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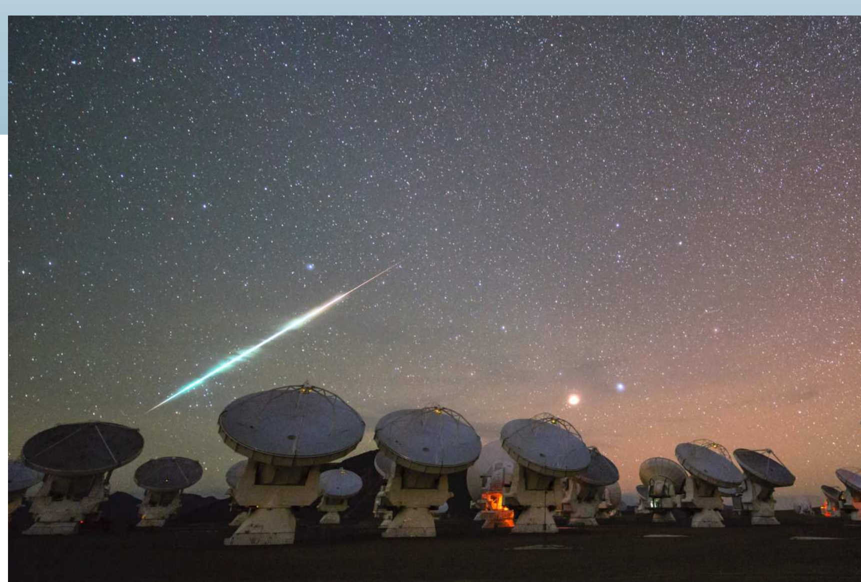

Enhanced activity of the 2014 Kappa Cygnids
The enigmatic sounds of meteors
November–December video meteors

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Administrative

Meteor science

Preliminary results

Front cover photo

Bright fireball recorded during a time-lapse set at the Atacama Large Millimeter/submillimeter Array (ALMA), located at 5000 metres above sea level on the remote and empty Chajnantor Plateau in the Chilean Andes. Credit: ESO/Christoph Malin.

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/docs/writingforwgn.pdf` .

Legal address International Meteor Organization, Jozef Mattheessensstraat 60, 2540 Hove, Belgium.

From the Treasurer—Supporting Members 2014

Marc Gyssens [1]

The following people have paid at least double the normal membership fee for 2014 (but not necessarily *in* 2014):

Christopher Abissi	Karl Antier	Luc Bastiaens	Luis R. Bellot Rubio
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Marc Gyssens	Richard Livingstone	Robert Lunsford	Sirko Molau
Ferhat Fikri Özeren	Jüergen Rendtel	Paul Roggemans	Walter Soto
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We are very grateful to the people above for their support. Several of them also contributed by providing a gift membership to a friend, or by paying a friend's or colleague's registration fee for the International Meteor Conference. It must also be emphasized that many other people gave gifts smaller than the regular membership fee; of course, these gifts are equally appreciated.

All the gifts we receive go into the IMO Support Fund, which is primarily directed towards supporting meteor astronomy projects. We repeat the call for applications in this issue. There are no deadlines—applications can be made at any time and will be evaluated by the IMO Council on their merits as we receive them. Unfortunately, only few meteor workers or groups of meteor workers make use of this interesting facility to bring their project to a higher level. Therefore, we strongly encourage applications!

Meanwhile, we thank once again all those of you who provided support to the IMO, in whichever way you chose!

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The IMO Support Fund

The IMO Council

The IMO supports amateur meteor research projects through the IMO Support Fund. We strongly encourage serious meteor amateurs or groups of meteor astronomers to apply and make use of this facility to bring their projects to a higher lever. To be eligible, these projects must

- be proposed by an IMO member;
- concern scientific and technological aspects of meteor observing;
- involve a medium- to long-term commitment of 3 years or more;
- return relevant results to the international community via the IMO and its journal WGN;
- respect the conditions defined in a contract between the successful applicant and the IMO.

An application for a grant from the IMO Support Fund can be submitted at any time and must be addressed to the IMO President. It should include

- proper identification of the applicants, including their past realizations in meteor astronomy;
- a scientific and technological justification of the project;
- a timing to realize the project;
- references to support the competence of the applicants, and to support the feasibility of and the timing for the project proposed;
- a motivation why a grant from the IMO Support Fund is necessary to realize the project;
- a realistic budget of the costs and revenues involved, including the grant requested from the IMO Support Fund, financing by the applicants themselves or by the local, regional or national association to which they belong, and revenues from external sources;

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- an explanation how the project will be managed during at least the first 3 years;
- a statement indicating whether you want to maintain your proposal for consideration during the next year should the budget for the current year be exhausted.

Successful applicants will be asked to sign a contract containing both the commitments of the applicants and additional requirements of the IMO that will constitute the terms under which the grant is provided. Under no circumstances will the IMO provide a blank check to the applicants! If the applicants do not live up to the terms specified in the contract, the IMO may withhold payment or even require a partial or full refund of the sums already paid. These terms will not only refer to the content of the project and the way it is managed, but also to a proper justification of the financial means provided, via invoices of the purchases agreed in the contract.

As the available budget is relatively small, the number of projects that can be financed will be limited to two or three per year. There are no deadlines; applications will be evaluated on the basis of first come, first served, and each proposal will be considered carefully on its merits. Proposals not meeting the criteria set above will be excluded from further consideration. In particular, proposed projects must be aimed at obtaining scientific results in a sustainable manner. Projects concerning outreach or education, or events of a more cultural nature will be considered out-of-scope.

Notice that the IMO Council reserves the right to support a cause at its own discretion when it feels it can further meteor astronomy in this way. The same holds for IMC support, which can still be made available in the form of waiving the standard registration fee, on a case-by-case basis. Requests for such support should be strongly motivated from a scientific perspective (required presence at a workshop, presentation of scientific results, participation in an international project, etc.). Grants of the IMO Support Fund will *not* be provided for outreach-oriented projects. This does not imply that the IMO fails to recognize the importance of outreach. For instance, the IMO Council appointed an IMO Outreach Officer in the person of Jure Atanackov. There are still many individuals who are serious about meteor astronomy, but who cannot afford IMO membership, for instance, but not exclusively, in developing countries. To encourage meteor astronomy, also in these countries, the IMO provides free membership with an electronic subscription to WGN to such individuals. Well-motivated requests for such gift memberships will be considered by the IMO Council.

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Meteor science

Enhanced kappa-Cygnid activity 2014

Jürgen Rendtel[1] *and Sirko Molau*[2]

The κ-Cygnid (012 KCG) meteor shower produced about 3–4 times the average visual rate and video flux in August 2014 for about four days. We are able to trace the increased activity to one component of the Cygnid complex proposed by Koseki recently. Video data indicate that the population index of all shower components is lower than that of the sporadic meteors, probably $r \approx 2.6$. Our analysis supports the suggested 7-year periodicity in activity enhancement of the κ-Cygnids

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1 Introduction

The κ-Cygnid (012 KCG) meteor shower has been observed and listed by many observers for a long time. It is observable over most of the month of August. The shower's activity becomes more obvious after the peak of the Perseids, i.e. after about $\lambda_\odot \approx 140°$. The average rates are low. Analyses of visual data obtained between 1988 and 2007 yield a ZHR of about 2. In some years, enhanced rates have been reported. A recent detailed discussion of meteor activity from the region close to the ecliptic pole by Koseki (2014) reveals a rather complex situation. The shower produces several radiants which are relatively close to each other. Koseki's work shows that the entries in the IAU meteor shower database are not conclusive.

Koseki (2014) discussed enhanced activity observed in 1950, 1993, and 2007. These observations may hint at a period of seven years. Hence, a note about possible higher KCG rates was published prior to the detailed analysis in the IMO Journal WGN in June 2014 (WGN 42:3, p. 89).

Figure 1 – The radiant of this slow, bright meteor observed on 2014 August 12, $20^{\mathrm{h}}45^{\mathrm{m}}$ UT by Pierre Bader from a location near Würzburg, Germany, obviously fits best with a radiant position which is designated ALY in Table 1.

2 Activity of the κ-Cygnids in 2014

Here we report on video and visual observations obtained in August 2014. The activity was predicted to occur from more than one radiant area. This required an extra run of the video data analysis because the list includes only one KCG entry. We distinguished between four centers derived from Koseki's (2014) data as listed in Table 1.

Various data support that we indeed recorded activity from different radiants. We report on the video data in detail in section 2.2. In Figure 1 we present an image of a bright κ-Cygnid meteor.

2.1 Visual data

Due to the unfavourable moonlight conditions in August 2014 with the full moon on August 13, the data sample is quite small. Visual observers made counting observations only during the moonlit nights right after the 2014 Perseid maximum. Hence it was not possible to check for association with the different radiants. Since the radiants lined up to a great extent for the most common fields of view – for example when looking towards Pegasus – we may assume that most κ-Cygnids of any of the radiants were counted as KCG. However, a certain portion of possible shower meteors particularly from the farthest radiant (ALY in Table 1) may have been missed. For a comparison between the video and visual data we need to combine all components from the video analysis and have to keep in mind that the visual ZHR is expected to be underestimated. It is not reported whether meteors radiating not from the listed radiant are considered as sporadic or whether the observer knew about the announcement and allowed a larger radiant area.

