1.0	2.31	0.680	0.642	264.7	132.1	6.5	98.1	89.6	6.0	1
2002/08/06.62	133.94	308.4	0.1	−6.7	0.3	19.3	0.5	2.11	0.683	0.669	260.8	133.9	7.1	98.3	85.2	5.1	2
0.05	0.05	1.7	—	0.2	—	0.5	—	—	0.002	0.023	3.1	0.0	0.1	0.7	2.3	0.3	
2002/08/07.62	134.90	309.5	0.1	−6.4	0.3	20.2	0.5	2.36	0.722	0.657	260.8	134.9	7.6	101.8	82–	4.4	1
Cook	128.	308.		−10.		22.8		2.53	0.77	0.59	269.0	127.7	7.0				
Lindblad	(129.2	308.4		−8.7		22.3)		2.42	0.758	0.586	270.2	127.6	7.3				
Kronk	129.3	307.4		−8.1													
IMO	127.	307.		−10.		22.4											

Note: Lindblad (1987) provides only the orbital elements; the radiant and velocity were calculated.

Radiant's motion of the Alpha Capricornids. (Equinox 2000.0)

This work	R.A.	=	304.8	+	0.53	*	($\lambda_\odot$-127.0)	Decl.	=	−8.1	+	0.20	* ($\lambda_\odot$-127.0)
Cook & IMO	R.A.	=	307	+	0.9	*	($\lambda_\odot$-127)	Decl.	=	−10	+	0.3	* ($\lambda_\odot$-127)

Longitudes, latitudes and heights above sea level of the Australian observation sites

Location	East site			West site		
Atherton	145°25′50.″8 E	17°09′06.″6 S	610 m asl	145°01′11.″9 E	17°08′34.″7 S	452 m asl
Hughenden	144°12′07.″1 E	20°52′01.″0 S	328 m asl	143°44′55.″5 E	20°53′05.″6 S	249 m asl
Rome	149°27′20.″0 E	26°37′16.″5 S	342 m asl	149°00′12.″0 E	26°35′08.″3 S	330 m asl

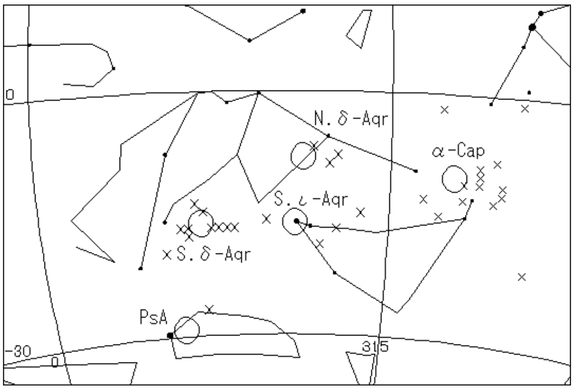
Table 2 – Daily Average and Standard Deviation of the Southern Delta Aquarids. (Equinox 2000.0) The upper line of each pair gives the averages and the lower line gives the scatter in the data in standard deviation and does not indicate the errors in the averages. The standard deviations σ are those of the value immediately to the left. V_G is the geocentric velocity. H_b and H_e are beginning and ending heights respectively.

		Corrected radiant															
Date (UT)	$\lambda_\odot$	RA α	σ	Dec δ	σ	V_G	σ	a	e	q	ω	Ω	i	H_b	H_e	Abs	No. of
Y/M/D	°	°	°	°	°	km/s	km/s	AU	—	AU	°	°	°	km	km	mag	mets
19980727.62	124.41	337.4	0.3	−17.0	0.4	41.0	1.0	2.67	0.972	0.073	151.9	304.4	26.9	101.0	84.7	4.7	4
0.01	0.01	0.7	—	0.6	—	0.5	—	—	0.004	0.008	1.7	0.0	2.8	2.3	0.5	0.8	
19980731.63	128.24	341.7	0.3	−15.5	0.5	39.4	1.1	2.05	0.962	0.078	151.9	308.2	25.5	98.2	83.0	3.3	8
0.02	0.01	0.8	—	0.7	—	0.9	—	—	0.007	0.008	1.6	0.0	3.0	3.3	1.1	1.6	
19980801.65	129.22	341.9	0.6	−15.9	0.8	39.2	1.1	2.16	0.959	0.089	149.7	309.2	25.3	100.5	86.3	3.5	17
0.04	0.03	1.2	—	0.7	—	0.9	—	—	0.007	0.010	1.8	0.0	2.9	1.9	4.1	1.6	
20020803.66	131.11	343.0	0.2	−15.5	0.3	38.7	1.5	2.13	0.954	0.099	148.2	311.1	23.1	101.8	85.7	4.1	8
0.05	0.04	1.2	—	0.8	—	0.9	—	—	0.007	0.010	2.1	0.0	2.8	1.2	3.1	1.2	
20020804.64	132.05	344.6	0.3	−15.6	0.5	39.8	2.0	2.31	0.960	0.091	149.2	312.0	27.4	100.9	87.8	4.2	6
0.03	0.02	2.0	—	0.9	—	1.1	—	—	0.009	0.016	3.5	0.0	4.2	2.2	1.7	1.2	
20020806.69	134.01	346.1	0.4	−15.2	0.6	39.5	0.9	2.11	0.951	0.104	147.3	314.0	25.7	102.7	82.0	4.5	3
0.04	0.04	1.1	—	0.2	—	2.7	—	—	0.010	0.007	1.3	0.0	3.0	1.1	—	0.3	
20020807.69	134.97	345.9	0.5	−14.2	0.7	41.1	1.4	3.77	0.977	0.086	148.4	315.0	26.1	99.5	83.7	4.6	3
0.04	0.04	0.6	—	0.7	—	2.4	—	—	0.014	0.017	2.1	0.0	2.1	3.2	—	0.4	
Cook	126.	340.		−16.		41.4		2.86	0.976	0.069	152.8	305.7	27.2				
Lindblad	(129.2	341.9		−15.7		40.2)		3.09	0.967	0.102	149.5	310.3	26.2				
Kronk	125.7	339.7		−16.7													
IMO	125.	339.		−16.		39.4											

Note: Lindblad (1987) provides only the orbital elements; the radiant and velocity were calculated.

Radiant's motion of the Southern Delta Aquarids. (Equinox 2000.0)

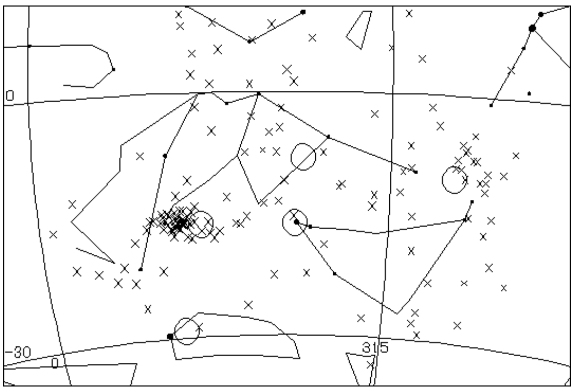
This work	R.A.	=	338.5	+	0.81	*	($\lambda_\odot$-125.0)	Decl.	=	-16.6	+	0.19	*	($\lambda_\odot$-125.0)
Cook	R.A.	=	339.2	+	0.80	*	($\lambda_\odot$-125.0)	Decl.	=	-16.4	+	0.18	*	($\lambda_\odot$-125.0)
Kronk	R.A.	=	339	+	0.8	*	($\lambda_\odot$-125)	Decl.	=	-17	+	0.4	*	($\lambda_\odot$-125)
IMO	R.A.	=	339	+	0.75	*	($\lambda_\odot$-125)	Decl.	=	-16	+	0.21	*	($\lambda_\odot$-125)



IMO predictions : ‘Circle’ of Figure 1,2 (July 29).

