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Front cover photo

Fireball of 2009 November 22 recorded by the Armagh Observatory's Polar Bear Survey Telescope at approximately 00^h57^m UT. The Telescope employs a Nikkor 85-mm $f/1.4$ lens stopped to $f/1.8$ and a CCD camera. Thirty-second exposure was used to obtain this image. Note the fine 'feathery' structure in the image in the transverse direction, caused by the meteoric 'smoke' being buffeted by high-altitude winds at the height (~80 km) of the fireball. Image credit Simon Jeffery.

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

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Editorial

Javor Kac

Big meteor events, such as major shower maxima or outbursts of activity, require careful planning to be captured in their full glory.

Many times, the observability of an outburst or a short-duration shower is limited to a narrow strip of the Earth's surface. Such was the case, for example, for the numerous Leonid outbursts at the turn of the millennium. Thanks to the highly accurate timing predictions made by a variety of researchers modeling this shower, a large number of observers were given an opportunity to be at the right spot at the right time. Such expeditions could not be done without reliable predictions. In return, the observers helped researchers refine their model to make even better predictions in the future.

On other occasions, the observer may just not live in the right place to be able to comfortably observe a particular shower. This happens, for example, for any observer living north of 50° and trying to observe the Southern δ-Aquariids. The only way to fully enjoy this shower is to move significantly south. Knowing the date of the maximum is helpful here as well, so as not to miss it.

Finally, the weather often does not co-operate during the major meteor showers. In my experience, the major showers notoriously connected with bad weather are the Autumn and Winter showers – the Leonids and Geminids. In these cases, the observer is tempted to travel significant distances to enjoy the shower under clear skies. Basic shower data, like the radiant rising time, the time of expected elevated activity, and other data are helpful to plan such short expeditions.

Shower Calendar 2011

To help readers plan their meteor observing well in the future, the IMO Meteor Shower Calendar 2011 is included with this issue.

I trust the Calendar will again prove to be the reliable source of information about the accessible meteor showers for meteor observers throughout the world.

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Douglas Orson ReVelle (1945 – 2010)

Peter Brown

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On May 2, 2010 one of the leading meteor scientists in the world, Douglas ReVelle, passed away in Albuquerque, New Mexico. Doug was trained as an atmospheric scientist at the University of Michigan in the late 1960s and early 1970s. Doug's early research interest was very interdisciplinary and focused on problems of meteor entry and the response of the atmosphere to fireballs. This interest led him to work in both the aerospace engineering group at the University of Michigan in addition to his home department of Atmospheric, Ocean and Space Sciences. As a result of his broad interests, his approach to meteor entry modeling had a strong grounding in hypersonic aerodynamics as well as an appreciation for the role of the atmosphere in this complex problem. It was at this time that Doug developed a passionate interest in meteors, a passion he retained for the rest of his life. His doctoral thesis, entitled "Acoustics of Meteors", reflected this passion and laid the modern foundations for interpretation and analysis of infrasound from meteors.

Doug's early research career as a post doctoral fellow at the Herzberg Institute of Astrophysics (HIA) in Canada working at the Springhill meteor observatory and later at the Carnegie Institution in Washington largely focused on meteoroid entry modeling and bolide kinematics. His work in this era was largely devoted to development of models of meteoroid entry using the three meteorites which at the time had instrumental records of their fall (Příbram, Lost City and Innisfree) as calibration events. He also began development of an analytical energetics-based theory of meteoroid entry (which he would continue to refine for the next three decades) which predicted heat, radiation, ionization, dissociation and acoustic production during meteoroid entry. Later, a variation of this model would evolve to incorporate triggered progressive fragmentation for fireballs and explicitly allow for porosity variations between different meteoroids, a physical factor he felt was often overlooked or un-

Figure 1 – Douglas Orson ReVelle

deremphasized in meteoroid entry models. While at the HIA, Doug also had the opportunity to get to know the institute's namesake (Gerhard Herzberg – 1971 Nobel prize winner in Chemistry) and discuss common topics of interest, such as meteor spectroscopy.

Doug's career path led him to teaching at Northern Arizona University and later at Northern Illinois University during the 1980s and early 1990s. Doug taught thousands of students over more than a decade in areas as diverse as planetary atmospheres, geoacoustics, and solar system astronomy. While he enjoyed teaching his true passion was research.

In 1994 Doug became a technical staff member in the Earth and Environmental Sciences division of the Los Alamos National Laboratory where he worked in infrasound research. He continued to actively pursue many research projects with content in both the meteor and infrasound fields. Fortunately, fireballs are a major source of impulsive atmospheric infrasound so their study in an infrasound monitoring context is well justified.

Doug often lamented that most of the time during his career meteor research had to be creatively incorporated into other projects for him to keep working in the field he loved so much. Indeed, only one time during his entire career was he funded for an extended period to explicitly pursue meteor research (1999–2000). The result of this two year "concentration" on meteor research was a flurry of more than 10 papers he authored or co-authored at the Meteoroids 2001 meeting in Kiruna, Sweden.

Doug retired from Los Alamos in February, 2010 but he continued active research until just before his death. His energy and enthusiasm for his research was infectious and he served as a mentor to many students and researchers in both the fields of meteor research and infrasound propagation. He will be greatly missed by his many colleagues and friends around the world. Doug is survived by his wife, Ann, of Los Alamos; his son David of Tucson, Arizona, and his son Peter, a student at NM Tech in Socorro, NM.

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History

Two New Letters by Denning

Martin Beech [1]

Two letters written by W. F. Denning to R. P. Greg in March and April of 1879 that had been tucked into the folds of an 1876 edition of the *British Association for the Advancement of Science* Reports were recently found at the Carnegie Institution in Washington D.C. The letters are wonderfully preserved, and offer us a snap-shot of the work being performed by a young Denning at the time when his influence in the field of meteor studies was in its ascendency. The contents of these two letters is analyzed and placed within context to Denning's other publications and private life.

Received 2010 January 25

1 Introduction

There are occasions when the postman truly delivers unexpected good news. Such an occurrence happened to me this past January when, out of the proverbial ether, I received an email from the library at the Carnegie Institution in Washington (DTM-Geophysical Laboratory Library). Found, hidden for over a century, between the pages of a copy of the 1876 *British Association for the Advancement of Science* (BAAS) Report were two letters written by the doyen of British meteor astronomy, William F. Denning (Beech, 1998).

The librarian, Shaun Hardy, was concerned that the letters find a safe home, although pressed between the pages of the volume in which they were found seems to have held them safe for a very long time: the library was founded in 1902 and the BAAS Reports were purchased at around that time. Following an exchange of further emails the letters are now with me at Campion College, where, hopefully, they will remain safe for many years yet to come.

2 Denning's correspondence

Although it is known that Denning pursued a vigorous correspondence with many of his contemporaries, very few of his letters have actually survived (Beech, 1991a). Indeed, little of Denning's original writings and observational records have survived to the modern era. Figure 1 provides a time-line overview of the works that have survived.

The recently discovered letters date to a March 26 [1879?] and April 3, 1879. Certainly one of the letters (that of March 26) was written to Robert P. Greg, but bears no year indication—there seems little doubt, however, from the topic of the two letters, that they are contemporaneous, and, accordingly, it is taken as being written in 1879. The second letter was almost certainly written to Greg as well, but has lost its final fold and is technically, therefore, missing the name of its intended recipient.

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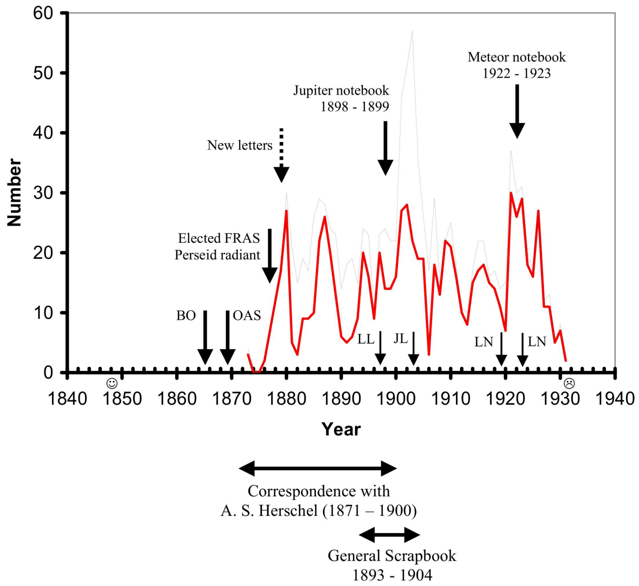


Figure 1 – Time-line for Denning's formal publications within the scientific literature. The thick line corresponds to meteor publications and observing notes, while the thin line is his total number of publications per year. Vertical and horizontal arrows indicate various key events and/or dates relating to the coverage of extant notebooks, journals and scrapbook. The following symbols have been used: ☺= birth, November 25th, 1848, ☹= death, June 9th, 1931; BO = the year in which Denning claims he began his astronomical work; OAS = founding year of the Observational Astronomical Society, of which Denning was a prominent member and its first Treasurer and Secretary (the society folded in 1872); LL = covering letter to the RAS librarian concerning a presentation copy of *The Great Meteoric Shower of November* on December 8th, 1897; JL = letters to T. E. R. Phillips on April 19th and May 22nd, 1903, concerning observations of Jupiter; LN = letters to his niece on November 25th, 1919 and September 4th, 1923.

The letters are both formal, concerned entirely with meteor-related observations and the analysis of data, and there is no informal discussion.

3 The first letter

The letter of March 26 (Figure 2) is written on four sides of a folded piece of good quality paper stock (dimensions 22.5 × 17.6 cm) and is primarily concerned with work relating to radiant reductions. Denning is writing from Tyndale House, in Ashley Down, Bristol (see

Table 1 – Known addresses for Denning between 1868 and the time of his death in 1931. Clearly, Denning did not lead a particularly settled life during the last decade of the 19th Century. The time spent at Tyndale House and later 44 Egerton Road—where he lived until his death—appear to be the most stable periods with respect to accommodation.

Year	Address
1868	2 Sussex Place, Ashley Road, Bristol
1872	Hollywood Lodge, Cotham Park, Bristol
1876	Tyndale House, Ashley Down, Bristol
1890	17 Berkley Road, Ashley Down, Bristol
1891	Bex Villa, Morley Square, Bishopston
1892	Shannon Court, Corn Street, Bristol
1895	102 City Road, Bristol
1896	51 Brynland Avenue, Bishopston
1898	102 City Road, Bristol
1899	51 Brynland Avenue, Bishopston
1906	44 Egerton Road, Bristol

Table 1) and begins by thanking Greg for the "several catalogues of large meteors" he has been sent. Denning explains that he will be using them in "finishing" a table of data. This study was with little doubt that published in the September 1st issue of *The Observatory* magazine (Denning, 1879b). Indeed, Denning refers to the catalogs assembled by Greg and published in the BAAS Reports for 1860 and 1867. Denning's paper is an analysis of some 3600 fireball reports gathered during the time interval 1492 to 1860 (Greg's data) and his own compilation of fireball observations up to circa 1878. Denning actually breaks down the fireball rate according to numbers seen per month of the year. To be included in his analysis, the fireballs must exceed the brightness of Jupiter, but no specific distinction is made between sporadic and shower events. August and November top the list according to fireballs per month, and much of this activity is due to the Perseid and Leonid showers, respectively.

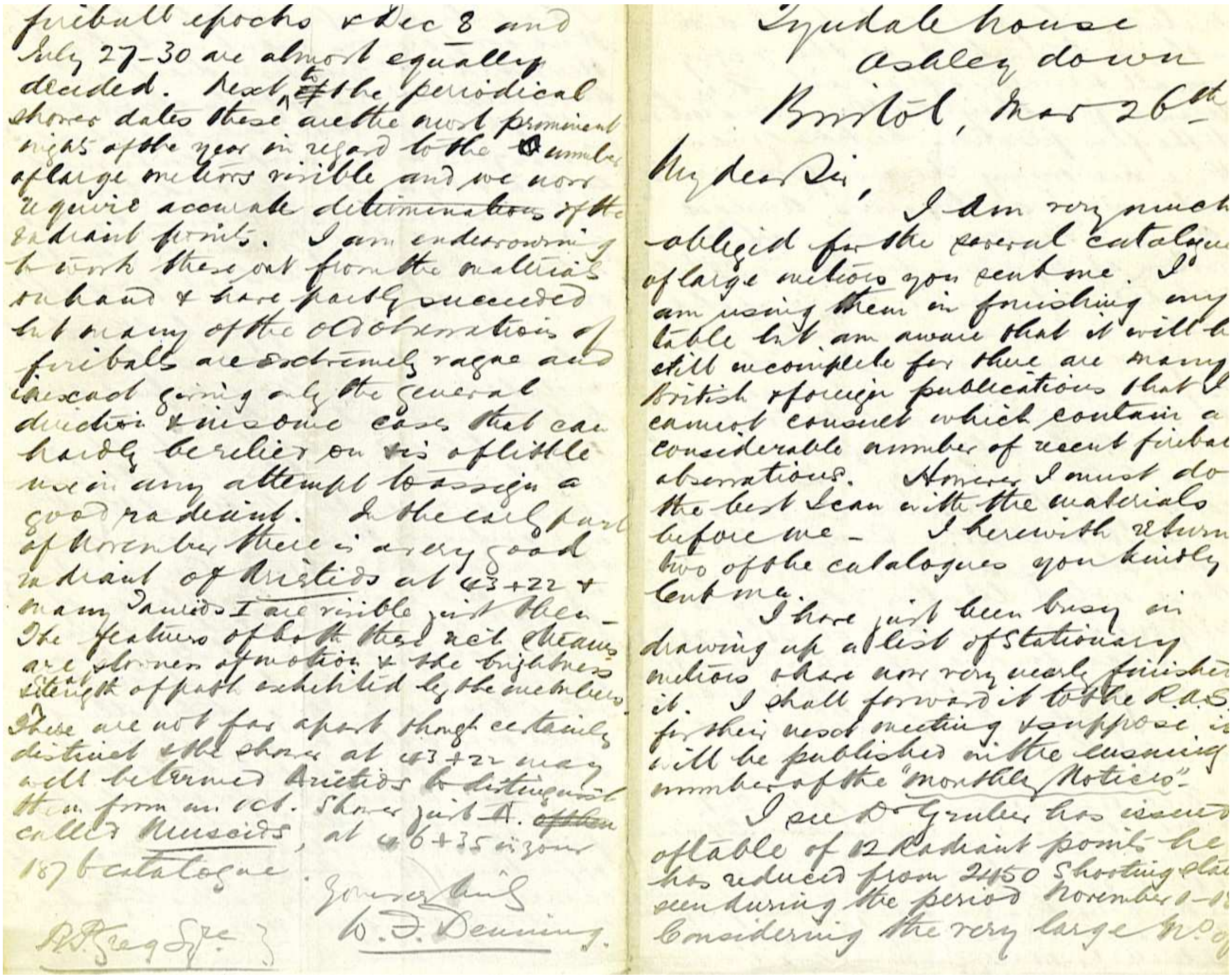
Denning continues his letter by explaining that he is in the process of finishing of a catalog of stationary meteors recorded at Bristol and which he will be sending to the *Royal Astronomical Society*. Indeed, this particular catalog was published in the May 1879 issue of the *Monthly Notices* (Denning, 1879a). He further goes on to comment on a new catalog of meteor observations by Ludwig Gruber. I have not been able to determine much about Gruber's life and works, but the NASA-Smithsonian ADS website list three papers by him for 1875, 1876, and 1877. The first paper relates to Asteroid (138) Tolosa, the second is concerned with a discussion of the orbit for the binary system η Cassiopeiae, and the third written with Ignatz Kurlander relates to Comet 1874 V = C/1874 O1. In the 1875 paper, Gruber indicates that it has been written from Leipzig, Germany, while the other two articles were apparently written from the Konkoly Observatory in Budapest, Hungary. Denning writes, "Dr. Gruber has issued a table of 12 radiant points he has deduced from 2450 shooting stars seen during the period November 1-8. Considering the very large [number] of meteors he projected I am rather astonished at the very small number of radiants he described from their paths." Denning, of course, expected to find many showers active every night of the year and would often fix a radiant from just three or four meteor paths (Beech, 1991b). Some of Gruber's radiant positions, however, agree with Denning's reductions and he provides Greg with a table of these concordances. The table is labeled "Gruber '77", and this presumably fixes the publication date of Gruber's catalog to 1877, although I have not been able to find a reference for it. Gruber is mentioned in an undated letter fragment written by Alexander S. Herschel to Denning. Herschel explains to Denning that Gruber wrote his Doctoral thesis "on the meteors of the October period a long while ago". The letters that survive between Herschel and Denning span the time interval 1871 to 1900 (Beech, 1991a). In all, 230 letters have survived but only one is extant for 1879. Posted on October 12th of that year, the small card from Herschel concerns the theoretical radiant coordinates for Coggia's comet (Comet C/1877 R1).