The total KCG activity from visual and video data is shown in Figures 2 and 3. We used a population index $r = 3.0$ and a zenith exponent $\gamma = 1.0$ for the visual data over the entire period, although there strong hints that r is lower. This is discussed in section 3. However, both r and γ are not critical for the visual data analysis. In many intervals the limiting magnitude was between 6.0 and 6.5. Further, the radiant was between 50 and 90 degrees above the horizon during all intervals. So the errors introduced by these values are negligible. The main limitation comes from the small sample and the assumed radiant position and thus inconsistent shower association.

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Table 1 – Assumed radiant positions from Koseki's (2014) analysis. For the KCG we refer to the video data shown in the analysis paper; ZDR is an average position of the ZDR1 and ZDR2 given in the paper. The given decimal does not represent the accuracy of the position but was used for interpolation of the radiant drift.

Sol.long. (deg)	KCG (7yr) (22.3 km/s)		KCG (bckg) (21.1 km/s)		ZDR (22.0 km/s)		ALY (20.2 km/s)	
	α	δ	α	δ	α	δ	α	δ
130	280.3	42.4	275.1	50.5	276.0	60.1	283.0	39.8
135	283.6	45.5	275.5	53.5	272.0	61.8	282.0	43.3
140	286.5	48.7	275.1	56.0	267.1	63.0	280.1	46.1
145	289.0	51.9	273.8	58.5	261.4	63.5	277.3	49.1
150	291.0	55.3	271.5	60.8	255.6	63.4	273.6	51.1
155	292.5	58.7	268.0	62.7	250.1	62.5	269.2	52.5
160	293.2	62.2	263.5	64.1	245.4	61.0	264.2	53.1

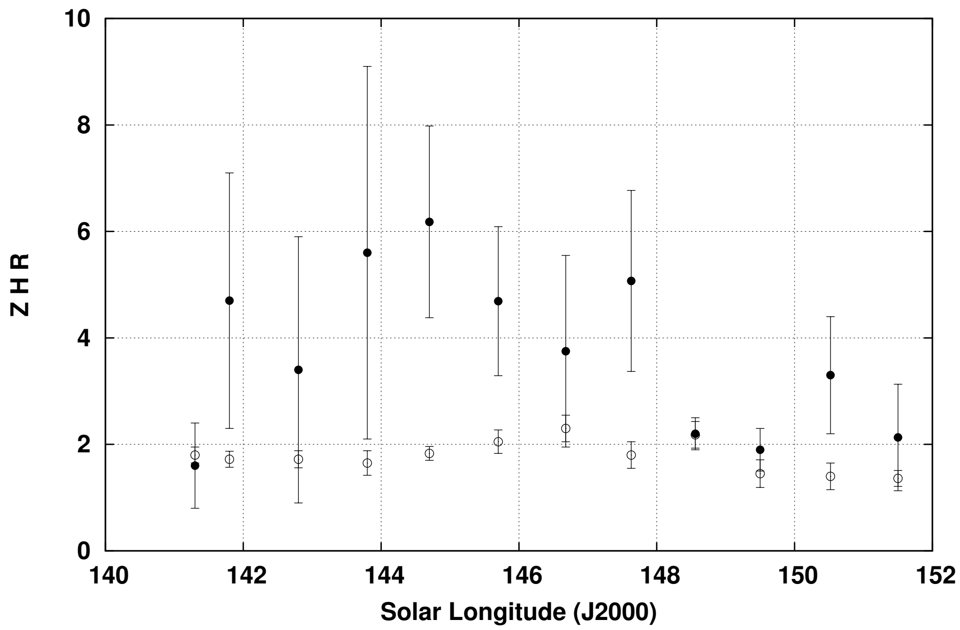

Figure 2 – Visual ZHR of the 2014 κ-Cygnids, calculated assuming a constant $r = 3.0$ and a zenith exponent $\gamma = 1.0$ over the entire period. Additionally, the average ZHR calculated for the KCG between 1988 and 2007 is plotted.

The average ZHR level (1988–2007) of the visual κ-Cygnids reaches 2 and has no obvious profile with a pronounced maximum, although we may consider the period around 145° solar longitude with ZHR ≈ 2.2 as the maximum. In contrast to this, in 2014 the ZHR reached ZHR ≥ 6 in the interval 144–145° solar longitude. This is about three time the average rate. Further, all intervals between 141°.5 and 148°.0 show a ZHR ≈ 4 or above – which is about twice the long-term level.

2.2 Video data – general activity

For the calculation of the video flux, we applied $r = 3.0$ as for the visual data and $\gamma = 1.50$. This value was found to be reasonable for video observations and is used as a standard if no detailed analysis is done. As in the case of the visual data, the radiant was high in the sky and hence the effect of a deviation of the zenith exponent remains negligible. The relative ratio between the 2014 and the average video flux data is of the order of 3–4. The period of enhanced rates extends from 136° until 154° which is longer than deduced from the visual data. The actual maximum period from the general video data set is between 141° and 145°, thus in good agreement with the visual data.

2.3 Activity from sub-radiants of the κ-Cygnids

The video data allowed to check for activity from the sub-centers listed in Table 1. Associating single station meteors to radiants which are very close to each other and have very similar velocity as well is limited (Molau & Rendtel, 2009). In our case, the radiant areas of the KCG (7yr) and KCG (bckg) are almost overlapping. Hence it may be that the KCG (7yr) is even stronger while the background KCG includes a portion of probable KCG (7yr) meteors.

The flux profile in Figure 4 shows that activity from the KCG radiant which is supposed to be responsible for periodic activity every seven years (Koseki, 2014) appears immediately from the background at 134°. The flux reaches a maximum of about $2.5 \cdot 10^{-3}\mathrm{km}^{-2}\mathrm{h}^{-1}$ and subsequently decreases towards 155°. (For comparison: the maximum value corresponds to the typical flux of e.g. the α-Capricornids (Molau et al., 2014)).

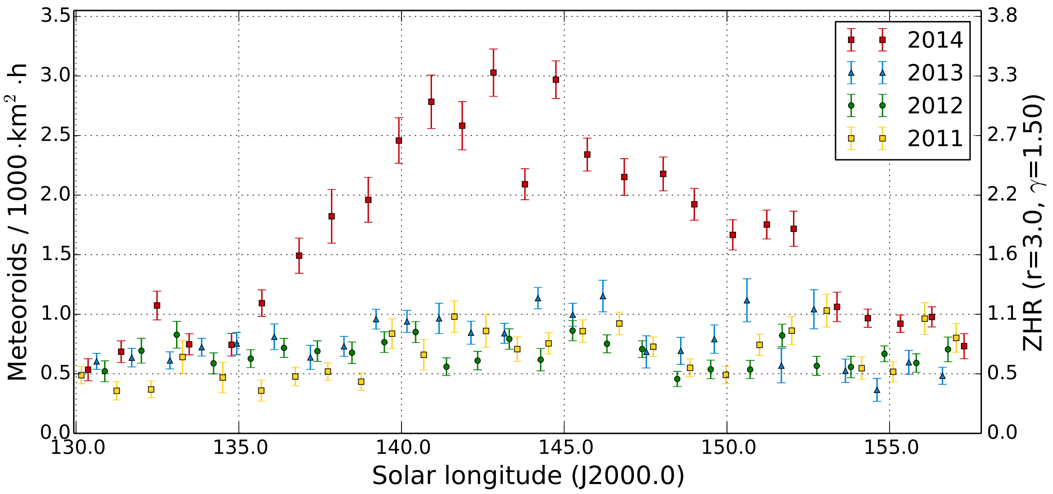

Figure 3 – Total video flux from the κ-Cygnid radiant area and comparison with the values observed in the previous years, using $r = 3.0$ and $\gamma = 1.50$ for all analyses.

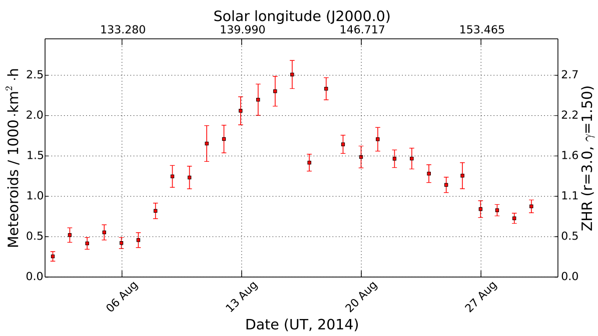

Figure 4 – Video meteor flux from the κ-Cygnid radiant designated KCG (7yr) in Table 1.

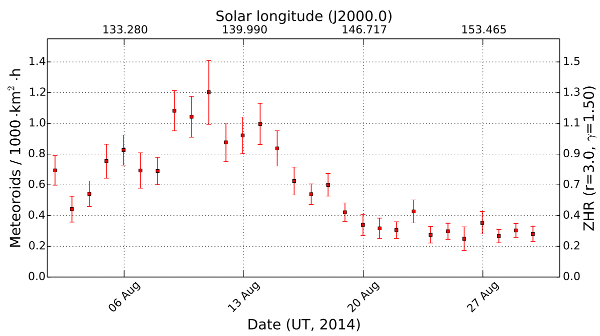

Figure 5 – The distant radiant designated ALY in Table 1 shows a flux which is about half the strength of the KCG flux.