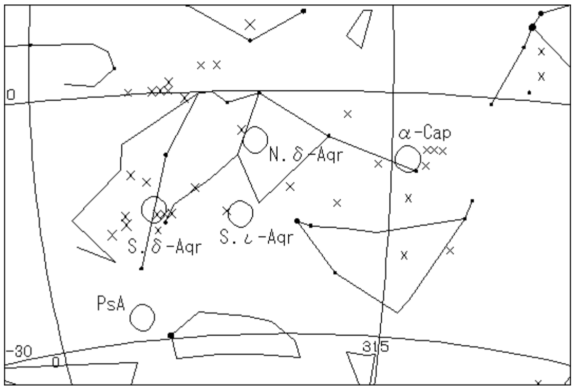
Meteor stream	Radiant	ZHR
Alpha-Cap	(307, −10)	3
S.Iota-Aqr	(327, −16)	1
N.Delta-Aqr	(326, −8)	2
S.Delta-Aqr	(339, −16)	20
Piscis Aust.	(342, −29)	5

Figure 1 – Corrected Radiants of McCrosky and Posen photograph. 52 meteors (1952–3 July 21–29).



Date	Lens	Field	no	Location
27	85/1.4	09° × 07°	27	Atherton
28	50/1.2	17° × 13°	4	Atherton
30	50/1.2	17° × 13°	7	Hughenden
31	50/1.2	17° × 13°	57	Hughenden
01	50/1.2	17° × 13°	90	Hughenden

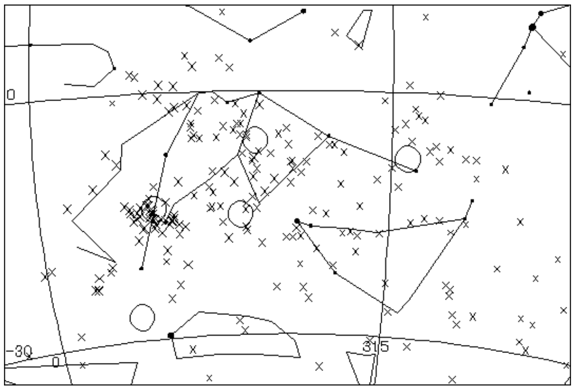
Figure 2 – Corrected Radiants of this work. 185 meteors (1998 July 27–August 01).



IMO predictions : ‘Circle’ of Figure 3,4 (August 05).

Meteor stream	Radiant	ZHR
Alpha-Cap	(313, -8)	3
S.Iota-Aqr	(334,-15)	2
N.Delta-Aqr	(332, -6)	3
S.Delta-Aqr	(345,-14)	5
Piscis Aust.	(348,-27)	2

Figure 3 – Corrected Radiants of McCrosky and Posen photograph. 99 meteors (1952–3 August 03–10).



Date	Lens	Field	no	Location
03	85/1.2	10° × 08°	52	Roma
04	85/1.2	10° × 08°	57	Roma
06	85/1.2	10° × 08°	105	Hughenden
07	85/1.2	10° × 08°	93	Hughenden

Figure 4 – Corrected Radiants of this work. 307 meteors (2002 August 03–07).

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Fundamentals of meteor science

The anthelion radiant

Robert Lunsford [1]

A short overview of the radiants positioned opposite the sun is presented. Their characteristics including positions and rates throughout the year are discussed. Possible causes of these radiants and how to best view these meteors are also mentioned.

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1 Introduction

Anyone who has glanced through the list of radiants provided by the I.M.O. has noticed that many of these radiants lie near the ecliptic and bear the names of the zodiacal constellations. There are the Delta Cancrids, Virginids, Sagittarids, Piscids, Taurids, Leonids and Geminids to name a few. Radiants such as the Leonids and Geminids are well known and produce strong annual displays. Their source and history are well known to all familiar with meteor astronomy. But most of these ecliptical radiants are weak and obscure. Rarely does the meteor enthusiast plan a watch for the Delta Cancrids or the Sagittarids. It is the more active and better known radiants that draw their attention. Yet while out under the stars viewing these strong radiants, meteors from unknown sources occasionally burst forth upon the stillness of the night. While most of these meteors are totally unrelated and classified as sporadic, a few of them radiate from that portion of the sky that lies nearly opposite the sun. These meteors are members of the anthelion or anti-helion radiant. Lying opposite the sun in the sky, these radiants rise near the end of evening twilight and lie highest in the sky shortly after local midnight. During the morning hours they proceed toward the western horizon and set shortly after sunrise.

The anthelion activity can be seen every night of the year. The question is, is this a group of independent radiants or just one radiant that marches endlessly eastward night by night? After studying the activity periods, radiant positions and velocity estimates, I have come to the conclusion that there is in fact one very large radiant located along the ecliptic 195° east or 165° west of the sun; however you prefer to look at it. This is not to say that the ecliptical radiants listed on the I.M.O. list are not independent and produced by a single parent object. I do believe though that there is a more or less continuous stream of particles encountering the Earth producing these anthelion meteors. This radiant follows the ecliptic and ranges from a declination of 23° north in late November and early December to 23° south in late May and early June. The core of the radiant stretches some 30° in right ascension (celestial longitude) and at least 20° in declination (celestial latitude). If one takes the positions of the Delta Cancrids, Virginids, Sagittarids, Piscids, Taurids and Chi Orionids from the IMO radiant list, they will lie within the core of the antihelion radiant for that particular time of year.

The antihelion radiants have been around as long as radiant lists have been published. Obsolete radiants such as the Psi Leonids, May Librids, Alpha Scorpiids, North and South Ophiuchids, Lambda Sagittarids, Tau Capricornids, and Northern Piscids all fall within the core of the antihelion radiant.

2 Sources of anthelion meteors

What produces these meteors? At present, the exact source is unknown for certain. Most likely it is a combination of material produced by the Jupiter family of comets and Earth-crossing asteroids. We do know for a fact that this material orbits the sun in low-inclination, direct orbits, and encounters the Earth on its inbound or pre-perihelion portion of its orbit. The radiant would lie near 180° from the sun were it not for the effect of the apex attraction. This attraction, caused by the Earth's motion in space, shifts the radiant 15° or one hour of right ascension east (toward the Earth's apex). Since these meteoroids encounter the Earth at a perpendicular angle, the resulting entry velocity is near 30 kilometers per second. To the eye these meteors appear to be of average velocity, lacking both very fast and very slow meteors.

3 Observing anthelion meteors

Of the five known groups of sporadic meteors, the anthelions are easiest to observe. The helion radiant lies too close to the sun for visual observing. The apex meteors are seen only after midnight. The toroidal radiants are huge and accurate positions of their centers are still being determined. Lastly, the Cyclids (Earth-like orbit) are very rare and seldom seen. Figure 1, from the I.M.O. Visual Handbook, depicts the density-distribution of sporadic meteor radiants with respect to ecliptic coordinates.

Since the anthelion radiant does not venture more than 23° from the celestial equator, shower members may be well seen from both hemispheres during the entire year. Table 1 lists the approximate center of the anthelion radiant and the constellation in which this position is located.