In addition to discussing Gruber's new radiant list in his letter, Denning also refers to "Heis's new 1877 catalogue". Eduard Heis (1806–1877) is a better-known meteor observer than Gruber, and the catalog Denning mentions relates to observations collected over the time interval from 1833 to 1875.

4 The second letter

The second letter of April 3rd begins with Denning agreeing to prepare, as must have been suggested to him in a now lost letter, a short list of the new meteor showers identified since the publication of Greg's list in the 1876 BAAS Report. This, indeed, appears to be exactly what Denning did in the fireball paper published in September of 1879 (Denning, 1879b). Denning actually explains in his letter that he will use, "the recent observations of Corder, Sawyer and myself and the new positions by Dr. Heis in his extensive 1877 list". These observers are Henry Corder, who lived at that time near Chelmsford in England, Edwin F. Sawyer, who lived in Cambridge, Massachusetts, USA, and Eduard Heis, who at that time lived in Westphalia, Germany, and was Professor of Astronomy at the Royal Academy in the City of Münster. Corder was to become Director of the *British Astronomical Association*'s Meteor Section (1892–1899), and was a close correspondent with Denning. Edwin Sawyer was a bank clerk by day, but an avid astronomer by night. He was one of the first amateur astronomer's to concentrate on variable star observations and he also wrote a long running column for *Popular Astronomy* magazine. Sawyer's first radiant catalog was published in the June 1879 issue of the *American Journal of Science and Arts*.

Moving on from the preparations of the fireball catalog, Denning thanks Greg for the loan of several old BAAS Reports and comments that he is pleased to hear that Greg has recommended to [A. S.] Herschel that the BAAS print more star charts for meteor path plotting. These charts, Denning notes, are invaluable with re-



fireball epochs & Dec 8 and
July 27–30 are almost equally
decided. Next to the periodical
shower dates these are the most prominent
nights of the year in regard to the number
of large meteors visible and we now
require accurate determinations of the
radiant points. I am endeavouring
to work these out from the materials
on hand & have partly succeeded
but many of the old observations of
fireballs are extremely vague and
inexact giving only the general
direction & in some cases that can
hardly be relied on & is of little
use in any attempt to assign a
good radiant. In the early part
of November there is a very good
radiant of Arietids at 43+22 &
many Taurids I are visible just then.
The features of both these rich streams
are slowness of motion & the brightness
strength of path exhibited by the members.
These are not far apart though certainly
distinct & the shower at 43+22 may
well be termed Arietids to distinguish
them from an Oct. shower just A. ~~often~~
called Muscids, at 46+35 in your
1876 catalogue.

Yours truly
W. F. Denning.

R. P. Greg Esq.

Tyndale house
Ashley down
Bristol, Mar 26th

My dear Sir,
I am very much
obliged for the several catalogues
of large meteors you sent me. I
am using them in finishing my
table but am aware that it will be
still incomplete for there are many
British & foreign publications that I
cannot consult which contain a
considerable number of recent fireball
observations. However I must do
the best I can with the materials
before me – I herewith return
two of the catalogues you kindly
lent me.
I have just been busy in
drawing up a list of stationary
meteors & have now very nearly finished
it. I shall forward it to the R.A.S.
for their next meeting & suppose it
will be published in the ensuing
number of the "Monthly Notices".
I see Dr Gruber has issued
a table of 12 Radiant points he
has reduced from 2450 shooting stars
seen during the period November 1–1[illegible]
Considering the very large No of

Figure 2 – The first and last pages of the March 26th, [1879] letter to R. P. Greg.

spect to radiant reductions. The final discussion of the letter relates to some recent work: "I have just been projecting a large number of meteors for April 11-12 in order to find the chief showers". Denning goes on to suggest that at least four showers are active and that, "after this Moon is gone I hope to make in conjunction with Mr. Corder a special effort to observe these several showers". The radiants that Denning reported in his letter were published in the May 1879 issue of *The Observatory* magazine (Denning, 1879c). In this latter paper, Denning explains that the new radiants were derived by projecting more than 700 meteors recorded by Giuseppe Zezioli (in Bergamo, Italy) during the years 1867 through to 1872.

5 Conclusion

So, what do we learn from the discovery of these new letters? Certainly, they suggest that Denning and Greg enjoyed a detailed correspondence beyond that of the all ready known correspondence between Denning and Herschel. Robert Greg (1826–1906) was an independently wealthy amateur astronomer, a Justice of the Peace for Hertfordshire, and ardent collector of minerals and a pioneer researcher on meteorites and meteor showers. Greg was an influential member of the BAAS Luminous Meteor Section (LMS), and it appears to be because of this connection that the correspondence with Denning was continued. Denning certainly submitted regular reports on his meteor observations to the LMS.

Alexander S. Herschel was also a prominent member of the LMS, but we know from his surviving letters (Beech, 1991a) to Denning that towards the end of 1874 something happened to sour their "working" relationship, and, indeed, Herschel returned all of Denning's reports and commented, "I will take no further concern of your observations, ... You will of course not expect a copy of the Report of last year. That for this year contains few signs of your observations in it yet, and it is not likely to have any traces of them, now, when it is published". Whatever happened in 1874, Denning continued to observe meteors, and we find Greg communicating a list of his radiant points to the *Royal Astronomical Society* in 1876. In addition, a letter dated August 30th, 1876, also survives, in which Greg comments to A. S. Herschel that "Denning's last list of (46) radiants was very good as to the places that he assigned...". Greg, it would seem, was an important figure in promoting Denning's early meteor work to "establishment" astronomers, and he perhaps "smoothed" the way towards re-establishing communications between Denning and Hershel (the main bulk of the surviving correspondence between the two observers being from 1889 to 1900, Beech, 1991a). Denning was elected a *Fellow of the Royal Astronomical Society* in 1877 (after failing to be elected on his first attempt in 1872). It was also in 1877 that Denning published his most important early research paper on the daily radiant drift of the Perseid meteor shower.

Greg clearly supported the publication of Denning's observational work in the *Monthly Notices of the Royal Astronomical Society*, and Denning both asked for advice and agreed to follow suggestions made by Greg. Indeed, we find Denning being the willing "work-horse" to prepare tables and sort through observational data derived by other astronomers. We also discover a detailed dialog between the two correspondents concerning the location of meteor radiant points. It has long been clear that Denning was a prolific correspondent (Beech, 1998), but the new letters are the very first to surface in which he actually discusses his meteor work. The letters are also the earliest dated letters of Denning's to, so far, be found. Sadly, the letters reveal nothing new about Denning himself, and he continues to remain a somewhat distant figure (Beech, 1990), but, importantly, they do offer a brief glimpse into the life of a dedicated 31 year old man at the very moment of his ascendancy towards becoming Britain's most recognized, and later celebrated, meteor astronomers.

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Handling Editor: Marc Gyssens

Meteors in Australian Aboriginal Dreamings

Duane W. Hamacher[1] *and Ray P. Norris*[2]

We present a comprehensive analysis of Australian Aboriginal accounts of meteors. The data used were taken from anthropological and ethnographic literature describing oral traditions, ceremonies, and Dreamings of 97 Aboriginal groups representing all states of modern Australia. This revealed common themes in the way meteors were viewed between Aboriginal groups, focusing on supernatural events, death, omens, and war. The presence of such themes around Australia was probably due to the unpredictable nature of meteors in an otherwise well-ordered cosmos.

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Going straight through the middle of Poojoorroona Gap
Tjidara is alight
Flashing like a meteor [a]

[a] A poem about *Tjidara*, a long legged goanna that became a star, who played an important role in the Dreamings of the Aboriginal people of Uaroo Station, Western Australia (Von Brandenstein & Thomas 1974, p. 3).

1 Introduction

The history of meteoritics as a scientific discipline has been studied extensively (e.g. McCall et al, 2006), and has incorporated the observations and records of meteoritic phenomena by various cultures around the world (e.g. Burke, 1986; Zanda & Rotaru, 2001). These phenomena have been studied more extensively recently as researchers have gained a better understanding of the frequency and potentially hazardous effects of cosmic impacts (e.g. Melosh, 1989; Gehrels, 1994; Lewis, 1999). While this attention has served to funnel more research into the scientific study of meteoritics, it has focused little on the cultural and anthropological study of meteoritics.

We define Cultural Meteoritics as the study of the influence of meteoritic phenomena and material (including comets, meteors, meteorites, tektites, and cosmic impacts) on society. This includes human interaction with such meteoritic materials, and the role of meteoritic phenomena in art, religion, music, ritual, and mythology. While some researchers have addressed this topic (e.g. Brown, 1975; Bevan & Bindon, 1996; Hughes, 1989; Bobrowsky & Rickman, 2007), the Meteor Beliefs Project (MBP), sponsored by IMO, is the first large-scale study of Cultural Meteoritics.

A majority of the MBP to date has focused on European views of meteors. In order to fill a gap in the literature, we present the first comprehensive study of the perceptions and descriptions of meteors by Aboriginal Australians. Previously, Baker (1957) and Edwards (1966) detailed the use of australites (Australian tektites) in Aboriginal cultures, while Bevan & Bindon (1996) were the first to address the Aboriginal use and transport of meteorites. Papers on Aboriginal views of comets, and meteorite falls and cosmic impacts, can be found respectively in Hamacher & Norris (2010a & 2010b). Norris & Hamacher (2009) reviewed the wider astronomical themes of Australian Aboriginal cultures.

Within the context of this paper, the term 'mythology' is used to refer to a body of stories owned by a particular culture, often invoking the supernatural to explain the nature of the universe and humanity. Such usage does not imply that the beliefs are untrue.

While we use data from many Aboriginal groups across Australia, we do not include data from the Torres Strait Islanders, who are of Melanesian extraction and are distinctly different from Aboriginal Australians (cf. Davis, 2004). Torres Strait Islander views of meteors will be the subject of a future paper.

We note for Aboriginal readers that this paper gives the names of, or references to, Aboriginal people that have passed away, and to information that may be considered sacred to some groups. It also contains information published in "Nomads of the Australian Desert" by Charles P. Mountford (1976), which was banned from sale in the Northern Territory in 1976 as it contained sacred/secret knowledge of the Pitjantjatjara (cf. Brown, 2004, pp. 33–35). No information about the Pitjantjatjara from Mountford's book is presented in this paper.

2 Meteoric Terminology

In general, we use the standard definitions for words such as 'meteor', 'fireball' and 'meteorite' in the following (those needing more information should see for instance Rendtel & Arlt (2008)). However, we also use the term 'bolide', which has no official IAU definition, and which has various meanings in the literature, to refer to an exploding or audible meteor. By 'audible', we mean both acoustic (delayed) and electrophonic (simultaneous) meteor sounds, both of which have been noted by different Aboriginal groups. These sounds are often an important component of the story or account, and bolides are so significant that some Aboriginal groups have separate words for them, including the Djaru *gulungurru* (Goldsmith, 2000, p. 32) and Mycoolon *goonbor* (Palmer, 1884, p. 294).

We must also note that, as with some cultures discussed in earlier MBP papers, comets and meteors can be conflated. In some Australian Aboriginal languages, the words for 'comet' and 'meteor' are reported to be the same, such as *nilgoolerburda*, in the Bindel lan-

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guage of northern Queensland (Morrill, 1864, p. 61) and *binnar* in a Western Australian language (Moore, 1842, pp. 126 & 145). In some cases, the description of one may indicate the other. For example, the Yolngu word for meteor, *ngarrpiya*, is also the word for octopus (Lowe, 2004, p. 116). An octopus moving through the water at speed could resemble a meteor (bulbous head leading, trailing tentacles streamlined like a meteor's tail), while some brilliant, usually fragmenting, fireballs can show a multi-tailed nature, sometimes looking briefly quite like a comet, but the simile could equally have indicated a comparison with a multi-tailed comet. It may also have resulted from the linguist or anthropologist confusing the two phenomena. Tindale (1983, p. 376) categorized comets and fireballs together, for example, despite them being different phenomena, though he only discussed the former. Haynes (2000, p. 86) described comets as flaming spears hurled across the heavens by a celestial Pitjantjatjara being named *Wurluru*, something that seems far more meteoric than cometary. To some Arrernte clans, a comet was a sign that a person in a neighboring community had died, with the tail pointing in the direction of the deceased (Spencer & Gillen, 1899, p. 549). A nearly identical description is given by Piddington (1932, p. 394) about the Karadjeri of coastal Western Australia, but attributed to the trajectory of meteors instead of the tails of comets.

We provide 59 Aboriginal words for meteors in Table 1, representing 50 Aboriginal groups from all states of Australia (some groups have more than one word for meteors).

3 Aboriginal Cultures

From approximately 70 000 to 15 000 years before present (BP), the sea level was much lower than it is today (Voris, 2000). During this period, Tasmania, Australia, and New Guinea were a single landmass, called Sahul. While archaeological evidence indicates that humans migrated to Sahul in multiple waves from South East Asia, genetic evidence reveals that current Aboriginal Australians share a common genetic thread with people from southern India, as opposed to Indonesia or Malaysia (Redd & Stoneking, 1999). The exact date of human arrival to Sahul is uncertain, but archaeological evidence indicates that Australia has been inhabited for at least the last 40 000 years (O'Connell & Allen, 2004). Claims for an arrival date before 50 000 years BP are based on uncertain, often disputed, evidence, but because they have survived into the present, even the 40 000 years' BP date makes Australian Aboriginal cultures the oldest continuous cultures in the world (cf. McNiven & Russell 2005, pp. 205–208).

Before the European colonization of Australia, between 350 and 750 distinct Aboriginal groups have been estimated as extant (Walsh, 1991), each with its own distinct language, customs, laws, religious practices and mythology. While adjacent groups often had a similar language and culture, others were very different. Each language group then, as now, was further divided into dialects, clans and smaller units. Laws and traditions varied, and still vary, between Aboriginal communities, even those of the same language group. For this reason, it is not possible to ask for the 'Aboriginal name of a meteor' or to describe the 'Aboriginal story of a falling star'. While some common themes exist across many Aboriginal groups, such as the concept of the Dreaming, each community sees them differently. For this reason, each reference to a particular Aboriginal story, ethnography, or word in this paper includes the name and location of the Aboriginal group from which it was reported.

'The Dreaming', an English term coined by Francis Gillen in 1896, was adopted by Spencer & Gillen (1899) to refer to a period in the religious mythologies of the Northern Arunta people in the Northern Territory (Dean, 1996). This term is frequently misinterpreted, as it has nothing to do with dreaming in the context of sleep. According to Dean (1996), the Dreaming is viewed by some Aboriginal groups (e.g. the Tiwi and Wuradjeri) as the period during the creation of the world when totemic ancestors came into being, representing a past reality. For other groups, it represents a past, current and future reality, either concurrently parallel to our own reality (e.g. the Ooldea and Warrabri), or within our own reality (e.g. the Murinbata and Mardudjara). In some cases, such as during ritual ceremonies, the past can become the present, so the term 'Dreamtime' used in an all-encompassing sense is not accurate, as it denotes a linear timeline, separating past, present, and future. While oral traditions are a component of the Dreaming, they cannot be thought of purely as mythology. In a general sense, the 'Dreaming' is the embodiment of Aboriginal culture, which includes the songs, stories, and oral traditions, dance, art and ceremonial practices, laws and traditions, magical practices and religion, and a complex social structure. Traditional knowledge is handed down primarily through oral tradition and typically involves a moral charter. Much of this knowledge is considered sacred and secret and is not shared with non-Aboriginal people. Even within the community, some information is secret to men, some is secret to women, and some is secret only to initiated individuals. This is all part of a complex social structure that has been an integral aspect of Aboriginal cultures for tens of thousands of years (cf. Ross, 1986).