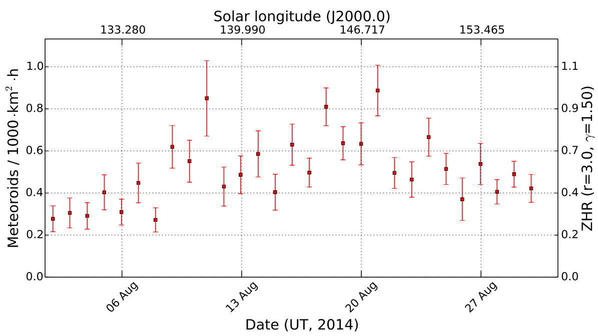

Figure 6 – The flux from the component listed as ZDR in Table 1 remains very low over the entire period.

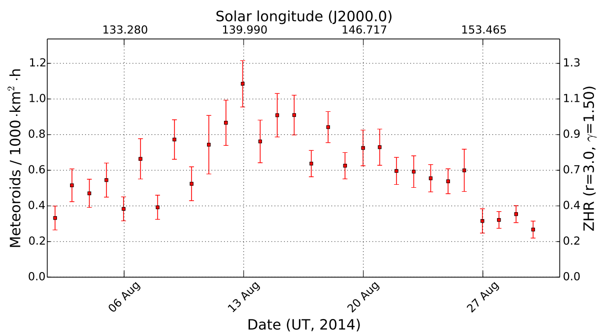

Figure 7 – Flux from the KCG background component.

The component designated ZDR appears like a background activity with relatively large scatter over the entire period under study (Figure 6) and with a low flux of less than $0.8 \cdot 10^{-3}\text{km}^{-2}\text{h}^{-1}$.

Contrary to this, the radiant designated as ALY (Figure 5) shows an increase already in early August at about 130° with a maximum before the Perseid peak in the interval 135°–141°. Here the flux reaches $1.1 \cdot 10^{-3}\text{km}^{-2}\text{h}^{-1}$ and thus about half the strength of the most active component KCG. At 144° the activity is at the detection limit again.

Finally, the flux observed from the KCG background component is of the same order as the ALY component, i.e. about $1.1 \cdot 10^{-3}\text{km}^{-2}\text{h}^{-1}$ at the moment of the Perseid maximum near $\lambda_\odot = 140°$. The flux is above $0.5 \cdot 10^{-3}\text{km}^{-2}\text{h}^{-1}$ between 130° and 153°, confirming the usually listed activity period of the κ-Cygnids.

We also see that the sum of the fluxes of the three components is larger than the flux shown in Figure 3. This is because we consider meteors from a much larger radiant area.

Table 2 – Average population index r for the meteors associated with the radiants given in Table 1 within the period August 10–19 ($\lambda_\odot = 137°$ to $146°$) and the sporadic meteors recorded in the same period.

Radiant	Sample	r
KCG (7yr)	1442	2.1
KCG (bckg)	573	2.0
ZDR	392	2.2
ALY	478	1.9
SPO	7407	2.3

Noticeably, the flux of the KCG component shows an obvious dip at $\lambda_\odot = 144°$ (August 17). This feature does not appear in the profiles of the Perseids and the sporadic meteors. We do not have an explanation for this at the moment.

3 Population index of the 2014 KCG

Applying the procedure described in Molau et al. (2014), we are able to determine the population index r for the meteors associated with the different radiants.

For the period August 10–19 ($\lambda_\odot = 137°$ to $146°$) we find average population indices for all radiants which are significantly lower than the value of 3.0 given in most compilations. The population index for the sporadic meteors is also significantly lower than the annual average $r = 2.95$ or the value found for the period in August of $r \approx 2.8$ (Rendtel, 2004). So we cannot exclude a systematic effect in our data sample. One source may be a small number of Perseids which is not correctly associated to the shower radiant. Since the values of r for each KCG component are all below the value for the sporadic meteors, we may conclude that the population index r of all KCG sub-showers are lower than 3.0 which is listed. Table 2 gives the results we obtained. We may try a calibration assuming a the sporadic $r \approx 2.8$ in the given interval, indicating an offset of about 0.5 which then hints at $r \approx 2.6$ for the KCG component under study.

4 Conclusions

The κ-Cygnids (012 KCG) showed enhanced activity in August 2014, centered around $\lambda_\odot = 144°$ (August 17). Such an enhancement was predicted by Koseki (2014). The ZHR derived from visual data as well as the flux calculated from video data is about three to four times the long-term average.

The additional activity can be associated mainly with a branch which is located about 8–10 degrees southeast of the listed radiant position (see, e.g., p. 37 in Rendtel, 2014). The population index r is significantly lower than the reference value $r = 3.0$ given in most compilations. The value of $r = 2.1$ found for the component under study may be underestimated, but a rather rough calibration would still put it at $r \approx 2.6$ for the 7-year KCG component.

The 2014 observations are a strong additional hint at a 7-year period of sections of higher density within the stream. Details and references concerning observations in 1993 and 2007 are given by Koseki (2014). Since not only the mentioned branch contributed to the higher flux but also the "mean stream" it is not possible to assign the periodicity to either of the components.

Our data also confirm the complexity of the κ-Cygnid shower as described by Koseki (2014).

Acknowledgements

The analysis of the visual data is based on those reports submitted electronically to the IMO web page during the Perseid period. The video data analysis is a result from the IMO Video Meteor Network. We thank all observers who provide their observational data which allow this research.

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"Hiss, clicks and pops" – The enigmatic sounds of meteors

J.A. Finnegan[1]

The improbability of sounds heard simultaneously with meteors allows the phenomenon to remain on the margins of scientific interest and research. This is unjustified, since these audibly perceived electric field effects indicate complex, inconsistent and still unresolved electric-magnetic coupling and charge dynamics; interacting between the meteor; the ionosphere and mesosphere; stratosphere; troposphere and the surface of the earth.
This paper reviews meteor acoustic effects, presents illustrating reports and hypotheses and includes a summary of similar and additional phenomena observed during the 2013 February 15 asteroid fragment disintegration above the Russian district of Chelyabinsk.
An augmenting theory involving near ground, non uniform electric field production of Ozone, as a stimulated geo-physical phenomenon to explain some hissing 'meteor sounds' is suggested in section 2.2. Unlike previous theories, electric-magnetic field fluctuation rates are not required to occur in the audio frequency range for this process to acoustically emit hissing and intermittent impulsive sounds; removing the requirements of direct conversion, passive human transduction or excited, localised acoustic 'emitters'.
Links to the Armagh Observatory All-sky meteor cameras, electrophonic meteor research and full construction plans for an extremely low frequency (ELF) receiver are also included.

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Foreword

> "Famous Meteor which was seen to pass over Italy, on the 21st of March 1676 Anno Domini... its perpendicular altitude was at least 38 Miles. That in all places near this course, it was heard to make a hissing noise as it passed ... it was heard to give a very great blow."
> (Geminian Montanari, Professor of Mathematics, Bologna, 1664–1678.)

Meteor mythology dates back at least three thousand years. Meteor comes from the Greek word *meteoros*, meaning "suspended in the air". Aristotle, the most influential of the ancient Greek philosophers, erroneously grouped meteors, comets, aurorae and the Milky Way into the same category as clouds, wind, lightning, thunder and rainbows.
The terrestrial explanation of meteors expounded in Aristotle's 340 BC treatise *Meteorology* persisted, until Prof Denison Olmsted and Alexander C. Twining established modern meteor science with their pioneering analysis and naming of the great Leonid meteor shower of 1833 November 13. Previously, this celestial explanation of meteors was "altogether denied by the highest authorities in science, and the strongest evidence resisted, when adduced in support of an event which was conceived repugnant to the laws of nature. Philosophic incredulity, though generally useful, was carried too far, and proved injurious to the progress of science; for while doubts were entertained concerning the reality of stony showers, the sources of the aeroliths and their nature was not, of course, likely to be made objects of investigation." Dr James Apjohn, Professor of Chemistry. 1836 May 23.

Significantly, Olmsted also reported noises from the meteors, "The sounds supposed to been heard by a few observers are represented either as a hissing noise, like the rushing of a skyrocket, or as slight explosions, like the bursting of the same bodies. These comparisons occur too uniformly and in too many instances to permit us to suppose that they are either imaginary or derived from extraneous sources." Even in more recent times, the scientific incredulity and the doubts entertained concerning the reality of 'meteor sounds' also made it unlikely that they would be made 'objects of investigation. In 2000, Dr. Donald Yeomans, presently manager of NASA's Near Earth Object Program Office, commented, "It's coming out of the realm of myth and into the realm of possibility, but there are some serious doubters."

Introduction

> "The stars rushed across the heavens... like grasshoppers in a field. This continued until dawn. The inhabitants cried out with terror and fervently implored the mercy of the Most High."
> (Arab account of the 1202 Leonid meteors.)
> (Littmann, 1998, p. 61)

On the evening of the 1783 August 16, just six years before the foundation of Armagh Observatory, a great ball of flaming light appeared over the Shetland Islands and in only half a minute passed across Britain, continuing onwards to France and northern Italy. After about ten minutes a rumbling noise, "as it were of thunder at a great distance", was heard. Sir Charles Blagden, secretary of the Royal Society of London, collected the reports of this startling event and prepared a paper for the society. He was puzzled by reports from some observers that a kind of hissing sound "attended the meteor" as it passed across the sky. He was sceptical that sound from an object apparently 50 English miles high "should be conveyed in an instance" but added, "testimony in support of it is, however, so considerable, on the occasion

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of this as well as former meteors, that I cannot venture to reject it, but would leave it as a point to be cleared up by future observers."