At the start of the year the anthelion radiant lies well north of the celestial equator in the constellation of Gemini. This is advantageous to observers in the

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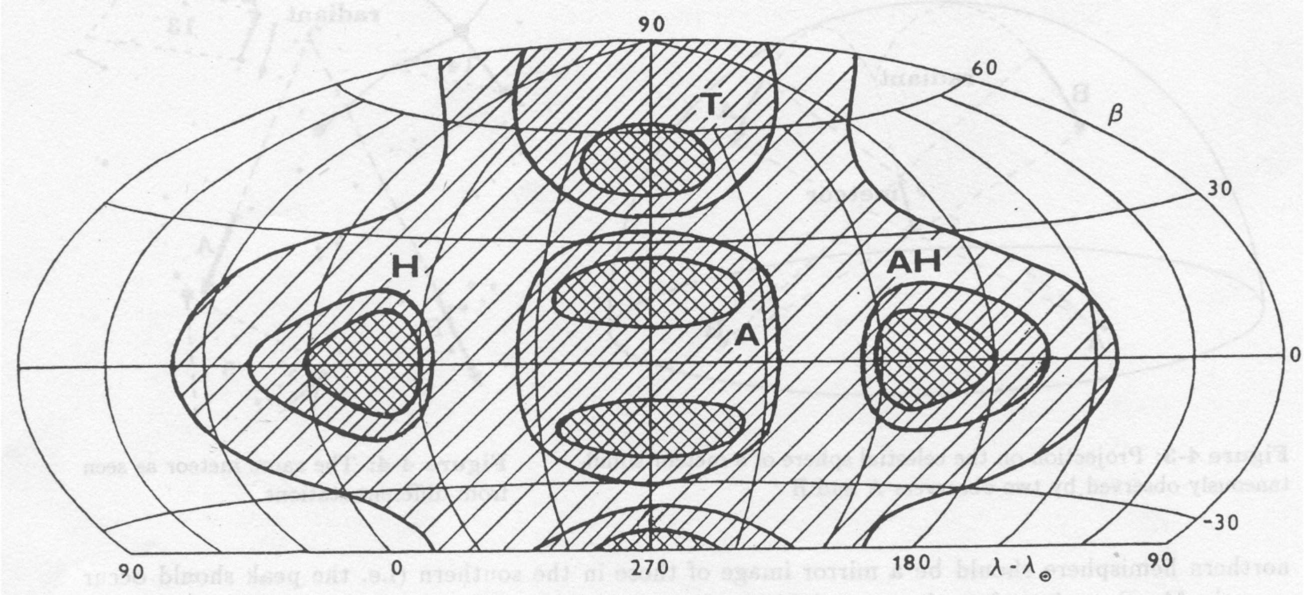

Figure 1 – The different sources are indicated as follows: A: Apex, H: Helion, AH: Anthelion, and T: Northern Toroidal. The Cyclids are not depicted but would appear from near the center of the apex near the position (270°, 00°). From (Znojil, 1995), p. 114, Figure 4-5.

Northern Hemisphere as the radiant lies high in the sky near midnight. ZHRs in January are near 4. In February the radiant moves into Leo and ZHRs remain near 4. In March the radiant moves into Virgo and ZHRs increase slightly to 5. The ZHR remains at 5 now through June as the radiant drifts through Libra, Scorpius, Ophiuchus and Sagittarius. During this period the radiant drifts southward favoring observers in the Southern Hemisphere. In July and August the anthelion radiant becomes hopelessly lost in the maze of radiants located in Capricornus and Aquarius this time of year. Visual methods are unable to differentiate due to the overlapping of radiants. Finally in September, the anthelion radiant escapes this maze as it moves northward and enters the constellation of Pisces. ZHRs this time of year are near 3. In October the radiant enters Aries and gains in strength as it combines with the particles from comet P1/Encke. In November the antihelion radiant overlaps the two Taurid radiants producing ZHRs approaching 10. This is the only time of year the anthelion radiant is considered a major shower. As it is impossible for visual observers to differentiate between the anthelion particles and those from comet P1/Encke, all meteors from this area should be called North or South Taurids this time of year. In December the radiant enters Orion and Gemini producing ZHRs of 3.

Table 1 – Anthelion radiant positions throughout the year

Date		R.A.	DEC	Constellation
Jan	01	115	+21	GEM
Jan	15	129	+18	CNC
Feb	01	146	+13	LEO
Feb	15	160	+08	LEO
Mar	01	174	+02	LEO
Mar	15	188	−03	VIR
Apr	01	205	−10	VIR
Apr	15	219	−14	LIB
May	01	235	−19	LIB
May	15	248	−22	OPH
Jun	01	265	−23	OPH
Jun	15	278	−23	SAG
Jul	01	294	−21	SAG
Jul	15	307	−18	CAP
Aug	01	323	−13	CAP
Aug	15	337	−08	AQR
Sep	01	353	−03	PSC
Sep	15	007	+03	PSC
Oct	01	023	+09	PSC
Oct	15	037	+14	ARI
Nov	01	054	+19	TAU
Nov	15	068	+22	TAU
Dec	01	084	+23	TAU
Dec	15	098	+23	GEM

While the majority of meteors from the anthelion radiant are dim, there are numerous occasions when fireballs are produced and reported. Unlike many radiants, the anthelion source can produce fireballs during the evening hours. In the Northern Hemisphere as the nights become warmer and often less cloudy in April and May, more people are outside and witness these spectacles. This may account for the seemingly increase in fireball reports this time of year. Actually the anthelion radiant produces fireballs year round. The best time to view this activity would be between the hours of $21^{h}00^{m}$ and $03^{h}00^{m}$ local standard time. These meteors can appear in any portion of the sky but all will trace back to the large radiant area opposite the sun. Meteors appearing near the radiant area will appear foreshortened and slower than those seen further from the radiant and higher in the sky. Apparent angular velocities will range from 0 to 18°/s.

Information on the currently visible showers, including the anthelion source, is posted regularly on the

IMO-News mailing list. Details can be found on the website `http://www.imo.net/news/imo-news.html`.

4 Conclusion

Observers are encouraged to record this activity during each and every session. Due to the large radiant area it is not difficult to trace this activity back to its source, even when it lies behind your back. Shower members should be noted with the appropriate I.M.O. designation such as DCA or SAG. Your data on these meteors, as well as the better known showers, will help us increase our overall knowledge of annual meteor activity.

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Ongoing meteor work

Meteoric aspects of the Earth-grazing asteroid 2004 FH

Marco Langbroek [1]

A search for meteors potentially associated with the recent spectacular earthgrazing asteroid 2004 FH in the IAU photographic meteor database yields three meteors from the Harvard project, which is probably not enough to support the notion that 2004 FH is one of the larger meteoroids in a stream. The theoretical radiant is located at $\alpha = 226°$, $\delta = -4°$ (for March 19), and meteors would have V_∞ of about 13.2 km/s, which is very slow. Asteroid 2004 FH would only be dangerous if it is an M-class asteroid. A stony asteroid of this size and speed would disintegrate almost completely in the atmosphere without doing much harm. An M-class (iron) asteroid, however, would shower down fragments weighing many tons, creating a crater field with craters up to 100+ meters wide, and serious blast damage within a few kilometers.

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1 Introduction

Near 2004 March 19, the newly discovered spectacular earth-grazing asteroid 2004 FH swept past earth in a breathtakingly close encounter. The asteroid was discovered on March 16 by the LINEAR asteroid search program (MPEC 2004-F24: Williams, 2004a) and approached Earth to a distance of only 0.00033 AU or slightly under 1/8th of the Earth-Moon distance, on March 18.92 UTC (MPEC 2004-F26: Williams, 2004b). This makes 2004 FH the closest observed asteroid approach on record, if we exclude events like the famous 1972 earth-grazing fireball.

With an absolute magnitude[2] H of 26.48 (JPL website[3]), 2004 FH is a small object. Depending on its (yet unknown) albedo, the size ranges from about 15 to 40 meters. (The 30 meter value quoted in most press reports was based on an early H estimate of 25.5 that was subsequently revised (Steve Chesley (JPL), pers. com.). The 30-40 meter estimate remains valid only if the albedo of the object is very low, in the low end of C-class asteroids.) An object in this size range is close (in a relative sense) to the realm of larger meteoroids, those which cause large fireballs. This contribution explores the potential meteoric aspects of 2004 FH.

2 Theoretical radiant and speed

The software of Neslušan et al. (1998) was employed to calculate a theoretical radiant for 2004 FH and particles in similar orbits. The result is a geocentric radiant at $\alpha = 226°$, $\delta = -4°$ for 2004 March 19.0. This is in the northern part of Libra. The geocentric speed is very low, 6.9 km/s, corresponding to a V_∞ of about 13.2 km/s, which is very slow. In terms of 'stream' characteristics, such meteors would come from a very diffuse radiant area, and be subject to significant zenith attraction, resulting in apparent radiant positions that significantly deviate from the geocentric position.