As part of the community, people are born into particular 'totems'. A totem may be represented by almost any physical object, for example, an animal, a geographic feature or a celestial phenomenon. In some communities, the totem can be the 'star' or 'falling star', and we have drawn attention to a few specific cases where such Aboriginal totems seem to have meteoric relevance.

4 Methods and Data Collection

We have reviewed the available literature for any references meteoritic phenomena (including 'falling' or 'shooting' stars) in the Aboriginal cultures. These sources included ethnographic and historical data, Dreaming stories and songs, anecdotes, and archaeolog-

Table 1 – Aboriginal terms for 'meteor', alphabetized by group name. The state abbreviations are: NSW = New South Wales, NT = Northern Territory, QLD = Queensland, SA = South Australia, TAS = Tasmania, VIC = Victoria, WA = Western Australia.

Group or [area]	State	Word	Reference
Arunta	NT	ulthana	Spencer & Gillen (1927, pp. 415–417)
Awabakal	NSW	Puttikan	Gunson (1974, p. 50)
Badaya/Gurudara	NT	Nyimibili	Berndt & Berndt (1989, pp. 25–27)
Bayungu	WA	gurilyanu	Burgman (2007, p. 39)
Boorong	VIC	Porkelongtoute	Stanbridge (1857, p. 140)
Bundjalung	NSW	yuaroam	Ryan (1963, p. 46)
Burarra-Gun-Nartpa	NT	an-marlpa, nomararta	Glasgow (1994, p. 815)
[Cape York]	QLD	titurie udzurra	Moore (1979, p. 156)
Danggali/Barundji	NSW	purli ngaangkalitji	Jones (1989, p. 41)
Dieri	SA	Yaola	Elkin (1937, p. 289)
Djaru	WA	gulungurru	Goldsmith (2000, p. 32)
Djirbalngan	QLD	chiko-binna	Roth (1984, p. 8)
Eora	NSW	duruga	Thieberger & McGregor (1983, p. 4.8)
Gamiliaraay	NSW	mirii yanan	Ash et al (2003, p. 202)
Goulburn	NSW	Goorbenee turt	Smyth (1878, p. 116)
Gunditjmarra/Moporr	VIC	gnummae waar	Dawson (1881, p. 101)
Gumbaynggirr	NSW	gumugan	Morelli (2008, p. 160)
Gunwinggu	NT	jarijaning	Elkin et al (1950/51, p. 258)
Jajowerong	VIC	Yalleenillong	Smyth (1878, p. 162)
Kayardild	QLD	burwaduwuru	Evans (1992, p. 196)
Kokatha	SA	Wonambi	Harney & Elkin (1949, p. 130)
Kuku-Yalangi	QLD	binyu	Oates (1993, pp. 78–79)
Kuku-Yalangi	QLD	Gi-we	Roth (1984, p. 8)
Kunwinjku	NT	Namorrorddo	Taylor (1996, pp. 189–190)
Lardil	QLD	kuwa thungal	McNight (2005, p. 209)
Lardil	QLD	Thuwathu	Roughsey (1971, p. 26)
Mara	NT	Tjan-wangu-wangu	Spencer & Gillen (1904, pp. 627–628)
Marduthunira	WA	Tjidara	Von Brandenstein & Thomas (1974, pp. 3 & 57)
Martu/Wangka	WA	mayla	Burgman (2005, p. 47)
Mycoolon	QLD	Goonbor (bolide)	Palmer (1884, p. 294)
Mycoolon	QLD	Jinbabora (meteor)	Palmer (1884, p. 294)
Narrunga	SA	wajaga	Black (1920, p. 89)
Ngalia	WA	Walanari	Mountford (1976, p. 457)
Ngarrindjeri	SA	Kulda	Tindale (1983, pp. 374–375)
Plangermairreenner	TAS	Puggareetya	Noonuccal (1990, pp. 115–119)
[Southern Tasmania]	TAS	Pachareah	Milligan (1866, p. 426)
Tanganekald	SA	Kuldalai/Kudai	Tindale (1983, pp. 374–375)
Tiwi	NT	Nimparipari	Berndt & Berndt (1974, p. 81)
Tiwi	NT	Papinjuwari	Mountford (1958, pp. 144–146)
Turrbal (Jagara)	QLD	Kundri	Howitt (1996, p. 429)
Wardaman	NT	Utdjungon	Harney & Elkin (1949, pp. 29–31)
Wardaman	NT	Wuja	Cairns & Harney (2003, p. 65)
Wathi-Wathi	VIC	Tha-tha-puli	Cameron (1885, p. 365)
Weilan	NSW	Gambil Gambil	McKay (2001, pp. 112–114)
Wembawemba	VIC	payika-turt	Thieberger & McGregor (1983, p. 6.8)
[Western Desert]	WA	Wuuna	Tindale (1983, pp. 376–377)
Wik-Mungkan	QLD	Pach-aw (story place)	Hercus et al (2002, p. 77)
Wik-Mungkan	QLD	patja	McConnel (1930/31, p. 205)
Wiradjeri	NSW	girralang buundinya	Thieberger & McGregor (1983, p. 5.8)
Wiradjeri	NSW	kirela	Berndt (1947/48, pp. 78–79)
Wiradjeri	NSW	Kurikuta	Berndt (1974, p. 28)
Worora	WA	mulalai	Blundell & Woolagoodja (2005, p. 4142)
Wotjobaluk	VIC	Yerigauil	Massola (1968, p. 163)
Yarra	VIC	Elalangi	Smyth (1878, p. 103)
Yindjibarndi	WA	garuwarra	Thieberger & McGregor (1983, p. 11.8)
Yolngu	NT	maramara	Lowe (2004, p. 116)
Yolngu	NT	ngarrpiya	Lowe (2004, p. 147)
Yolngu	NT	wulurrk	Lowe (2004, p. 180)
Yupangathi	QLD	cho-i	Roth (1984, p. 8)
[Not Specified]	WA	binnar	Moore (1842, p. 145)

ical data in the form of books, magazine and journal articles, audio and video sources, reputable web-sources, master and doctoral theses. The search produced 229 original references, including 30 references to comets, 150 references to meteors, 28 references to cosmic impacts, and 21 references to known meteorite falls and impact craters. Of the data regarding only meteors, 97 Aboriginal groups were represented. Broken down by state (and using the same abbreviations as in Table 1), the percentage of stories in decreasing order was: NT 26%, QLD 19%, WA 17%, VIC 14%, SA 12%, NSW 9% and TAS 3%.

It should be noted that the accuracy of the data presented here is dominated by the interpretations and views of the authors of the sources used, and does not necessarily represent either contemporary Aboriginal views, or the majority of Aboriginal views. There are often various views found within each Aboriginal group, so statements such as 'The [Aboriginal group] see meteors as…' simply denote the Aboriginal community from which the information was taken, and do not necessarily represent the views of that entire community.

Analysis of the data revealed major themes in the perceptions of meteors, the most prominent being an association with death, spirits, or omens. Not all views were negative, however. These are broken down by theme in the following sections.

5 Meteors as Benevolent Spirits

Spirits of the Deceased: The most common association between meteors and death was that they represented spirits, either good or evil. In many cases, meteors represented the benevolent spirits of important individuals, such as with the Worora, Ngarinyin and Wunambal peoples of the Kimberleys (Blundell & Woolagoodja, 2005, p. 41) and the Euahlayi of New South Wales (Parker, 1905, p. 91), while at other times the sight of a meteor simply told the people that "an old blackfella has fallen down there" (Smyth, 1878, p. 309), a reference to the deceased man's spirit (star) falling from the sky. Meteors signifying someone had died was a view shared by the Aboriginal peoples of the Kimberleys (Kaberry, 1935/36, p. 38; Piddington, 1932, p. 394), Kuku-Yalanji of Queensland (Oates, 1993, p. 79), Dieri of South Australia (Elkin, 1937, p. 289), Kuninjku of Arnhem Land (Taylor, 1996, pp. 189–190), Kurnai of the Gippsland region of Victoria (Massola, 1968, p. 163), Wardaman of the Northern Territory (Harney, 2009) and Wik-Munkan of the Cape York Peninsula (McConnel, 1930/31, p. 183). If a meteor was seen, followed by a large crash, the Euahlayi and Narran of New South Wales believed a great medicine man had died (Parker, 1905, p. 91; Parker, 1978, p. 148). A meteor could signify the action of a spirit, such as with the Aboriginal people near the Pennefather River, Queensland who saw a falling star as the spirit of a woman pouring water over yams to help them grow (Roth, 1984, p. 8). According to the Gunditjmarra near Port Fairy, Victoria, a haunted cave was believed to connect Julia Percy Island with the mainland. When a person died, the body was wrapped in grass and buried. If grass was found at the mouth of the cave, it was proof that a benevolent spirit, called *Puit puit chepetch*, had removed the body through the cave to the island, and conveyed its spirit to the clouds. If a meteor was seen at the same time, it was believed to be fire taken up with the spirit (Dawson, 1881, pp. 51–52). When a Yerrunthully person (central Queensland) died, they climbed to the sky on a rope. When they reached the top, they dropped the rope, which was seen as a meteor. If the meteor made a booming noise (exploded), it was the sound of the rope hitting the ground (Palmer, 1884, p. 292). An audible meteor could also signify that a person had been dropped as part of a game (Palmer, 1885, p. 174).

Meteors as Flesh: Some groups believed that a deceased person's flesh could transform into a star or vice-versa. An Aboriginal group on the Lyne River in the Kimberleys believed that when a person died, their flesh became a star (Kaberry, 1935/36, pp. 38–39), while the Andedja and Yeidji peoples believed this only applied to a *Barumannari* (a medicine man or clever man). To the Yiiji of the Lyne River, when a female Barumannari died, she took her child into the sky where their flesh became a star (ibid). The Wotjobaluk of Victoria saw a meteor as the falling heart of a man that had been caught by a *Bangal* (medicine man) and deprived of his fat (Howitt, 1996, pp. 368–369). The Yir-Yoront of Cape York Peninsula believed that when a man died, his spirit became a star, with the transformation accompanied by a meteor (Sharp, 1934/35, p. 34). The Karadjeri described the night sky as a dome composed of a hard substance, such as rock or shell, with the stars representing the spirits of the dead (Piddington, 1932, p. 394). One view was that stars were nautilus shells with living fish inside them. A meteor was the dead fish dropping from its shell (ibid). Another view was that meteors represented chunks of flesh falling from a tree where the culture hero Marela was placed when he died (ibid)[1]. When a Wardaman person died, their spirit went up and passed through a hole in the sky, which was seen as the star *Garrndarin* (Spica, α Virginis). While in the sky, the spirit appeared as a star and was looked after by the Rock-Cod star *Munin* (Arcturus, α Boötis). The spirit then fell back to Earth as a shooting star, falling into a stream, where the Rock-Cod looked after it again. Eventually the spirit found its mother-to-be, and entered her, to be reincarnated as a baby (Bill Yidumduma Harney, 2009, personal communication).

Spirits Returning Home: To some Aboriginal groups, a meteor signified that the spirit of a person who died far from their home was returning to their home country, such as the Yarralin (aka Walangeri) of the Northern Territory (Rose, 1992, p. 70), Nungubuyu of Arnhem Land (Harney, 1944, pp. 74–75, 79, 163), Yintjingga of Cape York Peninsula (Montagu, 1974, p. 155), Arunta of central Australia, and Kukata and

[1] We have a Wajuk account from Perth describing the relationship between meteors and children, but have been unable to contact our informant to obtain permission to share this information.

Narrinyerri of South Australia (Basedow, 1925, p. 296). This view was not confined only to the deceased. The Yolngu of Arnhem Land saw a meteor as a message that a living relative had arrived home safely (Wells, 1964, pp. 42, 59).

6 Meteors as Malevolent Spirits

Many Aboriginal groups associated meteors with evil spirits or magic, such as the Ngarrindjeri of South Australia (Smith, 1970, p. 136). To several groups in the Northern Territory, meteors were the glowing eyes of evil spirit beings (typically serpents) that hunted for the souls of the sick and dying. These beings included the ghoulish *Papinjuwari* from the Tiwi of Bathurst and Melville Islands (Mountford, 1958, pp. 144–146), the clawed *Namorrorddo* from the Kuninjku of Arnhem Land (Taylor, 1996, pp. 189–190 — see also Figure 1 here), the one-eyed *Indada* from the Badaya and Gurudara peoples (Berndt & Berndt, 1989, pp. 25–27), and the serpentine *Thuwathu* from the Lardil of the Wellesley Islands, who called meteors *kuwa thungal*, meaning "eye thing" (McNight, 2005, p. 209). Like Thuwathu, the Luritja and Arrernte of the Central Desert viewed meteors as the fiery eyes of celestial serpents that dropped into deep waterholes (Strehlow, 1907, p. 30). Similarly, the Western and Eastern Aranda compared serpents' eyes to bright stars (Roheim, 1945, p. 183). According to the Tiwi, when time began, spirits of falling stars (probably the Papinjuwari) searched with blazing eyes for living things to devour. To hide and protect babies from the eyes of evil meteor spirits, an old Tiwi woman named Mudungkala placed the infants in a string bag tied around her neck (Allen, 1975, p. 89).

The Boorong people of northwest Victoria saw a meteor as the evil being, *Porkelongtoute*, who would portend evil to men that had lost a front tooth (initiated men, Stanbridge, 1857, p. 140). This is in contrast to Gunson's (1974, p. 50) description from the Aboriginal people near Sugarloaf Mountain, outside Newcastle, New South Wales of an evil meteor-being named *Puttikan* that would kill and eat men that did not have a missing front tooth (non-initiated men). The Mara people told of an unfriendly celestial father-son pair called *Minungara*. If a man was sick, the son would come to Earth as a falling star to see how close the man was to death. If he was 'close-up dead', the father would come down and suck the blood of the dying man (Spencer & Gillen, 1927, p. 628). An unusual description of a malevolent meteor spirit was found among the Djirbalngan of Eastern Cape York Peninsula. The spirit, called *Jubena*, was associated with cooked eggs burnt on coals (which were seen as falling stars), and would hunt down people and tickle them to death (Dixon, 1964). If a meteor broke apart in the atmosphere, an Aboriginal community in Cape York Peninsula called it *titurie udzurra*, a spirit with lots of 'young ones', that caused great fear among those who saw it (Moore, 1979, p. 156).

Two nearly identical stories from opposite ends of the continent told how meteors represented an evil being flying across the skies. These stories came from the Weilan people of northern New South Wales (June Barker in McKay, 2001, pp. 112–114) and the Ooungyee people of the Kimberleys in Western Australia (Sawtell, 1955). Both stories described people disappearing from an Aboriginal camp near a waterhole. Upon noticing strange tracks, members of the community discovered that the missing people were victims of a shape-shifting monster who lured people to the waterhole with 'sugarbag' (honey), then dragged them under the water to their deaths. In the New South Wales story, the monster was female, but in the Western Australia story, it was male. In both stories, a clever man (Wirrigan in New South Wales and Jubertum in Western Australia) made a strong cord using the hair of women from the community. Upon reaching the waterhole, the clever man was offered a leg of kangaroo by the monster. The man told the monster, who appeared in the form of an Aboriginal man, that he wanted to take a nap first. The monster agreed and decided to nap as well. The clever man awoke, tied the cord to the sleeping monster, and jumped on its back. The monster woke and fought to remove the man from its back, diving into the water, turning it into the "hot soda water it is today". The man repeatedly stabbed the monster with a spear but it would not die. The monster flew into the sky with the man on his back, where they are seen today as meteors. The only difference between the stories is the name of the clever man and the gender of the monster. Additionally, in the New South Wales story, the clever man fell to Earth with a group of falling stars at Girilambone, New South Wales. The rest of the story is exactly the same, suggesting one story originated from the other. The account from the Kimberleys was recorded in the literature 46 years earlier than the New South Wales account, though it is unclear where the story was developed first. The Kimberleys story was published in a magazine 'for the Aboriginal people of New South Wales', suggesting it may have been adopted by the Weilan in that state. Given the nearly identical wording and theme of the text, we do not consider these to be independent stories.