Future observers reported similar effects to Armagh Observatory on 2012 March 3, 2012 September 21 and 2014 January 15. Before correct identification, the 2014 January 15 meteor, with its delayed sonic boom, initiated an air-sea rescue alert over the Irish Sea.

1 Meteor colours

> "It was the colour of a green traffic light – amazing! Seen shooting stars before, but never anything like this."
> (Fireball report to Armagh Observatory.)

When a meteoroid enters the Earth's atmosphere it collides with air molecules, rapidly creating very high temperatures which ablates its outer surface, creating a luminous plasma envelope of charged particles. De-excitation of the particles influences the meteors' luminosity and colour. The emitted colour can vary with altitude, at higher altitudes meteor metal atom emissions dominate. At lower altitude the shock front air plasma emissions may become dominant.

The light emitted by atmospheric nitrogen molecules (N_2) and oxygen atoms (O) appears red. Light emitted from the metal atoms composing the meteoroid can appear blue, green or yellow. Sodium (Na) atoms produce an orange-yellow light, Iron (Fe) atoms a yellow light, Magnesium (Mg) a blue-green light, ionised Calcium (Ca^+) atoms a violet light, Nickel (Ni) a green light and silicates a red light. With fainter objects, slow meteors often appear to be red or orange. Fast meteors often cause a blue sensation.

The velocity of the meteor also plays an important role, since greater kinetic energy will intensify certain colours compared to others. The collision velocities of meteoroids can range from as low as 15 km/s up to 72 km/s. Characteristic colours are associated with some particular meteor showers, since these meteoroids are usually composed of similar materials and enter our atmosphere at similar velocities. Comparisons are sometimes made with the colours of the Aurora Borealis and Australis, or Northern and Southern Lights. These comparatively rare, rapidly changing patterns of light in the sky are caused by coronal mass ejections or the solar wind, which disturb the Earth's magnetic field and produce high-energy particles that penetrate deep into the Earth's mesosphere, where their interactions with the different types of molecule in the Earth's upper atmosphere create the characteristic green, pink and sometimes red colours associated with aurorae.

Although scientific knowledge of the aurora explains the visual phenomenon, myths still persist among the inhabitants of the Arctic regarding audible phenomena. One says that you can communicate with the aurora by whistling. The Inuit believe that whistling to the aurora will affect its motion and that in response to a whistle you will hear a "rustling and sighing sound", known as "the whisper of souls of the dead".

2 Meteor related sounds

Armagh Observatory receives reports of sounds directly associated with some bright fireballs. They comprise two types: delayed sonic booms and simultaneous 'electrophonic' sounds. The investigation of meteor electrophonic effects at extremely low frequencies up to 24 kHz is an ongoing line of enquiry and observation at the Observatory.

2.1 Sonic Booms

> "We had never seen anything like it and we both commented if it would eventually crash. About two minutes later we heard a boom and were astonished as to what we had just witnessed."
> (Fireball report to Armagh Observatory.)

Meteors with magnitudes exceeding -3 are called fireballs. Fireballs brighter than -14 are usually called bolides and when brighter than -17, super bolides. If a very bright fireball, usually greater than magnitude -8, penetrates the stratosphere to below an altitude of about 40 km and explodes, it is possible that time-delayed 'sonic booms' may be heard on the ground. This is more likely if the disintegration occurs at an altitude angle of about 45 degrees to the observer and less likely if it occurs overhead or near the horizon. As sound travels at ~ 330 m/s (~ 20 km per minute at sea level), it will generally be several minutes after the visual event before a sonic boom can be heard. After more than ~ 5 minutes, only inaudible infrasound (<20 Hz) effects can propagate to the ground from bolides at $\sim 70+$ km.

The world's first confirmed recording of a fireball sonic boom occurred at 9:22 pm on 1969 April 25 at Bangor, N. Ireland, when the fall of the Bovedy meteorite was recorded by an amateur ornithologist recording bird song in her garden. Fireballs which produce meteorites are often associated with sounds, both sonic and electrophonic.

2.2 Electrophonic sounds

> "It was very bright and very orange and I heard bangs and crackling, which is what alerted me to it in the first place."
>
> "It disappeared about 10 seconds later in the west. I heard pops almost like fireworks sounds coming from the same direction I first saw the orange lights."
> (Fireball reports to Armagh Observatory.)

'Electrophonic sound' is an audibly perceived effect attributable to electricity and magnetism. The term was introduced by Prof. Stanley Smith Stevens (Stevens, 1937) to describe the sensation of sound caused by an audio frequency oscillating electric current flowing through the head. One cause was then thought to be electro-thermal elastic expansion and contraction of portions of the auditory system. Prof. Peter Dravert of Omsk University (Dravert, 1940) used the term 'electrophonic fireball' to describe a bright meteor simultaneously accompanied by non time delayed, therefore anomalous, ‘crackling’ sounds.

> “The witness recalls hearing a cracking sound during the whole light of the meteor, in duration of 5 seconds. The sound did not have direction. It was in the middle of his head like a sound in a stereo headphone.”
> (Eisse Pieter Bus. Visual and photographic meteor observations, 01:12:47 UT, 1972 April 23 at The Observatory of the University of Groningen at Roden. Global Electrophonic Fireball Survey (GEFS) catalogue.)

Electrophonic fireballs might simultaneously cause an intense, fluctuating, electric field effect around an observer. An electric field is generated by electric charge, as well as by a time-varying magnetic field. The fluctuation rate of an intense field could coincide with the ~ 10 Hz to ~ 15 kHz audio hearing range and might be demodulated and perceived under acoustically quiet circumstances; possibly by a direct electro-static response of portions of the auditory system causing the sensation of sound in the head with no corresponding wave motion of the air.

> “The surrounding air is often mentioned as the direction or source of the meteor sound.”
> (Global Electrophonic Fireball Survey (GEFS) catalogue.)

> “The fizzing sound was clearly very distant, from above, only with meteors that had sparkly persistent tails, and only when they were nearly directly overhead. Well, some people hear auroras, so I hope I’m not going crazy!”
> (Karen Newcombe, San Francisco. Report to NASA TV Live Leonids show. 2001 November 18.)

> “It’s actually loud. There’s a solid stream of hissing. Is it possible to hear meteors?”
> (Chris Hann, Lawrence, MA. Report to NASA TV Live Leonids show. 2001 November 18.)

It is possible that an associated, transient increase in the natural vertical geo-electric field gradient near the observer’s location could temporarily stress, polarise and disassociate atmospheric Oxygen molecules. The resulting electric field reactions [$O_2 \rightarrow 2O$] with the free radicals of oxygen recombining to create ozone [O_3] with nitrogen oxides as by products, can also produce incoherent, wideband audio frequency air pressure modulations; causing hissing sounds to simultaneously appear ‘out of thin air’, possibly from up to a few hundred metres above an observer.

Photoelectric production of Ozone, with nitrogen oxides as by products, verified during the Chelyabinsk super bolide event (see sections 4.2 and 4.3) could also cause audio frequency air pressure modulations, with associated noises, to occur around an observer during phases of an exceptionally large meteoroid’s disintegration and before the arrival of acoustically propagated sound.

> “Proposed dissipation of the meteor ‘ether waves’ into sound waves on objects attached to the earth, such as plants or artificial structures.”
> (Udden, 1917a,b)

> “There are also many individuals who report that the sounds seemed to have originated from surrounding objects rather than the fireball.”
> (Lamar & Romig, 1964)

Experiments by Prof Colin Keay at The University of Western Ontario, Canada, and at the University of Newcastle, New South Wales, have shown that a localised passive transducer effect can cause a field conversion process; creating around the observer coinciding airborne sound waves from suitably stimulated ‘emitters’. An electric field which fluctuates with time, such as due to the motion of charged particles producing the field, can affect the local magnetic field. Magnetically stimulated into faint audible vibration, sound emitters could include nearby metallic objects such as spectacle frames and electro-statically stimulated non-conductive materials such as hair and vegetation. In tests, three volunteers with fine hair were able to hear faint sound vibrations from their hair, passively transducing a 4 kHz oscillating electric field with a lower limit of 160 V peak to peak per metre. Most volunteers required Kilovolt per metre electric field levels before [cranial?] sound detection occurred. “Under [intense] electric fields of 400 kV peak to peak per metre varying at 0.5, 1, 2 and 4 kHz, samples including aluminium cooking foil and typing paper vibrated, producing [low] sound levels in the 40 to 60 dB range. Magnetic fields of up to 0.1 mTesla (~ 1.5 times the geomagnetic field) varying at audio frequencies were not audibly transduced” (Keay & Ostwald, 1991). Note that exciting self resonant audio frequency vibrations in the emitters will increase their radiated acoustic energy.

Between a fireball and an observer, within the Earth’s intervening magnetic, electric and charged particle fields, other electromagnetic processes can occur. Caused by turbulent head and trailing plasma interaction with the Geo-magnetic field, meteor-stimulated extremely low frequency (ELF) ‘radio wave’ generation may be one of these. A ‘radio wave’ propagates because of the self sustaining energy exchange between the oscillating electric and magnetic fields of which it is composed, even when its source ceases. If of sufficient intensity and the frequencies of oscillation coincided with the ~ 10 Hz to ~ 15 kHz frequency range of hearing, the passive direct conversion processes described previously might cause the sensation of simultaneous ‘sound’ to be experienced by an observer. Sustained radio frequency radiation is believed to be associated with turbulence in the continuum flow regime as a bolide ablates, decelerates and descends in altitude. Continuum flow usually occurs within a second of maximum brightness. A bolide lasting less than 3 seconds is unlikely to enter this continuum flow regime. Bolides which remain in the continuum flow regime to lower altitudes, due to their smaller inclinations and correspondingly longer trajectories, may enable sustained 'electrophonic sound' perception (Keay, 1992).