3 Meteors in similar orbits

Asteroid 2004 FH is an Aten asteroid with its aphelion barely outside the orbit of Earth, and its perihelion between Venus and Mercury. This is a type of orbit quite different from that of the more typical meteoroid stream. A search in the IAU photographic meteor database (Lindblad, 1991) using Drummond's D' criterion (Drummond, 1981) with the threshold set at $D' < 0.105$ and the pre earth-encounter orbit for 2004 FH from MPEC 2004-F26 (Williams, 2004b) resulted in three matching meteor orbits (Figure 1): one from

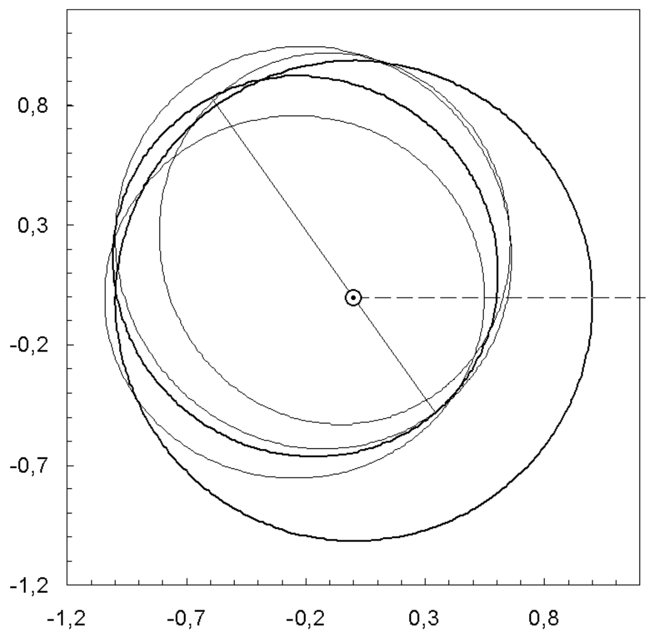

Figure 1 – Orbits of three meteors from the Harvard Super Schmidt Survey compared to the pre-Earth encounter orbit of 2004 FH (smaller thick ellipse). The larger thick ellipse is the orbit of the Earth. The diagonal line crossing this is the line of nodes. The dashed line to the right points to the first point of Aries. The scales are in AU, centered on the Sun.

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[2]H is a term from asteroid studies. It is the brightness the asteroid would have were it at 1 AU from both the Sun and Earth, and fully (100%) illuminated. It is a theoretical value calculated via a very difficult equation from the asteroid's brightness with distance and phase angle. Thus, H is something quite different from the absolute magnitude M in meteor studies.

In asteroid studies, the determined H value together with the object's albedo (or an estimate of the latter usually) can be used to determine the size of the object.

[3]http://neo.jpl.nasa.gov/orbits/

the high precision files, and two from the lower precision graphically reduced files. All three orbits were obtained by the Harvard Super Schmidt project. It concerns meteor 9673 photographed on 1956 December 13, meteor 7397 photographed on 1953 April 16, and meteor 6855 photographed on 1953 March 13. The spread in encounter dates is due to both a spread in perihelion direction p and the fact that the Earth encounters these meteoroids near their aphelion, so that small differences in aphelion distance and eccentricity result in considerable spread of the point of earth orbit intersection. Finding three possibly related orbits is probably not enough to justify the thought that 2004 FH was just a large meteoroid among a stream of similar objects. Moreover the three meteors found show quite a spread in perihelion direction, amounting to some tens of degrees (here we should realize that the perihelion direction of 2004 FH itself has some uncertainty as the pre-encounter orbit is based on only a limited arc of observations). However, as meteoroids in this type of orbit can have relatively frequent encounters with the inner planets, they will probably spread quickly. For example, the perihelion direction of 2004 FH itself changed by almost 10° due to its close encounter with Earth.

4 What if 2004 FH had struck?

A question frequently asked during the media attention connected to the 2004 FH flyby was: 'what would have happened if it had struck Earth? Would it have been dangerous? Would it have had the potential to wipe out cities or states?'. Such a question is difficult to answer as it is dependent on quite a number of factors: how large is 2004 FH exactly, what is its composition and material strength, what is the exact encounter geometry, and where would it strike. Moreover, existing models of small asteroid impacts have their intrinsic uncertainties.

Yet these models can give some rough indications. A well-known model is that of Hills and Goda (1993), who provide analytical model results in graphical form, which can be used to make a cautious assessment for various composition types, sizes and entry speeds.

The entry speed of 2004 FH, had it struck, is quite well defined at about 13.2 km/s. As mentioned in the introduction, the size of 2004 FH is (at the moment of writing) less well defined. In this discussion, we will assume a size of 30 meters if it is a C-class stony asteroid, and 20 meters were it an M-class iron asteroid, these sizes being something of an average for the typical albedo of these asteroid types combined with the absolute brightness H of 26.48 for 2004 FH. As an additional note, the data given here on crater sizes and blast damage areas should be taken to be rough 'order of magnitude' estimates only.

4.1 Fireball brightness

Upon entry in the atmosphere, 2004 FH would produce a fireball of about absolute magnitude $M \simeq -25$, this being not too dependent on composition. It would be visible even in broad daylight.

4.2 Effects of a stony asteroid

If 2004 FH were a stony asteroid, it would probably not result in a very threatening situation. It would be right in the size range where it would undergo catastrophic disruption upon entry, dissipating much of its energy in the fragmentation process, and slowing down considerably. No large fragments would survive and reach ground level. The Hills and Goda model suggests the largest fragments remaining would be in the order of a few kilograms, and these would have lost their cosmic speeds completely. Much of the asteroid would come down as small dust. The energy dissipated in the atmosphere would be of order 0.9 megatons TNT equivalent, and much of it would be dissipated at altitudes of 10 km and above. Strong sonic phenomena with possibly some damage could be expected at ground level, but not large-scale blast phenomena: it would not be a new Tunguska. Impacts of this magnitude and even surpassing it have actually been recorded during the past half-century (ReVelle, 1997).

4.3 Effects of an iron asteroid

In case of an M-class (iron) asteroid, effects would be more severe, but this class is rare amongst the Near Earth Asteroids. The resulting energy dissipation is less than in the case of a stony asteroid (of the order of 0.5 megaton), but much of it would be released low in the atmosphere. Iron objects are more sturdy and fragment less easily. The remaining fragments as a result would be much larger, of the order of several tons or even several kilotons weight. Moreover, they would retain a considerable part of their cosmic speed down to ground level, impacting with potential speeds close to 10 km/s. They would create a crater field with craters potentially being several tens of meters, even up to 100+ meters, wide. This is similar to for example the Henbury crater field in Australia, and the Wabar crater field in Saudi Arabia (Grieve, 1991). Serious blast damage would be experienced over an area a few kilometers wide. Were the impact to occur in a highly populated area, the results could be grim. In relation to other, relatively frequent explosive natural phenomena such as volcanic eruptions, the event would otherwise not be remarkable.

5 Conclusions

Asteroid 2004 FH would only be dangerous if it is an M-class asteroid. A search for potentially associated meteors in the IAU photographic meteor database yields three meteors from the Harvard project, which is probably not enough to support the notion that 2004 FH is one of the larger meteoroids in a stream.

Acknowledgments

An early version of this paper appeared on the Asteroid/Comet Connection website of 2004 March 19, at `http://www.hohmanntransfer.com/mn/0403/19.htm#04fh`. I thank Bill Allen for his interest, which led to the brief internet essay and this more elaborate paper.

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History

Edwin Forrest Sawyer (1849–1937) — 19th century observer, publicist, and mentor

Richard J. Taibi [1,2]

Sawyer, a United States amateur meteor observer, educated other amateur astronomers about meteors and how to make useful observations. Sawyer's work was greatly influenced by the Luminous Meteor Committee of the British Association and by William Frederick Denning. In the Science Observer, Sawyer's writings attracted a nation-wide audience that contributed meteor data in the last decades of the nineteenth century. Sawyer's influence on early twentieth century observers is considered.