7 Meteors and Evil Magic

Mushrooms, Meteors and Magic: According to the Arunta of the Central Desert, falling stars contained an evil magic called *Arungquilta*. Mushrooms and toadstools were believed to be fallen stars endowed with this magic. As such, they were considered taboo and their consumption was forbidden (Spencer & Gillen, 1899, p. 566; 1904, p. 627; 1927, pp. 415–417). Although this taboo was not shared by other Aboriginal groups of the Central Desert (Kalotas, 1996, p. 1), it may have stemmed from bad experiences resulting from the consumption of poisonous or hallucinogenic mushrooms common to the area, such as *Amanita phalloide*, *Paxillus involutus*, or *Psilocybe subaeruginosa*. The association of mushrooms with fallen stars is not unique to the Arunta, but is found across the globe (see Beech, 1986).[2]

[2] See also *WGN* **21:4** (1993), pp. 200–202; **21:4** (1993), p. 225; **22:2** (1994), p. 28; & **35:1** (2007), pp. 23–28 for other non-Australian examples — Project Coordinators.

Figure 1 – Namorrorddo was a malevolent spirit that manifested itself as a fiery meteor. His long claws were used to grab the souls of people and hearts of children, after which he sped across the sky as a meteor. Bark painting 'Figure with long fingers' (1960) by Arnhem Land artist Samuel Manggudja (1909–1983). Reproduced with permission, courtesy of Anthony Wallis. ©Aboriginal Artists Agency, 2009.

Protection from Evil Magic: Aboriginal peoples employed various methods to protect themselves against the evil of meteors, including throwing firesticks in the direction of the meteor's trajectory (Stanbridge, 1857, p. 140), or chanting and causing noise (Roth, 1984, p. 8). When a group of children from the Ooldea Region of western South Australia saw a meteor (which they called a *devil-devil*) they chanted *Kandanga daruarungu manangga gilbanga*, which roughly translates as 'star falling at night-time go back' (Harney & Elkin, 1949, p. 130; Berndt & Berndt, 1943/44, p. 53). A spirit called *Munpani* lived in the bush and was constantly watching over the Mara people, protecting them from the evil *Minungara* (Spencer & Gillen, 1927, p. 628). To prevent Namorrorddo from stealing the hearts of babies, they slept on their stomachs or sides when in the bush (Lewis, 2007, p. 2). If a Worora, Ngarinyin or Wunambal person saw a meteor while holding a baby, the person would kiss the baby on the forehead so the meteor-spirit would not see the infant as it flew overhead (Blundell & Woolagoodja, 2005, pp. 41–42). Aboriginal peoples of the Western Desert believed an evil sky-being named *Wuuna* would throw spears, seen as meteors, through the sky as he wandered across the heavens (Tindale, 1983, pp. 376–377). Because Wuuna hunted dingoes, epidemics spreading amongst the dogs were often blamed on the evil of Wuuna. The sight of a meteor would prompt the people to cover the animals in red ochre for protection (ibid). A special ceremony protected Tiwi initiates from the evil meteor spirit *Mabinua* (Spencer, 1928, p. 671), while only a medicine man could kill the Namorrorddo of Kuninjku lore (Lewis, 2007, p. 3). Similarly, a ceremony involving birth and circumcision wounds was used to protect Wardaman people against various forms of evil. This ceremony was connected to the Southern Cross and *Wuja*, the Wardaman word for meteors (Cairns & Harney, 2003, p. 65).

8 Meteors as Omens

Omens of Sickness and Death: The connection between meteors and evil spirits that hunted for the sick and the dead may account for the belief that meteors served as omens of sickness or death, a belief shared with the Tanganekald of South Australia (Tindale, undated), Aboriginal groups near the Bloomfield River, Queensland (Roth, 1984, p. 8), the Turrbal of Brisbane (Howitt, 1996, p. 429), Yir-Yoront (Sharp, 1934/35, p. 34), Lardil (Roughsey, 1972, p. 107), Kaurna of Adelaide (Schurmann, 1987, p. 242), and Kukatja of Western Australia (Poirier, 2005, p. 171). The Ngarrindjeri told of a being named *Kulda* who would manifest as a meteor emerging from the Southern Cross, warning the people of a disease epidemic. This led the people to shout *peika baki* meaning "death is coming" (Tindale, 1934, p. 232; Tindale, 1983, p. 375; Parker et al, 2007, p. 400). Aboriginal people of Cape York Peninsula shared a similar view (Thompson, 1933, p. 498). Tindale (1937, pp. 111–112) recorded a 'Fear Death' song associated with the appearance of Kulda, and the smallpox epidemic that followed. The meteor, supposedly a fireball as it was very bright and 'flashed' across the sky, came from the east and shot westwards towards Kangaroo Island, known by Aboriginal people of the Coorong as the 'home of the dead' (ibid).

Positive Omens: Omens associated with meteors were not always negative. In one incident, an elderly Kukatja woman fell ill and was driven to a clinic. Along the way, a bright meteor flashed across the sky. The woman's daughters-in-law saw it as a bad omen, and feared the worst. However, when the elderly woman began to recover, they instead viewed the meteor as a good omen (Poirier, 2005, p. 171). The Darkinung of New South Wales claimed meteors were a portent that something good was about to happen (Needham, 1981, p. 11). In Lardil culture, colored meteors were identified with sickness, while white meteors were seen as a sign of good luck, such as the arrival of a baby, or the finding of turtle eggs (McNight, 2005, p. 209).

9 Meteors and War

1 **Portents of War**: The association of meteors with omens of war was prevalent in various parts of eastern Australia, especially Queensland. In 1846, four survivors of a ship named 'Peruvian' crashed into the Great Barrier Reef. The survivors escaped to the shore of Cleveland Bay, near Townsville, where they wandered for two weeks before being discovered and fed by a band of local Aboriginal people. The Aboriginal people said they had been led to the place by following the paths of falling stars night after night, which foretold of the presence of a hostile enemy (Morrill, 1864, p. 16; Robertson,

1928, p. 144). The morning following the sight of a fiery meteor, Aboriginal men of the Tully River, Queensland would walk in the direction of the meteor's path to search for tracks left by possible enemies (Roth, 1984, p. 8), while Aboriginal people of Proserpine, Queensland saw meteors as killed enemies (ibid). The Ngarigo of southeast New South Wales believed that a bolide was a portent that showed the people where its path pointed, were gathering for war (Howitt, 1996, p. 430; Pring, 2002, pp. 27–28).

Implements of War: The link between meteors and war, including weapons of war, such as a spear or club, was found among several Aboriginal groups (e.g. Gibbs, 1996, p. 69). The Wathi-Wathi of the Murray River saw a meteor as the celestial passage of a *nulla-nulla*, a short spear-like weapon used to hunt the emu (Cameron, 1885, p. 365). Some Aboriginal groups in Queensland saw meteors as firesticks that were carried across the sky or thrown from the sky by their enemies (Roth, 1984, p. 8). The Turrbal (or Jagara) of the Brisbane region saw a meteor as a medicine man, called Kundri, dropping his firestick to kill (Howitt, 1996, p. 430), while Aboriginal people of the Western Desert believed Wuuna would throw showers of spears (meteors) from the sky. Images of Namorrorddo sometimes showed him carrying a *miyarrul* (fighting club) used to stun his victims (e.g. Blanasi, 1994). The Yarrungkanyi and Warlpiri people of the Northern Territory told how Dreaming men fell to the Earth as shooting stars, bringing the Dreaming to the people. The men, armed with weapons, travelled through the sky as falling stars and landed at a place called Purrparlarla, southwest of Yuendumu, Northern Territory (Warlukurlangu Artists, 1987, p. 127).

10 Meteors in Ritual and Ceremony

Causing Harm or Death: There existed a number of rituals in various Aboriginal cultures that served to harm people, often involving pointing a bone or stick at a person or enemy while chanting or singing a particular song, which caused the victim to become sick and die (Hollenback, 1996, pp. 208–210). Because meteors were frequently linked with sickness and death, they were often incorporated into these rituals. In the Lardil culture, the bone-pointing ritual was called *puri-puri* (Roughsey, 1971, p. 75) and involved the spirit of a shooting star magically entering the victim like a bullet, inciting a dream. In his dream, the victim would see the ceremony being performed, and realize it was directed at him. This would cause the victim great worry and distress, feeling as if there was something in his chest or stomach, and his health would deteriorate until he died. During the ritual, people of the Star Totems (Ngarrid-belangee and Bungarinyee) stayed awake at night chanting the name of the victim. If a meteor was seen, they knew the ritual was a success and the person had died. It was reported that the only cure for this act was to go to the man the victim saw in his dream and ask him to perform a ceremony to remove the shooting star from his chest.

Treating Sickness: Various rituals were utilized by the Lardil to treat an evil sickness called *Malgri* (probably a type of food-poisoning). One such ritual involved the treatment of a man who became sick after helping to catch fish near a beach, by a group of medicine men. The man likely had eaten unprepared palm nuts, which are poisonous when raw. At night, the medicine men made a long cord from human hair, tied it to the man's toe and trailed it out to sea. As the men chanted, when a meteor shot across the sky, this signified the Malgri had left his body, and returned to the sea. At the same moment, the cord was snapped, and the man began to groan and roll about (Roughsey, 1971, p. 80; Cawte, 1974, p. 110). If a meteor was seen from a Lardil camp where a person suffered from sickness, the people in the camp gathered bushes of Wattle leaves. To banish the sickness, they repeatedly warmed the leaves over a fire, then transferred the heat from the leaves to the sick person's abdomen, whilst chanting a song. When another bright meteor of red or blue color was seen, firesticks were thrown in the direction of the meteor. The Lardil believed the meteor was the evil of Thuwathu leaving the body and returning to the sea. If this did not happen, the sick person would probably die (Roughsey, 1972, p. 107).

Warning to Follow Laws and Traditions: Other forms of ritual that included reference to meteors involved warnings to follow laws and traditions. Examples of this were found across central and northern Australia, from Alice Springs, to Arnhem Land, to the Gulf of Carpentaria. For example, if a Lardil man were to break traditional laws, Thuwathu would afflict him with Malgri (Roughsey, 1971, p. 80), while a Wardaman deity, Utdjungon, would manifest as a fiery falling star and destroy the Earth (Harney & Elkin, 1949, pp. 29–31). According to Wardaman tradition, only Aboriginal people could ward off the threat of Utdjungon (ibid). Harney and Elkin interpreted this to mean that if no Aboriginal people were present to ward off Utdjungon, the colonists would be destroyed by the falling star. Therefore, the Wardaman felt it was in the best interest of the colonists not to force Aboriginal people from their lands or destroy their laws and traditions, as the consequences of their absence would be fatal.

In some cases, the casting of a star from the sky to punish lawbreakers was more literal. Harney (1969, p. 37) described an incident where a married woman ran away with her lover. Enraged, her husband sang a sacred song inciting magic, and slung a stone (which represented a sky-stone) at her using a hair-belt. The stone flew over her head, frightening her. Sobbing, she ran back to her husband who gave her a second chance. This was a practical example of the Utdjungon story, showing the application of the warning. Harney cited a similar account from Arnhem Land, where a fireball was slung at unfaithful women by a spirit-being who lurked in the Coal Sack, the dark nebula bordering the Southern Cross in the Milky Way (Coon, 1972, p. 294). Similarly, the western and southwestern Arunta of central Australia had rituals involving meteors and sky-stones that were used to punish people for disobeying laws and traditions. A small spear-like device was used in a particular magic ceremony to punish a man for stealing another man's wife (Spencer & Gillen, 1899, p. 550; 1904, p. 627; 1927, pp. 415–417). The spear, endowed with evil magic, was hurled in the direction of the man's home. The evil spirit within the spear would locate the law-breaker and kill him. The men conducting the ceremony would wait until a thunderous boom was heard, which signified that the spear had struck and killed the man, though it is not clear whether this sound indicated the passage of a bolide. This form of Arungquilta was seen "streaking across the sky like a ball of fire" (ibid 1927, pp. 415–417).

Spencer and Gillen (1899, p. 550; 1904, pp. 627–628; 1927, pp. 415–417) described another form of Arungquilta, which involved meteors and produced comets, that was used to punish unfaithful wives. A particular ceremony was performed to punish a woman who had run away from her husband. A pictogram was drawn in the dirt in a secluded area while the men chanted a particular song. A piece of bark, representing the woman's spirit, was impaled with a series of small spears and flung in the direction they believed the woman to be, which would appear in the sky as a comet. The Arungquilta would find the woman and deprive her of her fat. After a time, the emaciated woman would die. Her spirit then appeared in the sky as a meteor.

The Kaitish believed that a falling star indicated the location of a man that had killed another by magical means, using a pointing-stick or bone (Spencer & Gillen, 1904, pp. 627–628). When such a death occurred, friends of the murdered man would watch for falling stars. When one was seen, they would "settle to their own satisfaction where it reached the earth" (ibid). Armed with a *wailia-wailia* (a device made from the hair of the dead man), the son-in-law of the murdered man organized an avenging party and travelled to that spot and killed the murderer by spearing him. They left the corpse for the women to bury at the spot where the star fell. It is not clear if the women found the actual spot where a meteorite had fallen, or if they simply guessed or collectively agreed as to the location of where they believed it fell. Spencer and Gillen stated that the women could easily locate the spot, as the ground was soft. This description is ambiguous, and though the finding of such a meteorite is possible, it seems implausibly rare. See Hamacher & Norris (2010b) for further examples of Aboriginal meteorite beliefs.

Initiation Rituals and Medicine Men: There is a close association between medicine men and meteors in many Aboriginal cultures. Amongst the Aboriginal people of Sugarloaf Mountain, New South Wales, the tooth-rapping ceremony (part of an initiation ceremony) was conducted by a medicine man who came to the Earth from the Sky World as a fiery meteor, and was considered a benevolent and good person (Gunson, 1974, p. 50). This may imply a meteor had to be seen before the ceremony began. Among the Anula, medicine men are hereditary in the *Yuntanara*, or Falling Star Totem (Spencer & Gillen, 1904, pp. 479 & 488). Many rituals involving meteors centred on the disembowelment of the initiate and the symbolic replacement of his organs with those of a sky being, without harming him. Such rituals were found among several groups in Victoria, including the Jupagalk (Elkin, 1977, pp. 75–76), Mukjarawaint and Jajauring (ibid), Wotjobaluk (Smyth, 1878, p. 309; Massola, 1968, p. 116; Howitt, 1996, pp. 368–369), as well as the Euahlayi of New South Wales (Parker, 1905, p. 54; Elkin, 1977, p. 89), the Binbinga from the shores of the Gulf of Carpentaria (Howitt, 1996, pp. 114–115), and the Mara of Arnhem Land (Spencer & Gillen, 1904, p. 488; Elkin, 1977, p. 115). Sometimes, the removed entrails were believed to be replaced with sacred stones that provided the initiate with the magic he would need as a medicine man. These stones were typically identified as quartz crystals or australites (Cowan, 2001, p. 21). Aboriginal peoples of the Bloomfield River in Queensland believed these quartz-like crystals to be fallen stars (Roth, 1984, p. 8). For the Arunta, crystals were associated with divine properties and origins, believed to have fallen to Earth as 'solidified light' (Eliade, 1965, p. 25). In Wuradjeri lore, a spirit named Kurikuta came to the Earth in a crystal body at night as a fiery meteor (Berndt, 1974, p. 28). Among the Kokatha of South Australia, quartz crystals and australites, called *mabanba*, were used by medicine men to cure afflictions (Berndt & Berndt, 1943/44, pp. 56–57).