Electric-magnetic ELF phenomena attributable to meteors are an ongoing field of research at Armagh Observatory. Detectors covering from $\sim$ 5 Hz to 24 kHz have been constructed and utilised simultaneously with our meteor cameras. The ELF recordings are subject to detailed spectrum analysis. Since the Earth's geo-electric-magnetic ELF background is intensely active involving natural phenomena such as Sferics, Tweeks, Whistlers and Sprites, and also strong man-made emissions, distinct effects or disturbances directly attributable to individual fireballs are elusive.

Additional information examining these topics can be found at:
`https://goo.gl/Nlh7CQ`
`http://goo.gl/q7OQbQ`
`http://goo.gl/uRB9Bp`
`http://goo.gl/Rlrd3Y`
`http://www.allskycam.co.uk`
`http://www.gefsproject.org/`

Full instructions to build an ELF detector, based on (Rault, 2010), can be found at `https://goo.gl/Z8Lj69`

3 Meteor electrophonic sound reports

> "By an optimistic prediction, a person who could spend every night outdoors may expect to hear an electrophonic meteor once in a lifetime."
> (Prof Colin Keay.)

Reported fireball sounds include sustained hissing, swishing and sizzling. Also clicks and pops, possibly associated with pre-luminous phases or fragmentation. Review of the Armagh Observatory fireball records and previous international surveys suggest that many 'electrophonic sound' reports may originate within a $\sim$ 250 km wide fan shaped area ahead of and below some fireballs.

3.1 Historic reports

> "And there fell upon men a great hail out of heaven, every stone about the weight of a talent: and men blasphemed God because of the plague of the hail; for the plague thereof was exceeding great."
> Revelations 16:21. (King James Version)

23–79 AD.

> "Fiery shooting stars fall into clouds where they are extinguished with a hissing noise, just as when red hot iron is plunged into water"
> Pliny the Elder (23–79 AD) (Littmann, 1998)

817.

> Strange noises heard simultaneously with the passage of a bright fireball have a long history. Some are hidden in very old Sumerian, Arab and Chinese chronicles. For example, a Chinese record from the year 817 describes a meteor "which made a noise like a flock of cranes in flight."
> (Astapovich, 1951; LaPaz, 1958)

The following is a link to a similar meteor, recorded by an acoustic microphone in Mongolia during the 1998 Leonids: `https://goo.gl/Ru6dyB`.

1026.

> "A loud sound and intense light"
> Arab record of a meteor shower, probably the Perseids. (Rada & Stephenson, 1992)

1492 November 7.

> "A great stone fell out of the sky... accompanied by crashing thunder and lightning."
> "Gruesome thunderbolt and long lasting roar."
> Ensisheim meteorite. (Rowland, 1990)

1676 March 21.

> "Famous Meteor which was seen to pass over Italy, on the 21st. of March O.S.Anno 1676, ... its perpendicular altitude was at least 38 Miles: That in all places near this course, it was heard to make a hissing noise as it passed, ... it was heard to give a very great blow, (Tuono di maggior rumore di gross Cannonata), immediately after which, another sort of sound was heard, like the rattling of a great cart running over stones, which continued about the time of a Credo. ... it cannot be wonder'd that so great a body moving with such an incredible velocity thro' the Air, tho' so much rarefied as it is in its upper regions, should occasion so great a hissing noise, as be heard at such a distance as this was."
> Geminian Montanari. Professor of Mathematics, Bologna, 1664–1678.

1719 March 19.

> Electrophonic effects of a large bolide seen over England. Sir Edmund Halley reported some eye-witnesses as "hearing it hiss as it went along, as if it had been very near at hand" but dismissed such claims as "the effect of pure fantasy."
> (Halley, 1719a,b)

1783 August 18.

> Intrigued by reports of instantaneous hissing sounds from a large meteor, Sir Charles Blagden presents his arguments for the "electric origin of meteors." Since the nature of electricity was still not understood, he described meteors as "electricity fluid." It was

thought possible for this fluid to travel faster than sound and produce "hissing sounds" around an observer.
(Blagden, 1784)

1813 September 10.
The Great Limerick meteor. The 'Brasky mass', on loan from The National Museum, Dublin. The largest piece, weighing more than 27 kg, is currently on display in the Ulster Museum, Belfast, with a cast on display in Armagh Planetarium. It is the biggest meteorite to fall in Ireland and the UK in historic times (exceeding the largest of the 45 kg, total weight, 1965 Barwell meteorite fragments). There were numerous eyewitness accounts in newspapers showing that it was a spectacular morning event, possibly similar to the 2013 Russian Chelyabinsk meteor, with 'bright lights', loud bangs, 'hissing noise' and 'extraordinary smoke'.
(Heard, 2013; Apjohn, 1839)

1833 November 13.
"One or two instances were reported of persons who died with terror; many others thought the last great day had come."
Prof Denison Olmsted, writing about the great Leonid meteor shower of 1833.

1930 August 13.
"A multiple hissing noise is heard... the hissing noise comes closer and becomes more and more frightening... fishermen saw large balls of fire which fell from the sky like thunderbolts... they landed in the centre of the forest with a triple shock... causing tremors like those of an earthquake."
River Curuça. Brazilian Amazon. (Bailey et al., 1995; Steel, 1995)

3.2 Recent reports

This selection of electrophonic reports also includes high altitude trails, fragmentation, sonic booms and meteorite recovery; suggesting that fireballs which result in meteorites can generate sounds, both sonic and electrophonic.

1965 December 24, $16^{\mathrm{h}}12^{\mathrm{m}}$ GMT.

Az. 20° over Coventry area, England.

Multiple (at least three) fireballs. Magnitude very bright. Slope 20°. Few visual observations due to extensive cloud. Fireball 2 exploded into 4 major fragments. No such explosion for fireball 1 or 3. Fireball 3 developed a tail, 1 and 2 possibly did. Fireballs 1 and 2 left white trails. Many chondrites recovered from near Barwell village.

Numerous reports of sonic phenomena, including a few reliable reports of electrophonic noises. "One observer, for example, reported noises of this type before he saw the bolide break through the cloud cover towards him. Witnesses in Barwell itself have given consistent accounts of the actual sounds heard at impact. These are typically described as starting with a "swishing" noise and ending with a succession of dull thuds." Contact: Prof. P.C. Sylvester-Bradley, University of Leicester, England. (Miles & Meadows, 1966)

1969 April 25, $21^{\mathrm{h}}20^{\mathrm{m}}$ – $21^{\mathrm{h}}25^{\mathrm{m}}$ GMT.

Az. 322°, 1 km W of Lisburn, Northern Ireland.

Two meteorites recovered, one near Lisburn and another at Bovedy, near Kilrea, 45 km further along the path.

Many observers in SW England, Wales and Ireland. From various areas as far away as Dublin a swishing or rushing sound was reported as the fireball passed over. (Meighan & Doughty, 1969; Andrews et al., 1969)

1978 April 7. New South Wales, Australia.

Edgecliff, Sydney, 20 km from the ground track, A. Hayes "Heard a noise like an express train or bus travelling at high speed. Next an electrical crackling sound, then our backyard was as light as day."

Vales Point, 40 km from the ground track, J. Ireland "Heard a sound like an approaching vehicle and saw a flash of light, from behind my right shoulder, as everything was lit up like daylight."

Kotara, Newcastle, 40 km from the ground track, N. Jones heard a noise like a "phut" when the bolide flared, but "It was not loud enough to wake anyone."

Other descriptions of sounds simultaneous with the above sightings were "a loud swishing noise"; "a humming sound like a transformer or distant siren"; "like steam hissing out of a railway engine for a count of about ten"; "a swishing sound like the onset of an unexpected high wind" and "a low moaning, whooshing." Prof Colin Keay.

2001 November 18. San Francisco, USA.

"The weirdest thing was that I am sure I could hear several of the meteors. Several times when a meteor with a persistent streamer seemed directly overhead, I heard a faint fizzing noise. How is that possible when the thing is hitting the edge of the atmosphere a couple of miles above my head? Even if there were some sort of meteor thunder, I wouldn't think it could reach my ears through the air until after the meteor was no longer visible. The first time it happened I thought I was making up my own sound effects, but after five or six repetitions, the sound was clearly very distant, from above, only with meteors that had sparkly persistent tails, and only when they were nearly directly overhead. Well, some people hear auroras, so I hope I'm not going crazy!" Karen Newcombe, San Francisco.

I just walked outside at 4:46 a.m. EST [on Nov. 18th]... and it's actually loud. There's a solid stream of hissing. Is it possible to hear meteors? Chris Hann. Lawrence, MA. Reports on NASA TV Live Leonids show. 2001 November 18.

2012 March 3, $21^{\mathrm{h}}38^{\mathrm{m}}$ GMT. Cullen, Scotland.

"I noticed a slow moving bright light over North Sea in North direction, about 60 deg from horizon, moving towards me in southerly direction, a bit brighter than Venus, slowly getting brighter as it got directly overhead. It had a long fainter tail. There was a slight

'Shhh' sound and it kept going South at the same brightness until it was obscured by the houses behind me. Probably took about 10 seconds from noticing it, until it was obscured, to traverse the sky above – a lot slower moving than I've ever seen before!" Fireball report to Armagh Observatory.