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1 Historical introduction

Edwin Forrest Sawyer lived in the Boston Massachusetts metropolitan area all his life. He began employment as a bank teller at the Five Cents Savings Bank on his nineteenth birthday, in 1868, and his banking career was to continue for sixty-four years. Sawyer claimed that his interest in meteor astronomy began in 1868, as well (Boston Globe, 1937; Boston Herald, 1937; Sunday Herald, 1898). Sawyer's training as a bank teller is apparent in the clear, detailed, tabulations of meteor data that he published from 1877 until 1915.

When Sawyer began meteor work, the public had recently witnessed Leonid storms in 1866–1868, as predicted by Hubert Anson Newton (1830–1896) and Heinrich Olbers (1758–1840) (Beech, 1990a). These dramatic displays stimulated much interest in meteor phenomena among laymen and helped to inspire a new generation of amateur astronomers. Among them, in England, was William Frederick Denning (1848–1931). Denning benefited from the guidance and encouragement of Alexander Stewart Herschel (1836–1907), an astronomer who had investigated meteor spectra, and who was also the grandson of William Herschel (1738–1822). The younger Herschel was a member of the Luminous Meteor Committee (LMC), formed in 1860 by the British Association for the Advancement of Science. The LMC's goal was to encourage meteor observations, collect meteor reports, and detect new meteor radiants. To accomplish this, the Committee furnished observers with maps and instructions for recording the paths of meteors during watches. It also suggested the use of a straightedge, held up to the stars immediately after sighting a meteor, as a means of accurately noting the meteor's path on a star map (Sawyer, 1882a, 1882b). Denning used the Committee's methodology in a very disciplined and energetic way. Because nineteenth century meteor investigators believed that all meteors had specific radiants, no meteor was expected to be sporadic, in the current sense. They believed that if a meteor appeared to have a random origin, the fault, in fact, was that not enough observations had been made to find more meteors coming from an elusive radiant. Because meteor workers thought it was crucial to discover a radiant for all meteors, observational results made during weeks of watches were combined until meteors with similar visual characteristics were 'found' to radiate from a small spot in the sky. These radiants were called 'stationary' because they did not appear to shift against the background of stars over several weeks' duration, as actually occurs when the earth passes through a meteor stream. Operating under these assumptions, Denning had compiled a catalogue with thousands of stationary radiants by 1899 (Beech, 1990, 1991; Denning, 1884; Payne, 1899a).

Figure 1 – E.F. Sawyer, from an Obituary (Boston Herald, 1937) written on Saturday October 16, 1937.

In the United States, organized meteor shower investigations began when Denison Olmsted coordinated annual Leonid meteor watches, in 1837. Edward C. Her-

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rick, an amateur associated with Olmsted, increased the number of meteor showers being watched to include 'the meteors of April 20 [now known as the Lyrids], the meteors of August 9 and 10 [Perseids], and meteors of December 7 [Andromedids].' He coordinated national observations of these showers beginning in 1838 and continued them for the next twenty-three years. Herrick's work helped clarify the annual nature of these showers. Following Herrick's death in 1862, the Connecticut Academy of Arts and Sciences appointed a committee of Yale College astronomers to monitor the Perseid and Leonid meteor showers until about 1885 (Olmsted, 1838; Twining, 1862; Eastman, 1890). Although individual bright meteors were reported and catalogued in the United States during the last decades of the nineteenth century, few observers made regular, systematic surveys of meteoric phenomena in order to identify new showers[1]. Additionally, someone was needed to encourage, coordinate, and publish U. S. amateurs' meteor surveys. These were the roles that Edwin F. Sawyer filled during the 1870s and 1880s.

United States observers were influenced by English models of meteor observation. Sawyer corresponded with Denning and was strongly influenced by his assumptions about meteor radiants (Sawyer, 1877a). And other observers corresponded with Luminous Meteor Committee members and used their instructional material and observational methods. In the early 1890s, Denning wrote a series of articles for Popular Astronomy in which he familiarized Americans with observational techniques and information about the annual showers. In this way the LMC's observational methodology was acquired by U.S. meteor workers (Denning, 1893, 1894; Sawyer, 1882a, 1882b)[2].

2 Observational methods and report style

Sawyer watched for meteors after a day's work. He watched on clear, moonless nights, before midnight. He plotted the paths of as many as he could and would later examine the plots to search for radiants. He deviated from evening watches in order to monitor annual showers, like the Leonids, that are more active in the early morning hours. When he reported the quantitative results of the evening watches, they were from an observing period that typically lasted for a few weeks. His reports stated the total number of hours he had observed, the number of meteors seen, showed the magnitude distribution of all the meteors, and listed the radiants he discovered from the meteors he had plotted. Sawyer's data reduction method was clearly in the Denning style and Sawyer seemed to tacitly accept the existence of stationary radiants[3].

When he observed annual showers' maxima, he recorded data during fifteen-minute periods. For each period he tallied shower and non-shower meteors along with the entire session's magnitude distribution. He added comments about meteors' velocities, and other visual characteristics. He did not attempt to plot meteors during shower maxima[4]. His published accounts of shower observations reported all these quantitative data. Sawyer had developed this careful observational style early in his observing career. As a twenty-three year old, Sawyer and a friend noticed that many meteors were darting from the sky near Gamma Andromedae, on 1872 November 27. Although the two men had been caught by surprise, they quickly collaborated in a study of the display, now known as the Andromedid, meteor storm. One of the men called out the magnitudes of meteors seen during fifteen minute periods. The other recorded the data. At the end of two hours, the two had recorded 194 meteors and their magnitude distribution. In addition, the decreasing totals during the fifteen-minute intervals documented the rapid decrease in the rate of the 1872 meteor storm (Sawyer, 1881a).

During Sawyer's observational career, he published accounts of his meteor work in the American Journal of Science and Arts, Monthly Notices of the Royal Astronomical Society, and Astronomical Journal. However, his most frequent publication venue, during the period 1876–1887, was the Science Observer, journal of the Boston Scientific Society (BSS). The BSS was formed in 1876 by a number of scientifically-minded Bostonians. It counted Seth Carlo Chandler (1864–1913) among its founding members. Sawyer was also a member and held many leadership roles.

3 Sawyer's roles as publicist and mentor

The Science Observer's pages were the platform that Sawyer used to address other U. S. meteor enthusiasts. Sawyer published his meteor work in the Observer. In brief articles entitled Meteor Notes, he alerted his readers to watch stationary radiants that Denning and he predicted would become active so that a recurrence could be confirmed. Following Herrick's earlier example, he also listed annual showers that needed checking for activity. In addition to Perseids and Leonids, he informed readers about the Lyrids, Orionids, Taurids and Geminids and when they should be watched (Sawyer, 1877b). Following the showers, Sawyer published reports of his own and other's results, in the Observer.

Soon after the Science Observer began to be published, in 1877, its editor promised readers that '... any systematic observations upon meteors ... if sent to the Society, will be duly credited to the observers.' Further, the editor wrote, 'Amateurs desiring to take up the subject of meteoric showers, will find Mr. Sawyer, who has had several years experience as an observer, ready to give any and all needful assistance' (Ritchie,

[1]Benjamin V. Marsh was an observer who found new showers. See (Kronk, 1988, p. 246) for Marsh's co-discovery of the Geminids. Also see Catalogue 5 in (Eastman, 1890) for a long list of individual meteors seen up to 1879.

[2]One example of trans-Atlantic communication is the mute testimony given by an 1863 LMC annual report at the Library of Congress in Washington, D.C. It was signed by Alexander S. Herschel and addressed to B.V. Marsh, with 'respects.'

[3]For one example of Sawyer's reporting style, see (Sawyer, 1878b).

[4]For an example, see (Sawyer, 1878a).