11 Other Views of Meteors

Some perceptions of comets and meteors fall into none of the themes described above, and have no apparent cultural counterpart elsewhere. In north-east Tasmania, the Plangermairrener tell of Puggareetya, a mischievous woman who fought a snake in its earthly home, driving the ground up to form the surrounding landscape (Noonuccal, 1990, pp. 115–119). During the fight, the snake cast Puggareetya into the sky where she was held by the sky spirit Mienteina. Puggareetya continues to play her tricks on the sky deities, who become annoyed and occasionally throw Puggareetya across the sky, seen as a meteor. The Mara tell about the supernatural conception of a child from a pair of spirit children that were beckoned by a meteor (Harney & Elkin, 1949, pp. 35–36). In a similar vein, the Narangga and Kaurna peoples in South Australia viewed meteors as orphans (Transactions of the Statistical Society, 1842; Moorhouse, 1843; Black 1920, p. 89; Parker et al., 2007, p. 400). In New South Wales, Peck (1925, p. 160) told how meteors were warnings that the red blooms of the Waratah flower were being stolen, while a Queensland story tells of Priepriggie, a highly regarded figure in his community, who was able to make the falling stars dance to his songs (Reed, 1999, pp. 88–89). To the Moporr (Dawson, 1881, p. 101) and Gundidjmara (Parker et al, 2007, p. 400) of Victoria, meteors represented deformity, which tied closely with sickness. Perhaps one of the strangest descriptions of a meteor came from the Aboriginal people of the Loddon River in Victoria, who had a word for seeing a dog jump up and attempt to bite a falling star: *Bûrdi-dûrt* (Smyth, 1878, p. 205).

Some researchers have described woodcarvings of meteors, but the references tend to be vague. Mathews (1896, p. 41) recounted an earlier description of an initiation site in New South Wales surrounded by tree carvings, including images of meteors. Brown (2000, p. 27) claimed that in northwest and central Australia, marks and notches in wooden *churungas* depicted astronomical objects such as the flights of meteors and comets, but gave no examples and cited no references.

12 Meteor Showers

In 1939, an Amangu man from Mullewa, Western Australia told Tindale (1983, p. 376) that his paternal grandmother was a baby when 'the stars fell', alluding to a bright meteor shower in the early 19th century. Tindale speculated that this may have been the great Leonid meteor shower of 1833 November 13, an event where thousands of bright meteors lit up the sky every minute (cf. Littmann, 1999).

13 Conclusion

We have presented a comprehensive analysis of 150 Aboriginal Australian views of meteors, representing 97 Aboriginal groups from all states of Australia. Many of these views fell into particular themes, most notably fear, death, omens, and war. Many descriptions of meteors were included in ritual and ceremony, and focused on inciting harm to others, or providing protection from harm. However, not all views of meteors were negative. Of the accounts with a specific aspect, 38 (25%) described positive attributes, such as benevolent spirits or good omens, and 63 (42%) negative attributes, including evil spirits, evil magic, bad omens, weapons of war, deformity, or rituals causing harm. The remaining 49 stories (33%) described neutral attributes, such as the role of meteors in initiation ceremonies, definitions of meteors, or views of meteors that were considered neither good nor bad.

Many of these views were shared by Aboriginal groups across Australia. Although researcher bias has certainly played a role in how the accounts were recorded, there is little evidence to suggest this was the primary reason for these similarities. While circumstantial evidence exists to support the hypothesis that cosmic impacts may have caused a general fear of meteors, no physical evidence to confirm this has been found to date, as examined by Hamacher & Norris (2010b), and such events are so rare they are unlikely to have had any cultural effect even during the $\sim 40\,000$ years humans have inhabited Australia. The most probable explanation is that unexpected and random celestial phenomena were fearful because they disrupted an apparently ordered and predictable cosmos.

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Ongoing meteor work

What is the difference between image intensifier and CCD meteor observations?
I. CCD and image intensifier observations in Japan

Masahiro Koseki [1], *Masayoshi Ueda* [2] *and Yoshihiko Shigeno* [3]

Video meteor orbits have been obtained since the 1990s in Japan and the authors (Ueda, Shigeno) obtained valuable results. Video observations using an image intensifier or a CCD have distinct characteristics and it is necessary to treat their results very carefully. Image-intensifiers can record fainter meteors than CCDs, but a CCD can record meteors on a more regular basis. Image-intensifiers and CCDs register meteors in different ways so that recorded meteors are not identical.

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1 Equipment

1.1 What are image-intensifiers (II) and CCDs?

Image intensifiers (II) have been developed for military purposes in order to spot enemy movements at night. Therefore image intensifiers have a higher sensitivity in infrared than in visible light. These devices are expensive for amateurs. Image intensifiers show ghost images and blotted figures of bright objects due to their technical characteristics (see Part II – forthcoming).

Image intensifier observations need of course an objective lens and a video camera. A common family video camera is suitable for image intensifier observations as this emits enough light and its line density is lower than with popular videos. A brighter lens will improve the results of course. For orbit determination the focal length of the objective lens should be long enough because the faint meteors are shorter than the bright meteors.

Although image intensifiers have many disadvantages, it is the only tool that can record fainter meteors than what the human eye can see. Second stage image intensifiers with a proper objective lens can catch meteors as faint as the 7th magnitude or fainter (see Part II – forthcoming). Radar observations are the most powerful technique in meteor science, but it detects meteors by reflections from ionized paths. Optical observations, such as image intensifiers, record the emissions caused by collisions between a meteoroid and the atoms in the atmosphere. Image intensifier observations are the only possibility to investigate the differences between radar and optical meteors. The optical meteor showers and the radar meteor showers differ a lot in many cases (Koseki, 2009).

Charge coupled devices (CCD) are commonly used in our daily life. Digital cameras replaced film cameras and video cameras do not exist without CCD technique. CCD cameras have developed into one of the most promising instruments in meteor observing because of its suitable resolution and sensitivity. The modern industrial monochrome CCD cameras can catch meteors as faint as with the old film cameras using a bright lens on it.

It is difficult to get both a high sensitive CCD camera and a bright lens that can be mounted on the camera. Common photo lenses, such as $f/d = 1.4$, are not fast enough for meteor recording. The efficiency increases with the inverse square of f/d (the ratio of the focal length f of a lens to its diameter d). If we intend to record +2 magnitude meteors, we should get a lens with $f/d < 1.0$. There are a few of such lenses but they are often sold out. However, serious problems may occur in the recordings due to such ideal combination of a lens with a camera. Faster lenses have larger distortions and a larger field of view. A wider field of view will allow to record larger numbers of meteors but their paths will be shorter.

1.2 II-observations by Y. Shigeno

Yoshihiko Shigeno is the founding member of the Meteor Science Seminar (MSS) and he has been a leader of double station meteor observations. Together with MSS members he did five expeditions to Australia, three to photograph Eta-Aquariids and two to observe the summer southern showers with image intensifiers (Shigeno & Shigeno, 2004). Shigeno continued image intensifier observations since 1992 (Shigeno & Toda, 2008) from two stations where the equipment was installed and put away by himself. He also did the measurements and calculations to obtain orbital data by himself (Shigeno & Yamamoto, 2010).

He made the frames for image intensifiers (see Figure 1) and distributed these among more than forty Japanese observers. In the beginning he used standard camera lenses ($f = 50$ mm, $f/d = 1.2$) as objectives but changed to use longer focal lenses ($f = 85$ mm, $f/d = 1.2$) in order to get more accurate positions for the meteors.

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Figure 1 – Image-Intensifier set (top) and its inside view (bottom). The equipment consists of camera, lens, image-intensifier, close up lens and CCD video camera.

Figure 2 – CCD observation view. Easy vinyl sheet protects a camera and makes it possible to place it outdoors.

1.3 CCD observations by M. Ueda

Masayoshi Ueda started CCD observations in 2001 and he determined meteor orbits by himself during the years 2004 and 2005 (Ueda & Okamoto, 2008). He cooperated during these years with Okamoto. Their observing sites remained stable with the same equipment so that their data are very homogeneous.

CCD cameras are easier to use than image-intensifiers as they can be left outdoors all day long. Some vinyl wrapper can be used to protect the set up from the rain (Figure 2). This way we can operate the CCD camera during nighttime regardless it is clear sky or cloudy at that time. A CCD camera records the sky and feeds the data into a PC all night long. The UFO capture software searches for meteor paths where the sky is clear, even if it is partial.

2 Images of meteors

Optical meteor observations need wider and more sensitive objective lenses. On the other hand, it is necessary to use longer focal length lenses in order to achieve more accurate results. The effective pixels of image-intensifiers and industrial CCD video frames are practically the same. Longer focal length lenses are used in image-intensifier observations than in CCDs to get accurate data because image-intensifier frames are affected by noise. Wider lenses are used in CCD observations because it was originally intended to patrol for fireballs (meteorites).

2.1 Field of view

Image-intensifiers and CCDs have different characteristics and the recorded meteors give different images. A shorter focal length is used for CCD observations and while a longer one is recommended for image-intensifier observations in general. A CCD can capture a wider field than an image-intensifier. Figures 3 and 4 show two Eta-Aquaiid meteors recorded by an image-intensifier and a CCD as an example. The former one crossed Lyra and the latter appeared between Cygnus and Cepheus. The narrower view of the image-intensifier left both the beginning and the ending points of the meteor outside the field (Figure 3).

The shorter the focal length of a lens is, the wider the field of view becomes. The larger field reduces a meteor image to almost a point (Figure 6) while a narrower field shows it as an elongated bar (Figure 5) because of the difference in angular velocity. If we would use a bigger and longer focal length lens in order to observe fainter meteors, the observable field will be even less. Moreover, a higher angular velocity will diffuse the light from the meteor. A faster lens is required to register fainter meteors and thus to study smaller meteoroids by optical device.

2.2 Sensitivity of the device

Another difference between the two devices is the sensitivity. The CCD is less sensitive than the image-intensifier, but a CCD used for industry is constructed for night view and we can get a short focus and sensitive lens for it without any problem. Nevertheless, image-intensifiers can catch fainter meteors than CCDs and are more suitable to record meteor trains. Eta-Aquariids and Orionids are fast meteors and frequently leave trains. An image-intensifier recorded a distinct train of an Eta-Aquariid meteor (Figure 5) but the CCD failed to record such faint object, although the meteor itself was bright enough and had a long path (Figure 6). Compared with a CCD, a high sensitive device such

Figure 3 – Image-intensifier view of an Eta-Aquariid meteor crossing Lyra.

Figure 4 – CCD view of an Eta-Aquariid meteor appearing between Cygnus and Cepheus.

as an image-intensifier detects fainter parts of a meteor trail which are higher in the atmosphere too (see Part II – forthcoming).

2.3 Orionids vs. Eta-Aquariids

Longer focus lenses give a faster angular velocity. The distance of the field of view from the radiant point influences the angular velocity, too. The Orionid radiant passes near the zenith and the Orionid meteor trails are shortened for observers at Japanese locations (Figures 7, 8) while Eta-Aquariid meteors produce much longer trails.

A CCD trail of an Orionid meteor looks like an image of an image-intensifier's frame and their images recorded on separate frames show a slowly moving pinball (Figures 9 and 10). Trails of Orionids are short in image-intensifier's observations at dawn but the images on the separate frames are fast moving arrows (Figure 9). The Orionid meteor stream is the fourth major shower for Northern hemisphere observers but the pictures of them are often short and unattractive. A meteor path in the atmosphere is shortened when its radiant point rises high and its apparent path is short. The Orionids are a great objective for meteor observers in all techniques but it is difficult to get accurate results (see Part III – forthcoming).

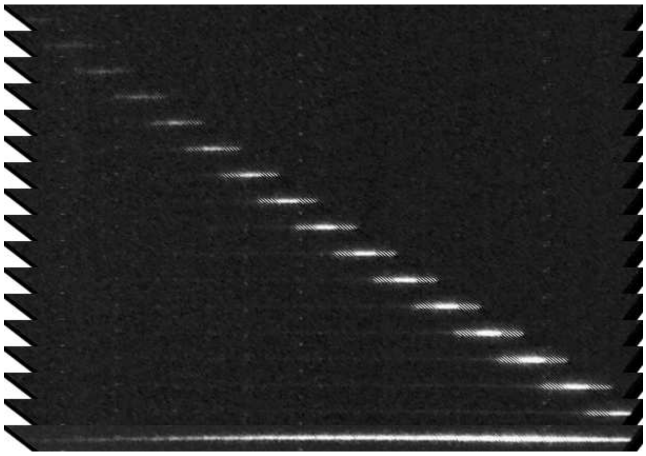

Figure 5 – Image-intensifier frame records of Figure 3.

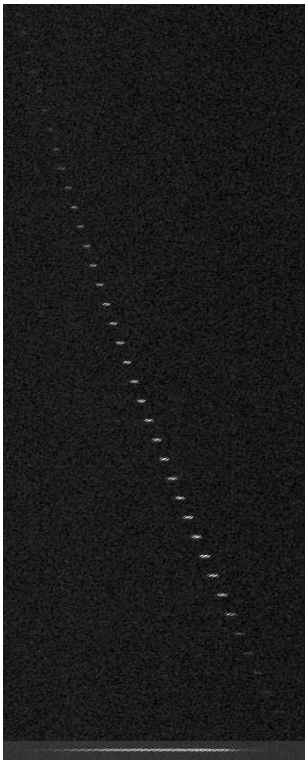

Figure 6 – CCD frame records of Figure 4.

The radiant point of the Eta-Aquariids is located low in the eastern sky and the apparent paths for these meteors are longer than for the Orionids. Therefore the Eta-Aquariids (Figures 3 and 4) are an excellent shower for our purpose. The Eta-Aquariids are also richer in bright meteors than the Orionids (see Part III – forthcoming). This is the reason why Eta-Aquariids are well recorded in Japan although the radiant's observability is shorter than two hours before dawn and its hourly rate is low.

2.4 Properties of images and characteristics of the devices

A meteor seems to move rather slow at its beginning height from ground-based observations because the meteor is more distant than the last part of the trail (Figure 6). This causes another difficulty for CCD observa-

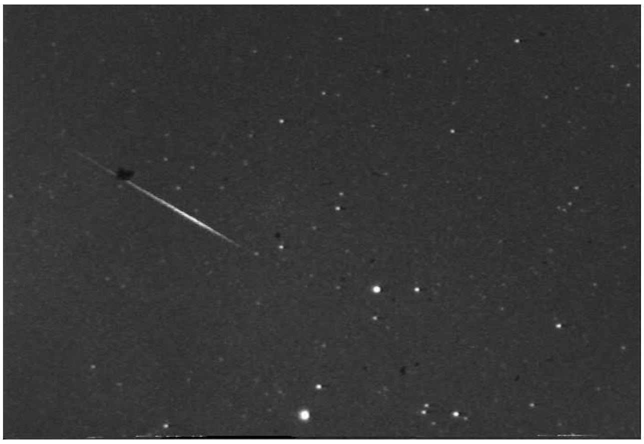

Figure 7 – Image-intensifier record of an Orionid meteor crossing Gemini.

Figure 8 – CCD picture of an Orionid meteor striking through the southern part of Gemini.