2012 September 21, 22^{h}55^{m} BST. Upton, Wirral, Merseyside.

"I saw a huge fireball travelling across the sky from the East heading West. It had a huge tail and parts of it were visibly breaking off. It was going very fast and it was fairly low in the sky, so would be hitting the ground shortly after I saw it disappear out of my view. It was very bright and very orange and I heard bangs and crackling, which is what alerted me to it in the first place." Fireball report to Armagh Observatory.

"What makes this exciting is that we're talking about a phenomenon that has been experienced by people for perhaps thousands of years, even in modern times people who reported hearing such sounds were ridiculed. It was only about 25 years ago that Professor Colin Keay was able to do the research and legitimise the experiences of all those generations of people." Dr Dennis Gallagher. NASA Marshall Space Flight Centre.

3.3 Electrophonic meteor theories

Keay (1980a,b,c) investigated reports of 'electrophonic sounds' associated with a number of bright fireballs. He classified the sounds into three groups: smooth (71%), staccato (18%) and sharp (11%). In 1980 he calculated that meteor plasma interaction with the geo-magnetic field could generate Extremely Low and Very Low Frequency (ELF/VLF) 'radio emissions' in the range $\sim$ 500 Hz to $\sim$ 10 kHz. Keay suggested that the geomagnetic field becomes "trapped and twisted" in the turbulent wake of a meteoroid and as the plasma cools the 'strain energy' of the field is released as ELF/VLF 'electromagnetic radiation'. Bronshten (1983) "confirmed that through this mechanism bright fireballs may produce radiated power levels of the order of Kilowatts" and "for such a fireball the kinetic energy dissipation rate exceeds ten Gigawatts." In 1988, this 'magnetic spaghetti' theory was reinforced when groups of Japanese observers from Nagoya University obtained simultaneous photographic and radio observations of a bright fireball, together with an audible "phut" sound report of the event (Watanabe et al., 1988).

However, the 'magnetic spaghetti' theory was not universally accepted as the definitive explanation. Electrophonic noise researcher Dr Andrei Ol'khovatov, The Radio Instrument Research Group, Moscow, reasoned that since the extremely active geo-electric-magnetic and anthropic background environment up to 15 kHz is not routinely transduced to sound by Keay's passive field conversion processes, then the magnitudes, at an observer's location, of the magnetic and electric field components of Keay's postulated meteor ELF 'radio emission' would have to exceed this background level to be passively detected. Keay stated that in his experiments audio frequency magnetic fields $\sim$ 1.5 times greater than the background geo-magnetic field were not audibly transduced.

Ol'khovatov (1993) wrote, "how little we know still, believing [that] the level of VLF generated by some audible meteors is insufficient for the perceived effect and that people would otherwise hear man-made VLF transmitters"... "I think that a bolide can trigger some [other] geophysical processes resulting in various geoelectric field disturbances."

"Personally, I don't think there is one single theory that can explain everything going on out there," Dr. Dejan Vinković, Global Electrophonic Fireball Survey. 2001.

As a phenomenon distinct from the longer duration hissing sounds, the sounds associated with electrophonic 'burster' meteors are characteristically described as staccato-like 'clicks' and short duration 'pops'. They appear similar in their sound characteristics to instrumentally detected Sferics and distorted Tweeks but remain difficult to explain.

Research by Beech & Foschini (1999; 2001) suggested that unlike the longer duration 'electrophonic sounds', the electrophonic bursters are not generated as a consequence of interactions between the meteoroid ablation plasma and the Earth's geo-magnetic field but appear as short-duration pulses in the observer's local electrostatic field. This is believed to be due to the generation of a strong electric field across a meteor shock wave propagating in plasma. Calculations for the description of the electric field strength, in terms of the electron temperature and the electron volume density, can link the electron line density to a meteor's absolute visual magnitude. This suggests a lower limit to the visual magnitude of electrophonic burster meteors as $M_v \sim -6$.

"Ironically Leonid meteors are least suitable devices for production of the VLF radiation via the Keay-Bronshten mechanism which demands the Reynolds number in the meteor plasma flow to exceed 10^6. In the case of the Leonids, which are mostly dust grains, this leads to unreasonably large initial size requirements, $D_0 > 3$ m and mass 3000 kg (Zgrablić et al., 2002). Nevertheless two clear electrophonic signals were instrumentally recorded during the 1998 Mongolian Leonid expedition. The first originated from the meteor at the altitude of 110 km and the second at an altitude of 85 to 115 km. In both cases the 'sounds' preceded the meteors' light maximum."

"These features are hard to explain, also in other models suggested for electrophonic bursters. No ELF/VLF signal was detected in these two events. But the [ELF/VLF] receiver apparatus was insensitive for frequencies below 500 Hz, while the frequency range of the observed 'electrophonic sounds' was 37 to 44 Hz. [An excited self resonant frequency of the microphone enclosure?] If one assumes that these sounds originated from the transduction of a ELF/VLF transient, the observed sound intensities will imply unreasonably high ELF/VLF radiation power, impossible to explain by any theoretical mechanism starting from [a] meteor alone" (Zgrablić et al., 2002).

Silagadze (2005) continues: "Therefore these remarkable observations show that the existing theories are at least incomplete and the electrophonic meteor mystery remains still largely unsolved. Zgrablić et al. (2002) suggested that the Leonids acquire large enough space charge, due to different mobility of ions and electrons and can trigger a yet unidentified geophysical phenomenon upon entering the E-layer of the ionosphere at ~ 110 km. It is assumed that such phenomena in its turn will generate a powerful electromagnetic radiation burst." "In this case no significant VLF signal is generated; instead we have a brief transient in the geo-electric field." This possibility was suggested by Ol'khovatov (1993). An electrostatic mechanism of geo-electric field perturbation, operating for bolides with steep trajectories, was also considered by Ivanov & Medvedev (1965).

Almost 300 years since Sir Edmund Halley's erroneous scientific dismissal, the phenomenon of sounds perceived simultaneously with meteors is still without a robust physical explanation or unified model. Current ideas and associated models usually present the following process: Disturbance/excitation—Coupling/ transmission—Observer perception.

Simple, selective, models can fail to indicate which of their physical factors changed or were absent between 'sound' perception and non perception. For example, they do not unambiguously explain why some periodic meteors appear to enable their proposed 'electromagnetic' field characteristics at an observer's location, while subsequent apparently identical meteors or most others do not.

Consensus suggests that most audible meteor 'sounds' are simultaneously created by meteor 'radio emissions' in the audio frequency range reaching ground level. How these propagating electric-magnetic field oscillations at audio frequencies then emit acoustically or are perceived or heard passively is mostly speculative. It also remains undetermined whether reported 'audible sounds' should coincide with specific instrumental ELF electric and magnetic field spectra, attributed unambiguously to the observed meteor. It is also necessary to clarify what is meant by 'simultaneously', since different types of sound perceived during several continuous seconds of visual observation may not coincide exactly with observed events, i.e. flaring, fragmentation, trail/train creation: perceptible delays suggesting additional, almost immediate, intermediary processes.

An augmenting theory involving meteor train initiated, near ground non uniform electric field production of Ozone as an "unidentified geophysical phenomenon" (see above) to explain some hissing meteor sounds is suggested in section 2.2. Unlike previous theories, electric-magnetic field fluctuation rates are not required to occur in the audio frequency range for this process to acoustically emit hissing and intermittent impulsive sounds; removing the requirements of direct conversion, passive human transduction or excited, localised, acoustic 'emitters'. Facilitating intermediary processes, occurring between the postulated near ground, atmospheric acoustic emission and the associated meteor trail or train, remain ill-defined. Persistent train interaction with the Ionosphere/neutral atmosphere in the complex 80 km to ~ 110 km Mesopause transition region might create or trigger these processes; temporarily enabling the near ground, Ozone producing, corona inception potentials to occur. Electro-statically effected by these processes, it is also possible that unstable, very low altitude stratified charged air masses of dissimilar moisture content, in the lower night time atmospheric boundary layer, could be intermittently neutralised; with the resultant localised air pressure modulations producing similar acoustic emissions. These speculative, low altitude acoustic mechanisms need not emit visually and might also be associated with some Auroral sound reports.

"The extreme rareness of the phenomenon [electrophonic meteors] has prevented substantial experimental work so far; consequently it remains on the margins of scientific interest" (Vinković et al., 2002).

This disinterest is unjustified, since these audibly perceived electric field effects indicate complex, inconsistent and still unresolved electric-magnetic coupling and charge dynamics; interacting between the meteor; the ionosphere and mesosphere; stratosphere; troposphere and the surface of the earth. There are possibly significant and currently unrecognised diurnal, seasonal and yearly variances in the occurrence of 'electrophonic meteors' caused by Sun dependent changes in ionosphere composition. For example, diurnal D-layer changes may inhibit downward, daytime transmission and propagation of ELF 'radio emissions' from higher meteor altitudes. Also, the 2001 Leonid activity occurred during the 1999–2002 peak of solar cycle 23, which may have contributed to the reports of high altitude meteors and prominent hissing sounds, since the enhanced atmospheric and ionospheric densities may have extended the meteoroid interaction region within the atmosphere. These mostly unexplored aspects merit further observation, research and discussion.

An exceptionally powerful disintegration, such as the Chelyabinsk super bolide airburst, causes all of the historically reported 'electrophonic' effects to be observed.