1877). Readers began to respond to the Observer's invitations. For example, Lewis Swift (1820–1913), the comet discoverer, wrote to report seeing 'a very brilliant shower of meteors' while he sought comets on the morning of 1877 December 12. Edwin Sawyer commented that Swift had probably seen the Geminid maximum in 1877 (Sawyer, 1878c).

Sawyer's success in extending his readership and collaborators in the U.S. can be judged by the names of his contributors and correspondents, as well as their geographical dispersion. From 1880 to 1882, prominent U.S. astronomers like Daniel Kirkwood (1814–1895) from Indiana University, Hubert Anson Newton from Yale College, Olin Henry Landreth (1852–1931) from Vanderbilt University, and Isaac Sharpless (1848–1920) from Haverford College published their own data or related the meteor observations of students and colleagues in the Observer's pages. A 22-year-old amateur from Nashville, Tennessee took time to report some meteors he had seen while observing Jupiter. In this way, Edward Emerson Barnard (1857–1923) began occasional brief reports of meteor sightings. A weather observer for the U.S. Weather Bureau, Charles G. Boerner (1827–1900), contributed his 1879 Leonid data including a magnitude distribution of the 43 meteors seen. Sawyer's correspondents during 1880–1882 spanned the U. S. from Florida to Massachusetts on the east coast, and from Colorado in the west to Washington, D.C. in the east (Ritchie, 1882, p. v).

Sawyer, as the Observer's meteor authority, criticized the way meteor data was reported in the U. S. Weather Bureau publication, the Monthly Weather Review. The Review was edited by Cleveland Abbe (1838–1916), an astronomer who had become convinced that a complete understanding of weather effects was necessary in order to make accurate astronomical observations. In his role as Bureau scientific director, Abbe had instructed the Bureau's weather observers to report any phenomenon that occurred in the sky. Accordingly, there were frequent notes printed about annual meteor showers and fireballs in the Review. Sawyer faulted the Review's practice of merely mentioning that a shower or fireball had occurred. He insisted 'that what is needed is the recording of sufficient data to locate at least approximately the apparent path (of meteors) among the stars' (Sawyer, 1879a). Sawyer suggested that this information could be adequately captured by requiring weather observers to note the azimuth and altitude of a meteor's beginning and terminal points in the sky. Sawyer required the Observer's correspondents to conform to this standard too.

4 Sawyer's later meteor work

Edwin Sawyer's notes and articles in Science Observer give the most detailed portrait of his meteor-related, as well as other, astronomical interests during the period 1877–1886. He took brief leave of the Observer to publish catalogues of meteor radiants in two other journals. His first catalogue appeared in 1879 in the American Journal of Science and Arts (Sawyer, 1879b). This was Sawyer's first publication in a well-respected national journal and signified his emergence as a significant figure in meteor studies. Sawyer's data came from 187 hours of pre-midnight meteor watches during 1877 and 1878. He plotted 600 meteors and was able to detect 36 radiants using a subset of 347 plots. His second catalogue appeared in 1881, before an international audience, in the Monthly Notices of the Royal Astronomical Society. For this radiant catalogue, he drew upon meteor plots made during 221 hours of evening observation sessions during 1879 and 1880. These years yielded 912 meteor plots that he used to find 82 radiants (Sawyer, 1881b). Sawyer's work was well received by W.F. Denning who cited several radiants in one catalog (Denning, 1884). Sawyer also wrote two brief articles in 1882 for Sidereal Messenger, a new astronomy magazine intended for amateurs. In the two articles, Sawyer taught U.S. observers about meteors and how LMC methodology was to be used to study them (Sawyer, 1882a, 1882b).

After Science Observer ceased publication in 1887, Edwin Sawyer published his meteor reports in Astronomical Journal. Sawyer ceased accounts of new radiants and, instead, concentrated on annual meteor showers from the late 1880s until 1915. He observed the Perseids in 1888, 1893, 1895, 1910, and 1915. He reported on his Leonid watches for the years 1893, 1896, and 1898. In all these, he continued using the data formats of his earlier work, listing the numbers and magnitude distributions of observed meteors. Often, too, the Journal reports included the right ascension and declination coordinates of shower meteors' paths[5].

5 Sawyer's legacy

Today, Sawyer's name is unknown to U.S. meteor observers. He is better known among variable star observers, because of variable star work published at the same time that he chronicled meteors. His early variable star brightness estimates appeared in the Observer, as well as his meteor results. Sawyer's earliest study was in 1879, in an article about o Ceti's maximum (Sawyer, 1879c). When he obtained a three-inch refractor he discovered an Algol-type variable in 1881 (Sawyer, 1882c). The Science Observer's index for the volume spanning 1882–1886 showed three articles about variable stars along with reports about 1882's Perseid and Leonid showers (Ritchie, 1886). After obtaining a four-inch refractor, circa 1883, he divided his attention between variables and observations of the Perseids and Leonids. His reports on the two annual showers continued intermittently up until 1915. Sawyer's society membership choices suggest that his enthusiasm for meteors may have declined. He failed to become a member of the American Meteor Society after its formation in 1911, but when he died in 1937, his membership dues to the American Association of Variable Star Observers were fully paid[6].

[5]An example of these later reports is (Sawyer, 1894).

[6]E-mail communication from Michael Saladyga, Ph.D, AAVSO staff, dated 2003 October 1.

It is difficult to specify the exact nature of Sawyer's influence on subsequent generations of U.S. meteor observers. However, despite what appears to be waning interest in meteor work in his later years, Sawyer kept Astronomical Journal readers mindful of meteor astronomy during the 1890s and the early years of the twentieth century. In addition, when Popular Astronomy printed star maps for readers to use in plotting Leonids during the expected 1899 storm (Payne, 1899b), it was consistent with the methodology that Sawyer had employed so often from the 1870s to 1915. Indeed, publishing star maps with meteor plots on them became the means by which a new generation of U.S. meteor observers communicated their results. At the beginning of the twentieth century, two young observers shared their first meteor shower reports in this manner, in Popular Astronomy. The two teenagers, Robert Dole of Massachusetts and Charles Olivier of Virginia, would continue to be active meteor students for the next seventy years, and Olivier would lead the American Meteor Society in 1911 (Dole, 1900; Olivier, 1901).

6 Conclusion

Edwin Forrest Sawyer served as an important model for United States amateur meteor observers, during the period 1877–1915. He served as a mentor to amateurs when he demonstrated the importance of meteor plotting, learned from the British Association's Luminous Meteor Committee. By using the methodology, he set the standard that United States meteor observers had to adhere to if they chose to be competent in their work. During the 1870s and 1880s, Sawyer popularized meteor astronomy and educated the amateur audience about observational techniques and objectives in the Science Observer and Sidereal Messenger. And, he used his columns in the Science Observer as a showcase for other observers' work. His success as a communicator is suggested by the nearly nation-wide distribution of contributors' addresses. They spanned the country from Colorado to New York, and from Florida to New England. Sawyer's later reports in the Astronomical Journal helped to promote meteor astronomy as an important field of amateur endeavor in the United States during the decades near the turn of the twentieth century.

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Meteor Beliefs Project: meteors in the poems of John Donne

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

An examination of the uses of meteor imagery in the poems of Englishman John Donne (1572–1631) is made, revealing a set of beliefs reflecting the period when ideas about astronomy, including meteors, were beginning to undergo radical change.

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1 Introduction

An earlier article in this series (McBeath, 2004) indicated the range of meanings 'meteor' has enjoyed in English during the last 530 years in written forms. As we shall see though, even by the time of one of England's late medieval major poets, John Donne (1572–1631), the fiery shooting-star type of meteor predominated, but with ambiguity appropriate for a time of changing ideas about science and what it was, while still retaining folklorically-important elements.