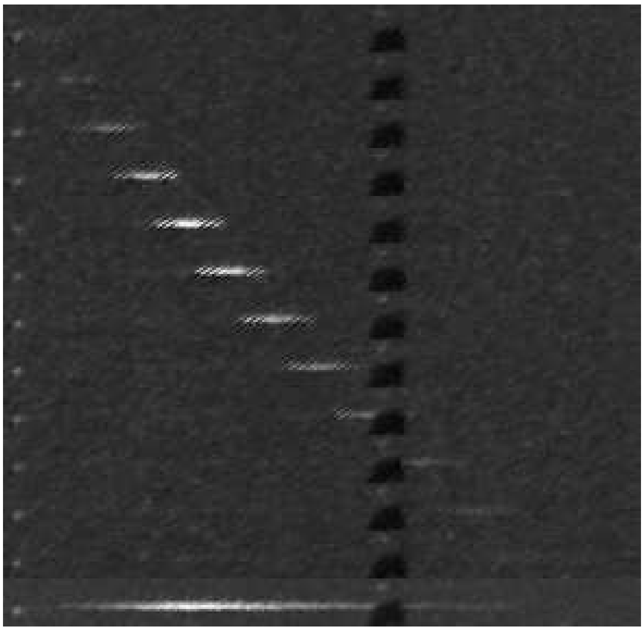

Figure 9 – Image-intensifier frame records of Figure 7.

tions because a meteor might be recorded as a dull spot especially in case of the close vicinity of a radiant.

Image-intensifier observations need specific techniques. The image intensifying technique multiplies noises from the sky and thermal air around the image-

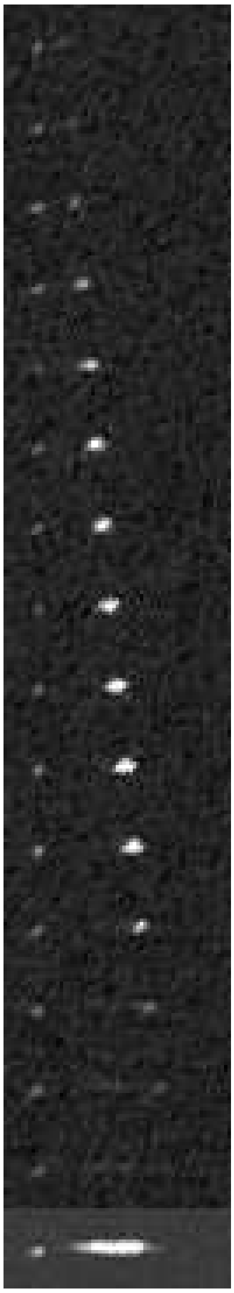

Figure 10 – CCD frame records of the meteor shown in Figure 8.

intensifier as well as the radiation from a meteor. Detecting meteor trails of image-intensifiers requires more patience and work than CCD records and causes problems for automatic verification. A meteor is a point object and the expected size of its images should not depend on the focal length within the range of image-intensifier and CCD observations. Blurred images of meteors from image-intensifiers are due to the image-intensifier properties themselves and are not representative for the size of the meteor. The spatial resolutions of image-intensifier observations depend on the image-intensifiers themselves and is not better than with CCD. However, the image-intensifier is the only device able to record faint meteors which could not be noticed by visual observers.

Both methods use a CCD to detect radiation from meteors and every 1/30 of a second the accumulated data is transferred to a video recorder. Video images do not match the fine details of photographs and therefore it is very difficult to determine the deceleration of meteors from video observations. However, the velocity of a meteor is required to derive its trajectory. Hence, fast and short meteors, such as Orionids, are rather difficult objects for video observations. Time resolution is now the limitation for the video observations but the situation may improve for amateurs because easily available video devices could be used like expensive one.

3 Characteristics of observations

Observations have their own characteristics and the results differ for different techniques. So-called video observations consist of two different techniques, image-intensifier and CCD. We should be cautious to treat their results in a similar way as for radar and photographs. Here we examine their properties compared to radar and photographic results in the region of ecliptic meteor stream activity.

3.1 Continuity

CCD observations are superior to image-intensifier results because they are quite independent from weather and sky conditions. CCD observations can be carried out when clouds cover more than half of the sky and when the full Moon shines at the sky. It allows us to get continuous data sets in an easier way. Ueda's CCD observations carried out during almost two years and which were disturbed by the Japanese rainy seasons, show very similar results compared to many years of photographic observations (Figures 12, 14). Image-intensifier observations are not permanent and cannot be operated continuously like in the case of radar (Figures 11, 13).

Image-intensifier and radar observations are not suitable to provide continuous results for meteor shower activity but are superior to record faint magnitude meteors.

3.2 Errors or sensitivity

Velocity distributions (Figures 11–14) show some other aspects of the differences between the observational techniques. It looks as if image-intensifier results are more erroneous than CCD results but that is not the case. Image-intensifiers are more sensitive than CCD and can register fainter meteors (Part II and Part III – forthcoming). Radar observations show results similar to image-intensifiers. These two sensitive techniques suggest that the scatter on meteor velocities increases for fainter meteors.

3.3 Detection of meteor showers

Ecliptical meteor activity shows the observational characteristic very well, especially for radiant distributions (Figures 15–18). Photographic results indicate distinct meteor shower activity (Figure 18) such as the Taurids, Geminids and so on. CCD observations give the same result (Figure 16). For radar radiants, the distribution shows no clear concentration (Figure 17), but these observations cover a different meteoroid size range. Image-intensifier data (Figure 15) can be situated somewhere between the photographic and radar results. Image-intensifier radiant concentrations, such as Taurids, seem to be more widely dispersed than the plots based on CCD observations, but this is less abundant than in the case of the velocity distribution. Image-intensifier and radar results suggest that the fainter the meteors are the larger the scatter on the radiant areas becomes (Part III – forthcoming) as already indicated by the comparison with the radar results.

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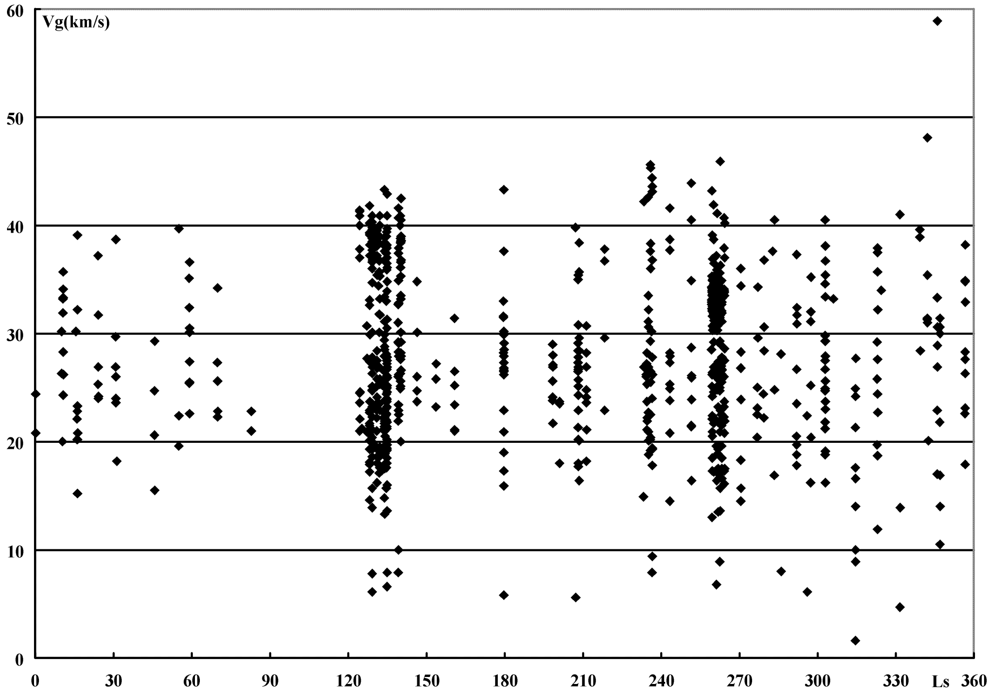

Figure 11 – Observed geocentric velocity of meteors from ANT by image-intensifier along Solar longitude (1950.0). It is obvious that image-intensifier observations are less suitable for constant meteor activity monitoring.

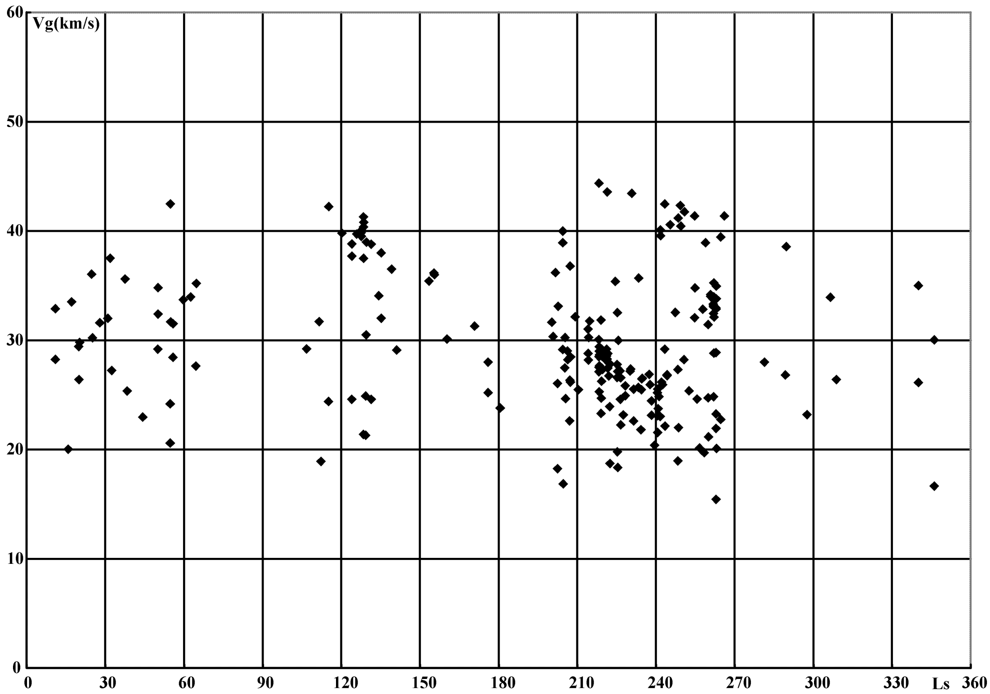

Figure 12 – Observed geocentric velocity of meteors from ANT by CCD along Solar longitude (1950.0). It is clear that CCD observations are better suitable for constant meteor activity monitoring.

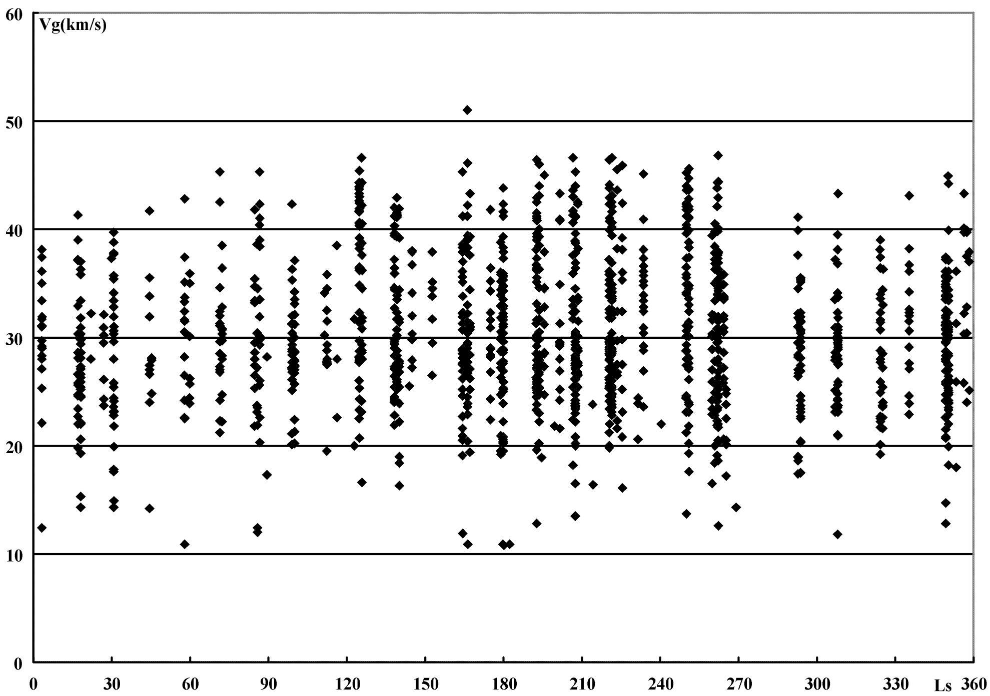

Figure 13 – Observed geocentric velocity of meteors from ANT by radar (Harvard 1968–69) along Solar longitude (1950.0). It is clear that radar observations are less suitable for constant meteor activity monitoring.

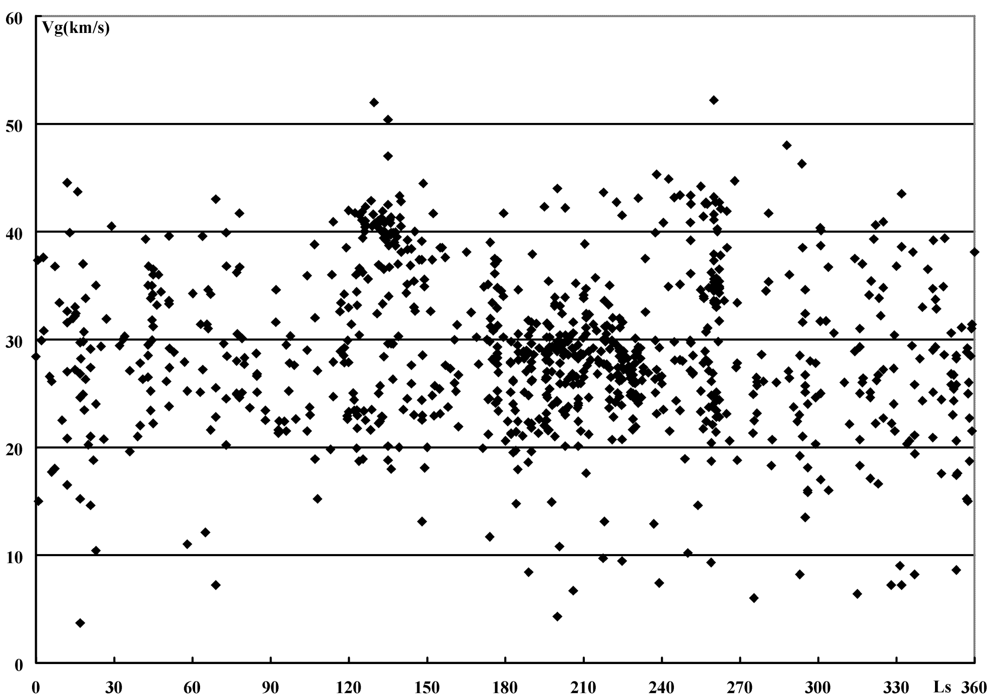

Figure 14 – Observed geocentric velocity of meteors from ANT by photographic work along Solar longitude (1950.0). It is clear that photographic observations over many years are better to monitor meteor activity on continuous basis.