4 The Chelyabinsk Airburst

"This object never got bright enough to be detected by a ground-based survey. Because it came at Earth from the direction of the Sun, It was basically undetectable before it hit Earth." Prof M. Campbell-Brown. Univ. W. Ontario.

"Such large scale invaders may be far more common than we previously suspected, the Earth may be subjected to three or four such events a century." Prof Mark Bailey. Armagh Observatory.

The Chelyabinsk super bolide was 100 times more energetic than the 4 kT of TNT equivalent[1] Sutter's Mill meteorite fall in California, USA on 2012 April 22. Possibly originating from the 2.2 km asteroid 86039 (Borovička et al., 2013) the 10 000 tonne, 19 m diameter fragment (Brown et al., 2013) that disintegrated

[1] 1 kT TNT equivalent= 4.185×10^{12} Joules

with the equivalent energy of 500 kT of TNT over the Chelyabinsk Oblast on 2013 February 15, was one of the largest airbursts since the $\sim$ 10 to 15 MT TNT equivalent Tunguska event of 1908 June 30 (Napier & Asher, 2009). The Chelyabinsk meteorite is classified by its low Iron, low metal, composition as a rare LL5 Chondrite (Popova et al., 2013). It is impregnated with cracks that had filled in with metal rich glass, suggesting that its parent body had survived an impact which had compressed and fissured it. This may have facilitated disintegration during its previous orbital history, preventing even larger fragments impacting the Earth. There is one other LL Chondrite parent body whose orbit is known: the asteroid Itokawa, visited by the Japanese Hayabusa spacecraft in 2005. Two large parts of the asteroid fragment survived the 30 km airburst. One broke up at an altitude of about 18 km while the other fell into Chebarkul Lake. This 1.5 m, 570 kg fragment was later recovered by divers. Thousands of much smaller meteorites fell 40 km south of Chelyabinsk, around the villages of Pervomaiskoe, Deputatsky and Yemanzhelinka. The total mass of all the recovered fragments are estimated to account for only about 0.04% of the original body, suggesting that most of the material ablated during the 30 second fireball. Its size and velocity suggests that a shock wave first developed at 90 km. Observations show that dust formation and fragmentation started at around 83 km, increasing at 54 km. Peak radiation occurred at an altitude of 30 km at $03^{h}20^{m}32\overset{s}{.}2$ UTC, at which time orbiting sensors measured a meteoroid speed of 18.6 km/s. Disintegration left a thermally emitting debris cloud, with the final burst occurring at an altitude of 27 km. Dust and gas settled at 26 km with the dust cloud splitting, creating two billowing cylindrical vortices due to the buoyancy of the hot gases (Popova et al., 2013).

4.1 Chelyabinsk – Electrophonic sound reports

During the Russian Academy of Sciences sponsored field study (Popova et al., 2013) some detailed reports of 'electrophonic sounds' were obtained. None of the following observers wore glasses.

1. While in his office in Yemanzhelinsk, Evgeny Svetlov, an electrical engineer, heard a noise like the buzz of an electrical transformer during the main bolide flash.

2. While standing on a street in Yemanzhelinsk, Alexander Polonsky, heard a noise like the roar of two fighter planes even before he saw the bolide.

3. In an open area near the Chelyabinsk regional hospital, Vladimir Bychkov, a police programmer and physicist by training, heard a noise like the sizzle of oil in a frying pan during the bright stage of the bolide. The noise appeared to be from the direction of the bolide. The noise stopped at the main bolide flash, accompanied by a sound like a clap.

Table 1 – Summary of electrophonic sounds; eye witness reports. Prof Sergey N. Zamozdra. Chelyabinsk University.

Sounds	No. of reports
Hiss or hissing, fireworks noise, interference	76
Like a passing plane	31
Whistle sound	26
Crackle, sparking or crackling	25
Rumble	19
Like sound of Bengal light	13
Rustle or rustling	6
Squeak	2

Of the 1 674 people interviewed during the internet survey 198 reported hearing sounds (Table 1).

The sound effects were described as "hissing", "fireworks noise", "interference", "the sound of Bengal light", "crackle", "sparking", "crackling", "rustle", "rustling", "like a whistle", "squeaking", "rumble" and the "sound of a passing plane". The term onomatopoeic refers to the formation or use of words such as "Hiss" or "Swish" that imitate the sounds associated with the objects or actions they refer to.

4.2 Chelyabinsk – Meteor Smells

A group of four observers of the Leonid meteor shower of 1833 reported a peculiar odour, "like sulphur or onions" (Olmsted, 1833; Olmsted, 1834). It was thought that "This apparent transmission of smells at the speed of light could be explained if they were due to nitrous oxide or ozone produced by an electric discharge." (Ozone [O_3] a gas. From the Greek, *ozein*, for smell). Observers of the Texas fireball of 1917 October 1 (Udden, 1917b; Udden, 1917a) also reported the odour of "sulphur and burning [gun] powder" as it passed. A possible explanation is suggested in the following Chelyabinsk observer reports.

Field survey reports of smells were concentrated in the area surrounding the fireball trajectory. After an initial strong burst, the smells continued for a few hours. The eastern edge of this area coincides with the eastern edge of the glass damaged area. Arkhangel'skoe is the most western village where smells were reported. It is situated near the western edge of the glass damaged area. Fourteen villages reported similar smells, with nearly all described as a sulphur smell, a burning smell, or a smell similar to that of gunpowder. Some of these smells may have originated from the decomposition of Troilite (FeS), an iron sulphide mineral named after Domenico Troili, who first noted it in a meteorite that fell at Albareto, Modena, Italy in 1766. Troilite is one of the main components of the Chelyabinsk meteorite. Some burning smells may also have been caused locally when the shock-wave dispersed soot from flues and stoves and some may be associated with nitrogen oxides, created during ozone production by the meteor.

Respondents in Yemanzhelinka, immediately under the fireball trajectory reported a distinct ozone smell, similar to the smell after a thunderstorm. Ozone, with nitrogen oxides as by products, may have been "produced in the immediate surroundings of the fireball by Ultra-Violet (UV-B $\lambda = 290$–320 nm wavelength) radiation from the meteor." Considerably more energy is required to produce a given quantity of ozone by UV radiation than by corona discharge. Industrial ozone production utilises UV-C 185 nm radiation (Pekárek, 2003; Buntat, 2005). These observations reinforce the reports about sunburn caused by UV radiation from the fireball.

4.3 Chelyabinsk – Eyestrain, Heat and Sunburn

Compiled by: A. Kartashova, P. Jenniskens, O. P. Popova, S. Khaibrakhmanov, S. Korotkiy, I. Serdyuk. (Popova et al., 2013)

"Others imagin'd they felt the warmth of its beams, and some there were that thought, at least wrote, that they were scalded by it." An account by Sir Edmund Halley "of the extraordinary meteor seen all over England on the 19th of March 1719."

People who looked directly at the Chelyabinsk fireball had painful eyes. 180 people said their eyes hurt and 70 were temporarily blinded. All of them closed their eyes or turned in the opposite direction. Many mentioned feeling heat in the neck when the fireball was behind them. There were no reports of lasting eye damage to the lens or retina from watching the fireball, estimated as reaching magnitude -27.3, approximately the same brightness as the midday Sun. The total radiated energy of the fireball was estimated by NASA to have been $\sim 3.75 \times 10^{14}$ Joules. Throughout the survey area, there were reports of mild sunburns following the fireball sighting. Of 1 113 respondents in the internet survey who were outside at the time of the fireball, 25 were sunburned (2.2%), 315 felt hot (28%), and 415 (37%) felt warm. In Kokino, approximately 33 km below the point in the trajectory where peak luminous radiation occurred, Vladimir Petrov reported sunburn so severe that his skin peeled off sometime after the event. "We calculated how much UV light came down and we think it is possible, but he was also in a snowed-in landscape and snow is very efficient at scattering UV light. This may have helped." Dr P. Jenniskens.

5 Discussion and Summary

Almost 300 years since its first scientific assessment and rejection, the phenomenon of sounds perceived simultaneously with meteors is still without a robust physical explanation or unified model. Consensus suggests that most audible meteor 'sounds' are caused by meteor 'radio emissions' in the audio frequency range reaching ground level. How these propagating electric-magnetic field oscillations at audio frequencies then emit acoustically or are perceived or heard passively is mostly speculative. There is no convincing theory that fully explains why some meteors appear to enable these particular audio frequency fields, while subsequent, apparently identical meteors or most others do not.

It also remains undetermined whether reported 'audible sounds' coincide with specific instrumental ELF electric and magnetic field spectra, attributed unambiguously to the observed meteor. It is necessary to clarify what is meant by 'simultaneously', since different types of sound perceived during several continuous seconds of visual observation may not coincide exactly with observed events, i.e. flaring, fragmentation, train/trail creation: perceptible delays suggesting additional, almost immediate, intermediary processes.

An augmenting theory involving near ground, non uniform electric field production of Ozone as an associated "unidentified geophysical phenomenon" to possibly explain some hissing 'electrophonic sounds' is suggested in section 2.2. Unlike previous theories, an electric-magnetic field fluctuation rate is not required to occur in the audio frequency range for this process to acoustically emit hissing and intermittent impulsive sounds; removing the requirements of direct conversion, passive human transduction, or excited, localised, acoustic 'emitters'. The intermediary processes occurring between near ground acoustic emissions and the associated meteor trail or train remain ill-defined. In the lower night time atmospheric boundary layer, it is possible that unstable very low altitude stratified charged air masses could be intermittently neutralised by them; with the resultant localised air pressure modulations producing similar acoustic emissions. These low altitude acoustic mechanisms need not emit visually and might also be associated with some Auroral sound reports.