Donne's poetry is fascinating for many reasons. His metre and scansion can best be described as 'coarse' at times, in that he did not stick to the standards established in poetry before his time in English literature. This can make his works difficult to read, especially with the spelling variants common to the period, and his use of unexpected — sometimes modernly obsolete — words and phrases, with punctuation that occasionally seems to make no sense at first. His poems are dramatic to the point of theatricality at times, and while he often seems entirely preoccupied with love, he is generally regarded as the foremost English poet, and prose-writer, on death. These apparent contradictions make him a great speaker on and to the human condition. He is of course unique, as with all great talents. In his lifetime, and aside from the corpus of his surviving writings, he participated voluntarily in military naval campaigns against Cadiz and the Azores, was Minister of Parliament for places in Northampton and Somerset, travelled widely in Europe including as part of a diplomatic embassy to Germany in 1619–20, was a priest, a royal chaplain, and latterly Dean of St Paul's in London, and fathered twelve children, six of whom survived his death on March 31, 1631.

More details on Donne's life and works can be found in the reference we have used for all our quotes here, (Patrides, 1985). We cannot resist concluding our opening remarks with the following quote from Patrides' own introduction to Donne's works (op. cit., 1985, p. 44):

> Donne was much praised in his lifetime, underpraised thereafter, and over-praised earlier this century. The lowest point of his reputation was during the eighteenth century, in spite — and doubtless because — of the revision of his satires by Pope. At the outset of the nineteenth century, however, Donne was inching forward; by the end of it, he was rising meteorically; and three decades later he was stepping gingerly into the throne said to have been vacated by Milton.

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2 'Songs and Sonets' and 'Epithalamions'

The three poems containing meteors in these works have already been featured by Martin Beech in WGN (Beech, 1993c). One is from an untitled song which first appeared in the 1635 collection called 'Songs and Sonets', and described a collection of impossible tasks beginning with the line, *Goe, and catche a falling starre* (line 1; (Patrides, 1985, p. 50)), with a view to apparently indicating the implausibility of ever finding a faithful woman! There is enough ambiguity in lines 19–20 to suggest Donne might not have considered this an entirely impossible task, however.

Secondly, and also from 'Songs and Sonets', is a verse from 'A Feaver' (lines 21–24 (op.cit., 1985, p. 65)), which suggested the, perhaps wishful, belief that the bouts of fever would (or should) be short-lived, and that the poem's subject, a sick woman, would soon recover. Lines 21–22 from this run: *These burning fits but meteors bee,/ Whose matter in thee is soone spent./* The idea of the brief appearance of a meteor is possibly drawn on here as well because of its fiery nature, appropriate for someone suffering from a fever.

The third item is from the Epithalamion (an epithalamion is a marriage-song) in the work titled 'Ecclogue. 1613. December 26.' (op.cit., 1985, pp. 197–208). Some manuscripts suggest this was written for the marriage of Robert Carr, Earl of Somerset, to Lady Francis Howard, who were both soon after convicted of the murder of Sir Thomas Overbury, all part of the general politico-religious intrigue of the times in England. Lines 1–4 of verse X (lines 204–207 of the whole poem; (op. cit., 1985, p. 207)) contain the meteoric aspects, which concern a landed falling star that is discovered as a jelly on the ground. (Beech, 1993c) and the subsequent letters to WGN (21:5 (1993) p. 225 and 22:2 (1994) p. 28) discussed the subject of meteoric fungi and jellies like this in some detail. To the references in those items we must add the very detailed discussion regarding such star-jelly given by (Belcher & Swale, 1984). We should also comment that no folklore concerning the possible association between the Earthstar (*Geaster*) fungi and meteors has been discovered by us, following on from the discussions in the WGN correspondence seeking anyone with information concerning such.

3 'Letters to Severall Personages'

A pair of Donne's letters in verse are entitled respectively 'The Storme' and 'The Calme'. They derive from events experienced by him while serving as a volunteer in the naval expedition to the Azores in 1597, when 60 English ships attempted to intercept a Spanish fleet carrying silver from the Americas. The English fleet was badly damaged and scattered by a storm, and then becalmed for several days. The first verse-letter is addressed to one of Donne's closest friends, Christopher Brooke, a lawyer and occasional poet, who was imprisoned in 1602 after serving as Donne's best man at his clandestine marriage to his employer's niece, Anne More, the previous year. It is likely 'The Calme', where our meteoric quote comes from, was also intended for Christopher Brooke.

Lines 19–24 of 'The Calme' run (Patrides, 1985, pp. 254–255): *Earths hollownesses, which the worlds lungs are,/ Have no more winde then the upper valt of aire./ We can nor lost friends, nor sought foes recover,/ But meteorlike, save that we move not, hover,/ Onely the Calenture together drawes/ Deare friends, which meet dead in great fishes jawes:/*

Some explanation is needed for these lines. A popular belief was that winds were caused by the Earth 'breathing', and that caves acted somewhat like lungs (this probably derives from readings of Greek and Roman authors and mythology), while the 'upper vault' of the air high above the surface and the clouds, was thought utterly calm. So the ships, without wind to power their sails, were also still, and hung like immobile meteors. Meteors at the time, again following the ancient authors, were believed to be vapours risen high into the air, invisible until they were ignited in their brief moment of glory. By Donne's day, the wisdom of this concept was finally being questioned, which seems to be implied by his slightly ambiguous comment. More on all these meteoric vapour ideas, including how things were beginning to change by the late 16th to early 17th centuries, can be found in (Beech, 1993a, b and c). The 'lost friends' line refers to the ships scattered by the storm, while 'Calenture' was the name for a tropical delirium causing sailors to leap to their deaths in the sea.

This uncertainty about what meteors were is found again in our next example, again from a verse-letter, this time to Lucy, Countess of Bedford, one of the leading social and intellectual figures of the period, patron of many important poets of the day, and a poet herself. She greatly favoured Donne, and was godmother to his second daughter (also Lucy, his fifth child; born 1608, died 1627, the same year as the Countess). Donne wrote more of his verse-letters to her than anyone else.

Our quoted verse comes from 'To the Countesse of Bedford. On New-yeares day', lines 1–5 (Patrides, 1985, p. 277): *The twilight of two yeares, nor past nor next,/ Some embleme is of mee, or I of this,/ Who Meteor-like, of stuffe and forme perplext,/ Whose* what*, and* where*, in disputation is,/ If I should call mee* any thing*, should misse./*

Donne is referring here to the in-between night, where one year changes to the next, in a way part of both, and yet outside either. In choosing this brief meteoric simile, we can see better what he is driving at. The event is meteorically short-lived. In a way, it is gone in an instant as midnight passes, yet it is something beyond ordinary life, as meteors are far beyond humans' ability to physically examine them. The changeover point is as difficult to comprehend at a philosophical level as meteors are at a physical one. 'Perplext' here is taken by Patrides' notes to mean only 'confusedly intermixed', which draws on the meteoric vapour concept, but it is clear from the following lines that it is more the nature of both the new-year moment and what meteors are that is actually not certain. Unfortunately, which new year he is referring to is not known, although it must be in the early 17th century.

4 'The Anniversaries'

Donne's two 'Anniversaries' are among the longest works published during his lifetime. 'The First Anniversarie' was published in 1611 as 'An Anatomy of the World'. It was reprinted retitled in 1612, with another long poem 'The Second Anniversarie', subtitled 'Of the Progress of the Soule'. The 'Anniversaries' commemorate the death of a 14-year old girl, Elizabeth Drury, who died in 1610. Donne never met her, and seems to have become friends with her wealthy parents only after 'The First Anniversarie' was published. The poems describe the transformation of the young girl into an idealized concept, of, as Donne put it ('First Anniversarie', lines 227–228, (Patrides, 1985, p. 336)): *Shee that was best, and first originall/ Of all faire copies.*

Given the nature and subject of both poems, it is not surprising that they contain substantial amounts of astronomical and astrological material. As poetry on the nature of death by a master of death-related poems, they still retain surprising relevance and power today. As usual in these articles, we would encourage all who are interested to read the full texts of what we merely give extracts from.