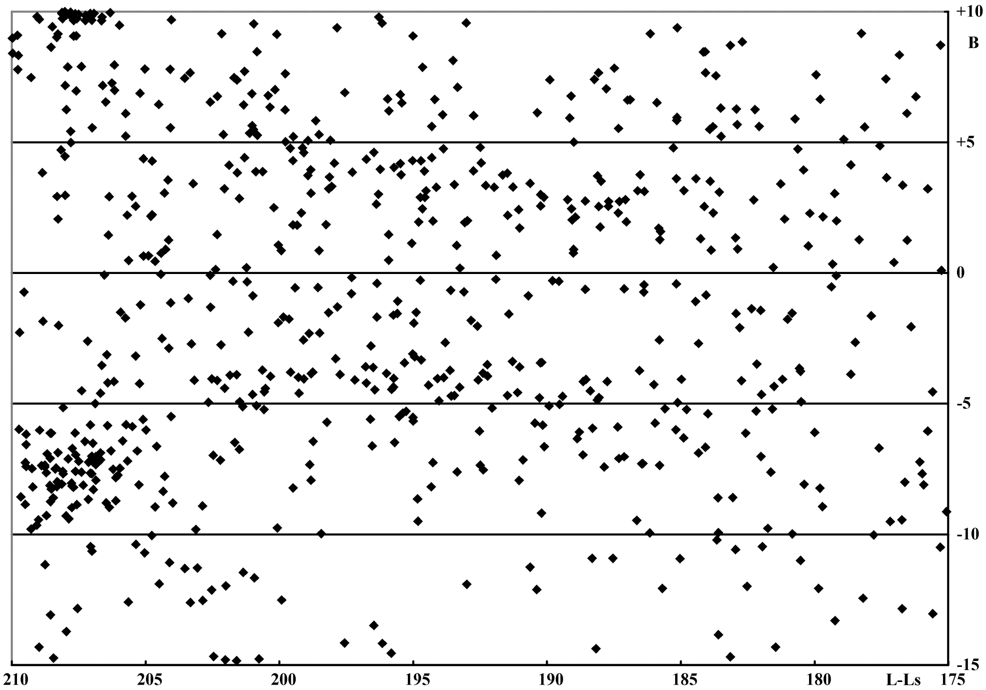

Figure 15 – Radiant distribution of meteors from ANT by image-intensifiers in (L-Ls, B) coordinates. Radiants seem to increase left upward with several concentrations.

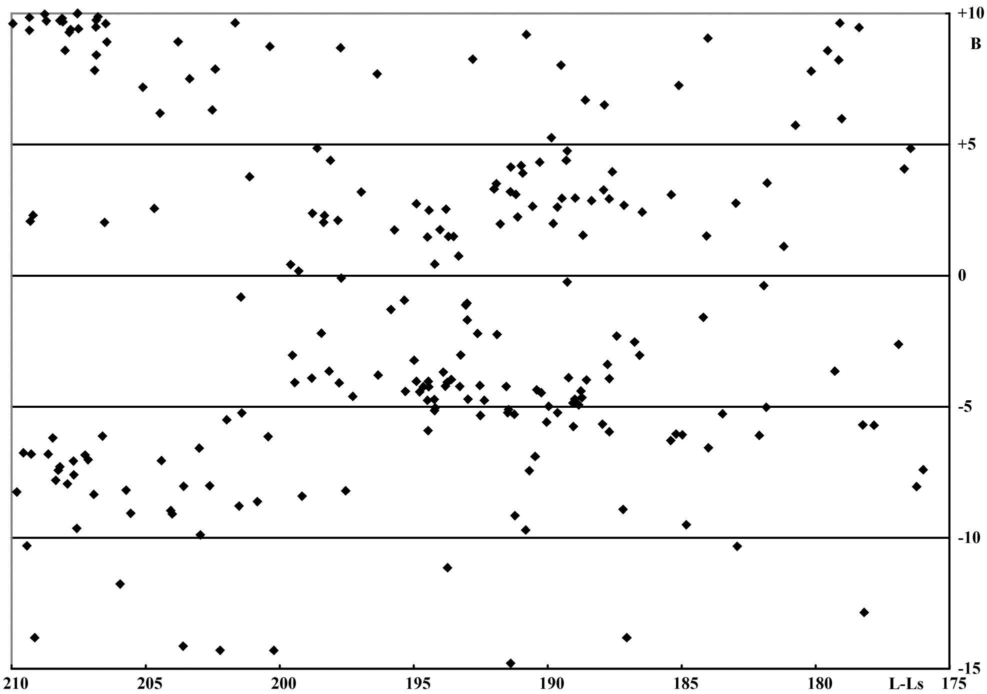

Figure 16 – Radiant distribution of meteors from ANT by CCDs in (L-Ls, B) coordinates. There are some obvious concentrations of meteor showers.

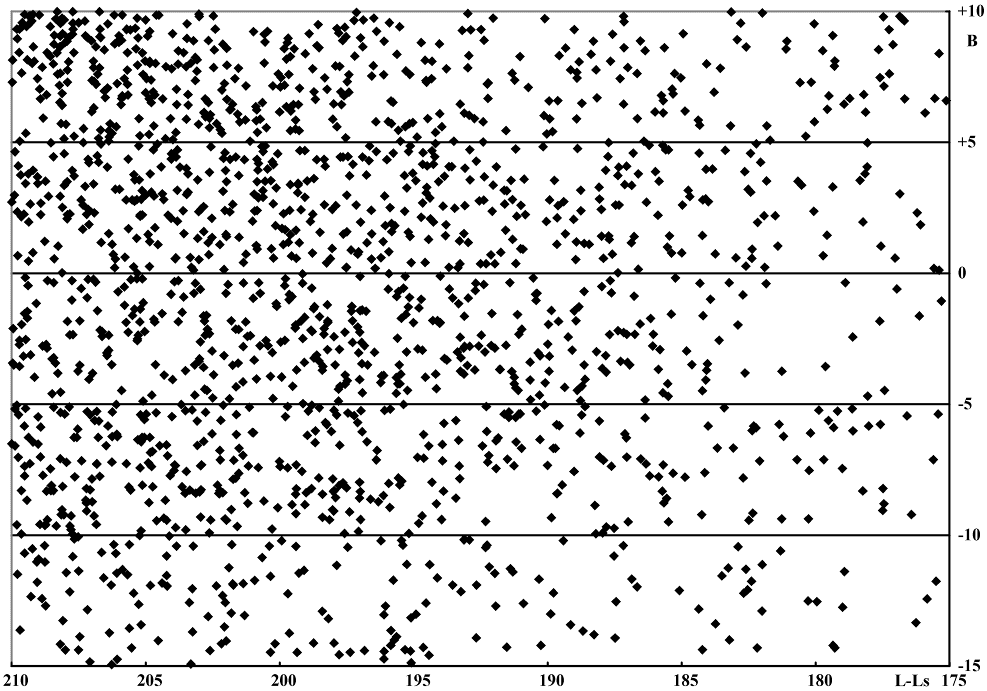

Figure 17 – Radiant distribution of meteors from ANT by radar (Harvard 1968–69) in (L-Ls, B) coordinates. There is no concentration recognizable but a slight increase toward top-left.

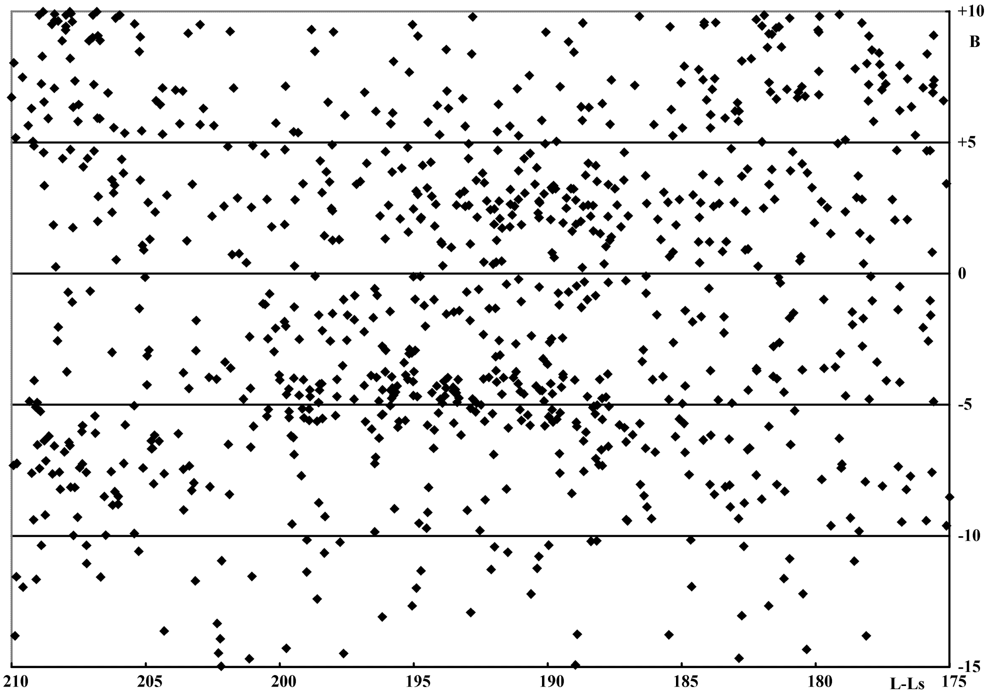

Figure 18 – Radiant distribution of meteors from ANT from photographs in (L-Ls, B) coordinates. There are some obvious concentrations of meteor showers.

Results of the IMO Video Meteor Network — March 2010

Sirko Molau [1] *and Javor Kac* [2]

The results of the IMO Video Meteor Network for 2010 March are presented. The Network expanded again; 39 cameras were operated by 24 observers. Almost 2 000 hours of effective observing time were collected and almost 5 500 meteors were recorded. The ζ-Serpentids were studied, but their activity could not be distinguished from the sporadic background. A summary of the third Meteor Orbit Workshop is also given.

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1 Introduction

In March, the weather finally turned back to normal in northern Europe also. The number of observing nights increased to the usual level, and most cameras were operated for between 10 and 20 nights. Only SALSA2 of Carl Hergenrother once more enjoyed exceptional conditions and had to pause for just a single night. With 2 000 hours, the total effective observing was slightly below the record of 2009, but the number of meteors (5 200) clearly above last year's figure (Table 1 and Figure 1). Once more, the hourly average increased, from 2.0 to 2.7 meteors. We cannot say at this time whether this is a real effect or only due to the now automated and therefore more strict estimation of cloud gaps.

A new camera station was set up in Hungary, and provided first data from test observations in March. Jozsef Morvai is operating a Watec camera with 3.8-mm $f/0.8$ Computar lens at Fülöpszallas. More camera stations in Hungary are in preparation.

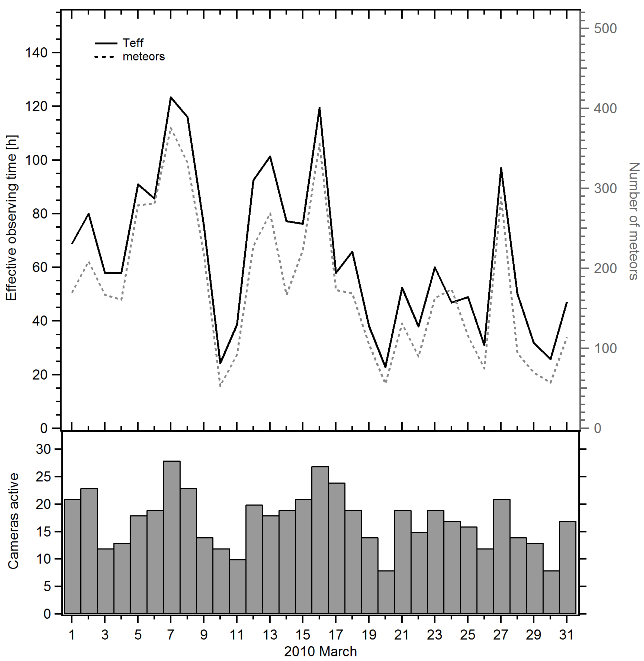

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 March.

2 Zeta Serpentids

March is even poorer in meteor showers than February. With the ζ-Serpentids (43 ZSE), our 2009 analysis yielded just a single shower in that month (Molau & Rendtel, 2009). This minor shower reaches video rates up to 1.5 in the final third of March – reason enough to check for traces of this shower in the 2010 data set. As usual, the meteor shower assignment of all observations between March 21 and 30 (1259 meteors) was repeated with a modified shower list. A total of 43 meteors were assigned to the ζ-Serpentids, and 161 meteors to the Antihelion source. Figure 2 gives the distribution of shower meteors relative to the number of sporadics in each night. The ZSE seem to have been active all the time at a very low level of just one third of the Antihelion source activity (by number). To check whether such an activity level can be distinguished from the sporadic background at all, we added two 'synthetic' showers to the list – one 45° east and one 45° north of the ζ-Serpentid radiant. Their 'activity' is plotted with thin dotted lines in Figure 2. Except for March 29, they show the same activity level as the ZSE, hence, the ζ-Serpentids cannot be distinguished from the sporadic background in 2010.

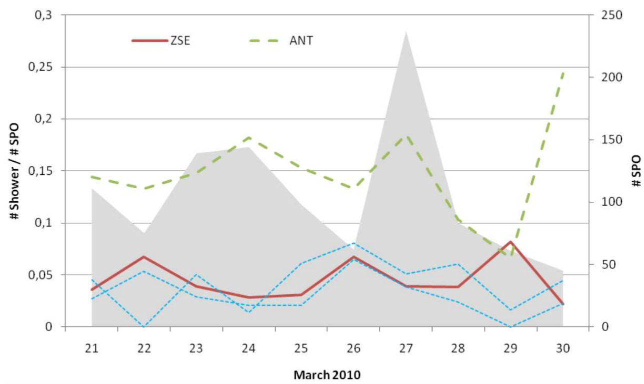

Figure 2 – Number of ζ-Serpentids and Antihelion meteors from March 21 to 30, relative to the number of sporadic meteors in the same night. The absolute number of sporadics is given in the background. The 'activity' of two 'random showers' is plotted with thin dotted lines.

3 Meteor Orbit Workshop

Finally we would like to report on the third *Meteor Orbit Workshop* that was held from April 17 to 20 at ESTEC in Noordwijk, the Netherlands. That meeting, which was initiated and coordinated by and large from Detlef Koschny, was the most interesting and fruitful

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workshop for video meteor observers, camera network operators and programmers that the first author ever joined!

The key for success was that the operators of the largest video camera networks and the authors of the most important software packages for the detection and analysis of video meteors were all present, even though the number of participants was limited to 20. Beside the IMO network, also the Polish, Hungarian, Croatian, and Japanese networks were present in the workshop. In addition, there were participants from Slovakia, France and Spain, where further networks are under construction, and representatives of different astronomical institutes. At the same time, the authors of MetRec, Ufo* and MeteorScan joined the meeting, just as Polish, Croatian and other programmers of meteor analysis software. In short: the list of participants read like the 'Who is Who' in video meteor observation.

At first it looked as if the famous volcano in Iceland (that nobody can pronounce) would put a spoke in our wheel at the last moment, because just at the day of arrival all airports in central Europe were closed. Fortunately, three participants from overseas already arrived earlier, and other participants switched to train or car at short notice. In the end, two thirds of the participants managed to come to Noordwijk. Right from the start, US-based Pete Gural planned to join the workshop by video phone (and each morning he indeed entered the meeting at $03^{\rm h}15^{\rm m}$ local time sharp). The day before the meeting it was decided to organize a real video conference with video, audio and presentation sharing via Webex, which proved to be highly successful in the end. At times there were up to five virtual participants from Ireland, Croatia, Germany and the US, and some of them even presented their talks remotely. Of course, they could not take part in the many discussions taking place during breaks and in the evenings, but at least in the meeting room they were almost as present as the local participants.

What was the workshop all about? On the one hand, many problems and solutions were discussed, starting from the automated detection and measurement of video meteors, up to the calculation of orbits and the search for meteor showers, thanks to the pooled competence of the participants. It was a unique chance to welcome the Japanese programmer and network operator SonotaCo (the SonotaCo network is the largest video meteor network in the world with currently about twice as many cameras as the IMO network), and much time in particular was spent on the presentation and demonstration of the Ufo* software suite. The workshop lasted for four days, which gave sufficient time for each topic instead of having to jump from one lecture to the next. In fact, SonotaCo and Sirko Molau even had five days, since they already met the day before the workshop at Detlef's house and discussed in detail about MetRec and Ufo*.

On the other hand, the workshop covered practical aspects of organizing large camera networks, the equipment, the collection and analysis of observations, and the prerequisites that would enable all observations to be collected in the unified VMO (Virtual Meteor Observatory) database in the near future. It was most interesting to learn which approaches were followed by the different meteor networks, and which advantages and disadvantages each of these have.

The first author's personal highlight (and that of many other participants) was the presentation of UfoRadiant by SonotaCo. Its functionality is comparable to the RadFind and StrmFind tools of MetRec. This program, which is not (yet) available to the public, allows finding meteor showers in the observational database. Moreover, UfoRadiant provides breathtaking options for data visualization. The presentation started with the known projection of radiants in ecliptic minus solar longitude vs. ecliptic latitude based on the latest SonotaCo network data set. Then, the data set was filtered for individual orbital elements (semimajor axis, eccentricity, inclination) and suddenly it became clear which type of meteors provided what part of the overall sporadic background. None of the experts in the meeting room had ever seen these interrelations in such an illustrative way before.

When preparing his talk, SonotaCo had stumbled over an inconspicuous aggregation of orbits that did not fit to any known shower. During his talk he demonstrated live, how he obtains the shower parameters. His preliminary analysis resulted in a shower that is active between late October and mid-November with a radiant position at maximum ($\lambda_\odot = 223°$) of $\alpha = 144°$, $\delta = 45°$ and a velocity of 65 km/s. At that moment, the first author was almost brimful of curiosity whether this shower would also be present in the IMO Network data. A short glimpse at the 2009 analysis (Molau & Rendtel, 2009; `http://www.imonet.org/wgn09/sol223.html`) yielded the following: The fourth strongest radiant (behind NTA, STA and ORI) at 223° solar longitude has a position of $\alpha = 144\overset{\circ}{.}1$, $\delta = 45\overset{\circ}{.}5$ and a velocity of 64 km/s! At this point, everyone jumped up and SonotaCo and Sirko fell in each other's arms amidst the applause of the other participants. A little later it was found that we could not only confirm SonotaCo's radiant positon, but also that the shower as such was already detected in our 2009 analysis. Just because of its similarity to the northern Apex source we did not follow up on this one so far. The clustering of orbits in the Japanese data set, however, lets us now suppose this to be a real meteor shower rather than a diffuse sporadic source.

Looking back one can say that not only technical aspects were discussed at the workshop, but that the 'video meteor observer scene' world-wide has moved closer together once more, and that a big step was made towards the ultimate aim of a unified meteor database. Therefore once more, many thanks to Detlef Koschny and the other organizers for the idea and organization of this wonderful event!

Table 1 – Observers contributing to 2010 March data of the IMO Video Meteor Network.

Code	Name	Place	Camera	FOV	LM	Nights	Time (h)	Meteors
BENOR	Benitez-S.	Las Palmas	TIMES4 (1.4/50)	⊘ 20°	3 mag	3	5.3	16
			TIMES5 (0.94/50)	⊘ 10°	3 mag	2	1.3	2
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	17	53.2	164
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	21	70.0	162
			BMH2 (0.8/6)	⊘ 55°	3 mag	12	40.6	86
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	17	75.5	233
			STG38 (0.8/3.8)	⊘ 80°	3 mag	16	46.6	91
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	8	29.6	58
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	11	70.7	193
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	14	54.8	125
HERCA	Hergenrother	Tucson	SALSA2 (1.2/4)	⊘ 80°	3 mag	30	106.4	238
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	13	50.2	103
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	20	36.6	72
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	3	28.6	103
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	10	19.6	51
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	17	38.1	91
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	6	34.3	131
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	3	9.4	24
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	10	55.0	293
KOSDE	Koschny	Noord-	LIC1 (1.4/50)	⊘ 60°	6 mag	13	80.1	380
		wijkerhout	TEC1 (1.4/12)	⊘ 30°	4 mag	10	16.7	42
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	15	84.6	265
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	11	68.1	367
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	22	64.8	141
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	21	55.6	124
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	18	66.8	145
MORJO	Morvai	Fülöpszallas	HUFUL (0.8/3.8)	⊘ 80°	3 mag	15	19.1	42
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	16	79.1	146
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	19	86.4	207
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	17	44.0	105
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	13	62.8	133
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	15	81.8	198
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	14	77.6	196
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	14	86.9	247
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	18	34.3	82
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	13	27.8	54
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	15	53.6	152
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	10	38.7	84
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	12	45.3	110
					Overall	31	1 999.9	5 456

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Results of the IMO Video Meteor Network — April 2010

Sirko Molau [1] *and Javor Kac* [2]

The 2010 April results of the IMO Video Meteor Network are presented. Nearly 9 000 meteors were recorded in about 2 700 hours of effective observing time by 41 cameras of the Network. The Lyrid activity post-maximum was studied, showing a decreasing trend with unexpectedly strong fluctuations.

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1 Introduction

In April, finally all observers enjoyed favourable observing conditions. Whereas in the first few months of 2010 the weather was often poor, it presented mostly clear skies to the observers in April. There was hardly any camera with less than ten observing nights, but 15 cameras with twenty and more nights. So it comes as no surprise that we collected nearly 9 000 meteors in 2 700 hours of effective observing time – far more than in any other April before (Table 1 and Figure 1). That result was not only achieved thanks to the good weather, but is also an outcome of 41 video cameras active that month. Among them was Hupol, a new camera on the outskirts of Budapest, which further completes the Hungarian network.

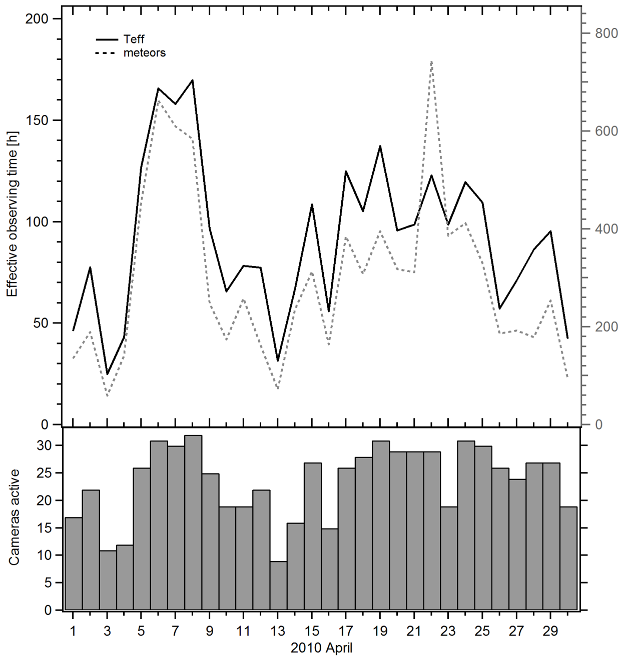

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2010 April.

2 Lyrids

As expected, the Lyrids were the highlight of April. Their maximum was predicted for the early evening (UT) of April 22 (McBeath, 2009). The data of ten video systems (mainly from Germany) which enjoyed clear skies almost all night long, were used as a basis for the following analysis. Between 21^h and 03^h UT, they recorded 279 Lyrids. The number of shower meteors was accumulated in half-hour intervals, corrected by the radiant altitude, and accumulated over all cameras.

Figure 2 shows the resulting activity profile. It shows the expected trend of decreasing rates in the night following the maximum. In particular, the first half of the night was hampered significantly by moonlight. As the limiting magnitude was not taken into consideration in this analysis, the real activity at the start of the night was even a bit higher. Amazing are the strong rate fluctuations in the course of the night, in particular the drops near 22^h45^m and 00^h45^m UT (and correspondingly the activity peaks in between). Both dips in activity are not only visible in the sum of all cameras, but also in the individual profiles of the three most sensitive (image-intensified) cameras Avis2, Lic4 and Ond1. For this reason it is unlikely that the dips are breakdowns were caused by short cloud patches at single sites.

The results from the preliminary analysis of visual data are given for comparison (crosses in Figure 2). They show the same tendency, but they were based on about a quarter fewer meteors in the same time interval. Due to the lower temporal resolution, short-term fluctuations would not become visible in the visual data.

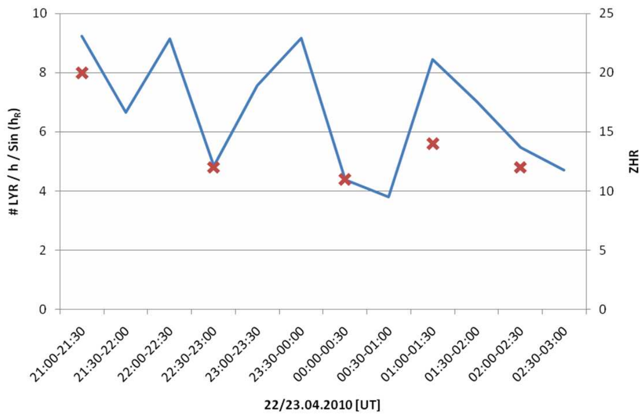

Figure 2 – Lyrid activity profile of 2010 April 22/23. The left-hand y-axis scale is the hourly rate of meteors, normalized by the sine of the radiant altitude and given as an average per camera. Crosses mark the ZHR (keyed to right-hand y-axis) from preliminary IMO analyses of visual observations (International Meteor Organization, 2010).

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Table 1 – Observers contributing to 2010 April data of the IMO Video Meteor Network.

Code	Name	Place	Camera	FOV	LM	Nights	Time (h)	Meteors
BENOR	Benitez-S.	Las Palmas	TIMES4 (1.4/50)	⊘ 20°	3 mag	10	17.4	50
			TIMES5 (0.94/50)	⊘ 10°	3 mag	7	5.2	15
BRIBE	Brinkmann	Herne	HERMINE (0.8/6)	⊘ 55°	3 mag	29	111.9	326
CASFL	Castellani	Monte Baldo	BMH1 (0.8/6)	⊘ 55°	3 mag	25	77.9	202
			BMH2 (0.8/6)	⊘ 55°	3 mag	14	51.0	147
CRIST	Crivello	Valbrevenna	C3P8 (0.8/3.8)	⊘ 80°	3 mag	23	96.4	249
			STG38 (0.8/3.8)	⊘ 80°	3 mag	22	72.4	137
ELTMA	Eltri	Venezia	MET38 (0.8/3.8)	⊘ 80°	3 mag	18	74.9	168
GONRU	Goncalves	Tomar	TEMPLAR1 (0.8/6)	⊘ 55°	3 mag	15	83.0	236
			TEMPLAR2 (0.8/6)	⊘ 55°	3 mag	18	71.1	181
GOVMI	Govedič	Središče ob Dravi	ORION2 (0.8/8)	⊘ 42°	4 mag	12	41.0	97
HERCA	Hergenrother	Tucson	SALSA2 (1.2/4)	⊘ 80°	3 mag	27	103.8	223
HINWO	Hinz	Brannenburg	AKM2 (0.85/25)	⊘ 32°	6 mag	14	58.0	127
IGAAN	Igaz	Budapest	HUBAJ (0.8/3.8)	⊘ 80°	3 mag	20	37.5	93
			HUPOL (0.8/3.8)	⊘ 80°	3 mag	19	40.1	91
JOBKL	Jobse	Oostkapelle	BETSY2 (1.2/85)	⊘ 25°	7 mag	14	84.9	419
KACJA	Kac	Kostanjevec	METKA (0.8/8)	⊘ 42°	4 mag	11	27.9	66
		Ljubljana	ORION1 (0.8/8)	⊘ 42°	4 mag	23	40.8	96
		Kamnik	REZIKA (0.8/6)	⊘ 55°	3 mag	9	49.8	220
			STEFKA (0.8/3.8)	⊘ 80°	3 mag	6	31.3	101
KERST	Kerr	Glenlee	GOCAM1 (0.8/3.8)	⊘ 80°	3 mag	11	81.8	515
KOSDE	Koschny	Noord-wijkerhout	LIC4 (1.4/50)	⊘ 60°	6 mag	19	99.2	484
LUNRO	Lunsford	Chula Vista	BOCAM (1.4/50)	⊘ 60°	6 mag	11	61.8	203
MOLSI	Molau	Seysdorf	AVIS2 (1.4/50)	⊘ 60°	6 mag	11	54.2	309
			MINCAM1 (0.8/8)	⊘ 42°	4 mag	28	112.6	313
		Ketzür	REMO1 (0.8/3.8)	⊘ 80°	3 mag	24	71.0	155
			REMO2 (0.8/3.8)	⊘ 80°	3 mag	24	105.3	259
MORJO	Morvai	Fülöpszallas	HUFUL (0.8/3.8)	⊘ 80°	3 mag	21	42.0	93
OCHPA	Ochner	Albiano	ALBIANO (1.2/4.5)	⊘ 68°	3 mag	21	85.8	167
OTTMI	Otte	Pearl City	ORIE1 (1.4/16)	⊘ 20°	4 mag	18	57.7	154
ROTEC	Rothenberg	Berlin	ARMEFA (0.8/6)	⊘ 55°	3 mag	21	67.5	191
SCHHA	Schremmer	Niederkrüchten	DORAEMON (0.8/3.8)	⊘ 80°	3 mag	28	68.2	171
SLAST	Slavec	Ljubljana	KAYAK1 (1.8/28)	⊘ 50°	4 mag	14	58.8	143
STOEN	Stomeo	Scorze	MIN38 (0.8/3.8)	⊘ 80°	3 mag	17	113.8	429
			NOA38 (0.8/3.8)	⊘ 80°	3 mag	19	127.0	425
			SCO38 (0.8/3.8)	⊘ 80°	3 mag	19	124.5	481
STORO	Stork	Kunžak	KUN1 (1.4/50)	⊘ 55°	6 mag	3	25.8	225
		Ondřejov	OND1 (1.4/50)	⊘ 55°	6 mag	5	37.1	481
STRJO	Strunk	Herford	MINCAM2 (0.8/6)	⊘ 55°	3 mag	21	44.3	109
			MINCAM3 (0.8/8)	⊘ 42°	4 mag	1	3.1	6
			MINCAM5 (0.8/6)	⊘ 55°	3 mag	16	68.1	204
TEPIS	Tepliczky	Budapest	HUMOB (0.8/3.8)	⊘ 80°	3 mag	9	46.0	127
YRJIL	Yrjölä	Kuusankoski	FINEXCAM (0.8/6)	⊘ 55°	3 mag	10	25.2	66
					Overall	30	2 758.0	8 954

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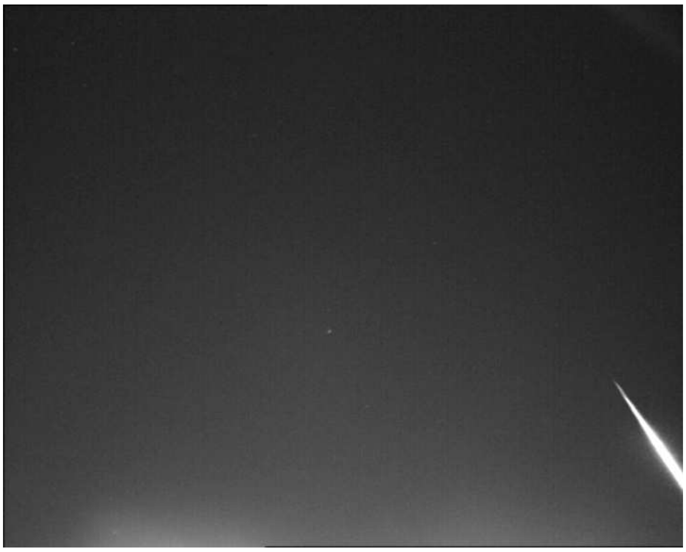
Bright fireball over Poland and Slovakia

A bright fireball was recorded on 2010 June 10 at $21^{h}20^{m}24^{s}$ UT by three video cameras of the Polish Fireball Network (PFN), and at least five recordings were made from Slovakia.

Cameras of the Polish Fireball Network

PFN Szamotuły. Image credit: Maciej Reszelski.



PFN Wrocław.

Slovak video meteor network all-sky stations

Astronomical and geophysical observatory in Modra, Slovakia.

Arboretum Mlynany, Slovakia.

Viktor Čech from Marianka, Slovakia captured the fireball using Canon 450D and 18-mm f/3.5 lens, 30 s exposure at ISO 800.