'The First Anniversarie', lines 387–388 (op. cit., 1985, p. 342): *Th'Ayre showes such Meteors, as none can see,/ Not onely what they meane, but what they bee./*

Again, we have some uncertainty over what meteors are (taking 'see' in line 387 as meaning 'understand', as well as implying the meteor-vapours are present, but invisible, until ignited). Patrides (ibid., note to line 387) comments simply that 'Meteors' here refers to both atmospheric phenomena and comets, both of which he suggests were believed to portend disaster. However, this does not fit with what Donne says here or elsewhere. For example, one of Donne's verse-letters to the Countess of Huntingdon describes comets as *Wonders, because they'are rare* (line 6 of (op. cit., 1985, p. 280); 'they'are' uses Patrides' notation for showing the words separated by the " ' " are intended to be pronounced with almost no gap between), and casts them in a very positive light. He does not seem to view comets and meteors as the same things at all, while the text of this section of the 'Anniversarie' concerns things not understood or misinterpreted by mankind, not of things which foretell ill-fortune.

'The Second Anniversarie', lines 185–196 (op. cit., 1985, pp. 358–359), is part of a section of the poem dealing with the young girl's soul having been liberated by her death:

> And thinke this slow-pac′d soule, which late did cleave,
> To′a body,′and went by the bodies leave,
> Twenty, perchance, or thirty mile a day,
> Dispatches in a minute all the way,
> Twixt Heaven, and Earth: shee staies not in the Ayre,
> To looke what Meteors there themselves prepare;
> Shee carries no desire to know, nor sense,
> Whether th′Ayrs middle Region be intense,
> For th′Element of fire, shee doth not know,
> Whether shee past by such a place or no;
> She baits not at the Moone, nor cares to trie,
> Whether in that new world, men live, and die.

Patrides refers back in his notes to the above-mentioned comment concerning meteors in this section too, but once more this is most unhelpful. Now Donne is simply using meteors as indicating a level in the high atmosphere, as shown by his references to the 'intense' (= denser) middle atmosphere, from Aristotelian thought believed to be the region of fire. Meteors are not used here to indicate the great speed Donne imagined possible for the soul freed of its mortal substance, to compare with the typical plodding earthly rate of 20–30 miles (30–50 km) a day. Instead he is referring back to the Aristotelian doctrine of meteoric vapours collecting in the atmosphere, awaiting a chance to ignite once sufficient are concentrated in one place.

Although not strictly relevant to meteors, we have included the lines about the girl's soul not pausing ('baits' = pauses) at the Moon, and the question about whether men existed on 'that new world', as a reminder that it was only in 1610, two years before this poem was published, that Galilei had reported his telescopic observations of the heavens. Educated people of the time were still coming to terms with the idea the Moon was a solid body, probably like the Earth, with all the obvious questions about whether it was inhabited, and if so, by what creatures.

5 'Metempsycosis'

Our final meteoric dip into Donne's poems comes from another of his long works, 'Infinitati Sacrum. 16. August 1601. Metempsycosis. Poêma Satyricon' ('Sacred to Infinity. 16 August, 1601. The Transmigration of the Soul. A Satiric Poem'). Various commentators have tried to discuss it in as many ways. We prefer to say it has epic qualities, and is not complete in its surviving form, probably because Donne left it so, though whether by accident or design is unknown. Beyond this we will not be drawn!

The meteor quote is from verse XVIII of the section titled 'The Progresse of the Soule. First Song', although as this heading includes the entire extant poem excepting the opening short 'Epistle', this is of scant importance. The title certainly suggests Donne originally intended the work to be substantially longer, given that the 'First Song' runs to 52 verses, a total of 520 lines. The opening two lines of verse XVIII (lines 171–172 of the whole poem; (Patrides, 1985, p. 412)) are: *To an unfetterd soules quick nimble haste/ Are falling stars, and hearts thoughts, but slow pac′d.* And so at last we see Donne using meteors as indicators of great speed, although here as still far below what we might consider 'soular' velocity!

6 Conclusion

Donne's references to meteors in his work were never more than passingly minor. Despite this, he still managed to involve a surprising variety of uses, reflecting the meteoric beliefs, and the beginnings of changing beliefs, of his time. Perhaps most interestingly, he only seems to use 'meteor' in the sense we would modernly recognise.

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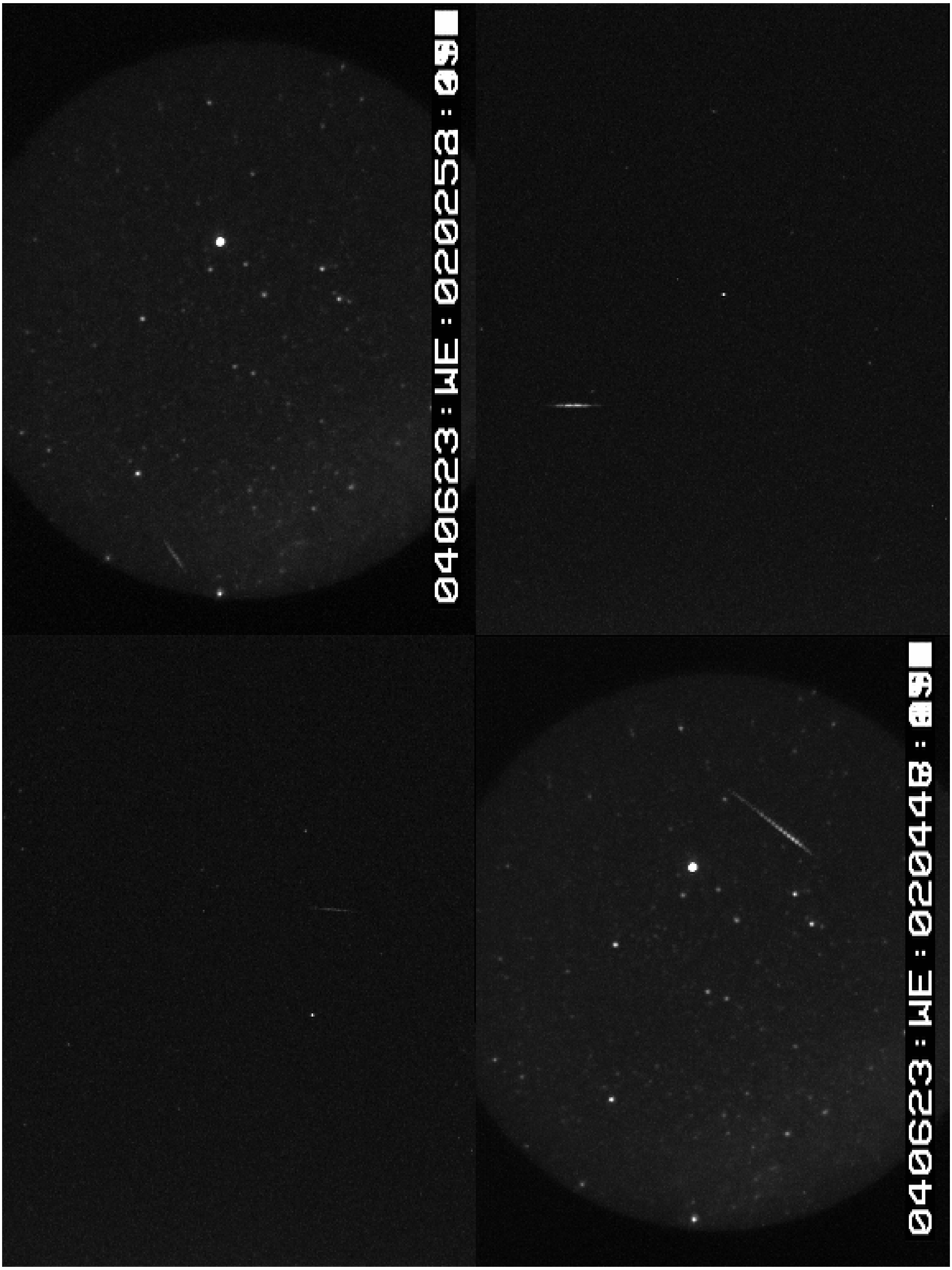

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