The perceived improbability of 'meteor sounds' has prevented substantial experimental work; consequently the phenomenon remains on the margins of scientific interest. This is unjustified, since these audibly perceived electric field effects indicates complex, inconsistent and still unresolved electric-magnetic coupling and charge dynamics; interacting between the meteor; the ionosphere and mesosphere; stratosphere; troposphere and the surface of the earth. Meteor Interaction with the Ionosphere/neutral atmosphere in the complex 80 km to ~ 110 km Mesopause transition region might create other processes which facilitate 'electrophonic sound' production. There are possibly dominant and currently unrecognised diurnal, seasonal and yearly variances in the occurrence of 'electrophonic meteors', caused by Sun dependent changes in ionosphere composition. These unexplored aspects merit further observation, research and discussion.

At Armagh Observatory, sensors with continuous coverage from ~ 5 Hz to 24 kHz have been utilised simultaneously with our meteor cameras. The resultant ELF recordings are subject to detailed spectrum analysis. Since the Earth's geo-electric-magnetic ELF background is intensely active involving natural phenomena such as Sferics, Tweeks, Whistlers and also strong man-made emissions, distinct effects or disturbances directly attributable to individual bright fireballs remain elusive. See also Andreić et al. (1993), McKinley (1961). Exceptionally powerful disintegrations, such as the Chelyabinsk super bolide airburst, indisputably confirm all of the historically reported meteor 'noise', 'odour' and 'scalding' phenomena.

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Preliminary results

Results of the IMO Video Meteor Network — November 2014

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In 2014 November, 84 cameras of the IMO Video Meteor Network recorded over 25 000 meteors in nearly 6 600 hours of observing time. Flux density profiles are presented for the Leonids, covering the period from 2011 to 2014. The population index profile is calculated for the 2014 Leonids. The usefulness of meteor observations using MetRec for following the brightness of variable stars is presented on the case of α Comae Berenices.

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1 Introduction

November started with two perfect nights that seamlessly continued the nice observing conditions of the previous months, but the situation soon worsened. The observing statistics show more and more gaps and towards the end of the month almost no one enjoyed clear skies. Whereas 69 out of 84 cameras were active on November 1, only 15 cameras were operating on November 29 and 30. Only Carl Hergenrother of Tucson experienced excellent observing conditions all month long and did not have to pause a single night. Beside his camera Salsa3, only seven other cameras obtained twenty or more observing nights, which underlines how poor the weather was. Observers in south eastern Europe were particularly affected. Overall we observed just about 25 000 meteors in 6 600 hours of effective observing time (Table 1 and Figure 1), which is less than in Novembers of the last three years.

In November, Stane Slavec started to operate a second camera Kayak2, after his first camera Kayak1 became nearly blind after many years of operation. Kayak2 is a Mintron camera with 12 mm $f/0.8$ Panasonic lens.

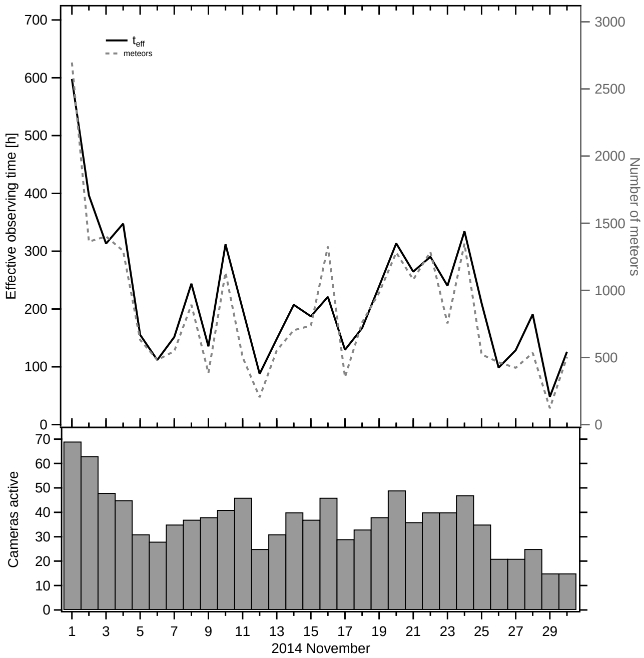

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2014 November.

2 Leonids

Near the millennium, the Leonids made November the most attractive month for meteor observers, but the last unmissable rates happened a long time ago. In 2014, the shower presented a similar flux density as in the years before with roughly 8 meteoroids per 1 000 km^2 per hour at best (Figure 2). Only in 2013 rates were a bit higher. A clear peak cannot be found in the 2014 data set – the activity level remained constantly high (or low) for several days.

The population index also yielded no surprises (Figure 3). The r-value of the Leonids was clearly lower than that of the sporadic meteors, and the sporadic population index was smaller than the expected "default value" of 3.0. In addition, it was confirmed again that

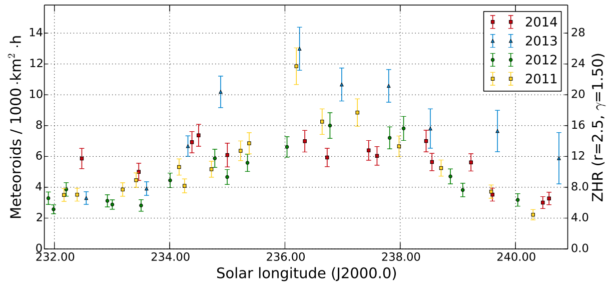

Figure 2 – Activity profile of the Leonids, derived from data of the IMO Video Meteor Network 2011-2014.

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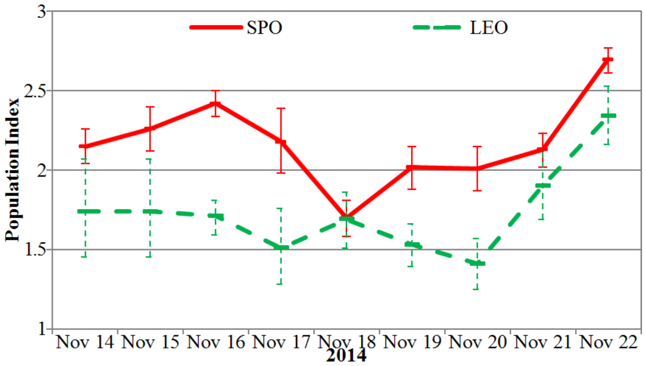

Figure 3 – Comparison of the population index of Leonids and of sporadic meteors in 2014 November.

the convergence of flux density vs. population index graphs is much better for minor showers with smaller meteor counts, and also the population index profile shows fewer fluctuations than in case of major showers.

3 MetRec and variable stars

When analyzing the November data, there was yet another topic in focus, which is completely unrelated to meteors. For the first time we could support the observers of variable stars!

What happened? Alpha Comae Berenices (α COM), the 4.3 mag primary star in the constellation of Coma Berenices is a known double-star that presents an occultation every 25.8 years. The event was predicted to happen around 2015 January 25 (Muterspaugh & Henry, 2014), and several variable star observers started their observing campaign in 2014 December. However, after a numeric error was detected and fixed it turned out that the occultation had already occurred in late fall 2014, when the star slowly escaped morning twilight. The most probable point in time was now 2014 November 20 (Muterspaugh et al., 2015). The occultation was expected to last 1 to 2 days with a brightness dip of less than one magnitude. The hope of the variable star observers was that maybe all-sky meteor recordings might show the star, which is why they contacted meteor observers.

The initiative was not fruitless: It turned out that several video cameras of the IMO Network observed the respective region of sky in the November early morning hours, and that they were sensitive enough to detect the star. Now we only had to search for relevant meteor images, whereby our photometry was clearly inferior to the accuracy that variable star observers typically obtain. One reason is that meteor sum images are not averaged over several video frames (which would decrease the noise level) but they are rather made of the maximum of all video frames. Still, they should be sufficient to decide whether or not an occultation has taken place by comparing α COM with nearby reference stars.

We could even go one step further: To determine the limiting magnitude, MetRec detects and measures every minute all stars in the field of view and writes their data (position, pixel sum) into a new reference file. These reference files are only used when the observer decides to re-calibrate the camera position every few

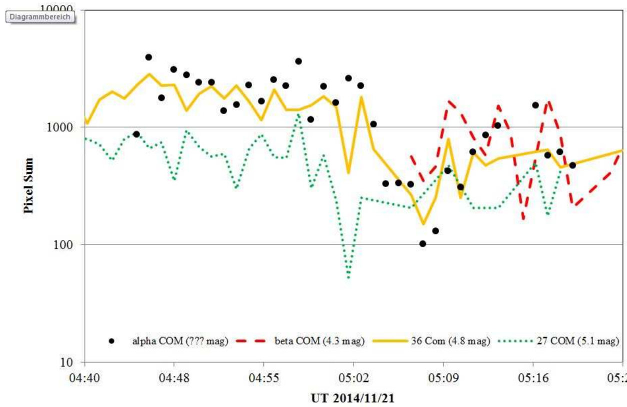

Figure 4 – Brightness (log pixel sum) of α Comae Berenices and three reference stars on the morning of 2014 November 21. The data were extracted from the Mincam1 reference file.

weeks or months. Still we had decided once to keep all these files, which was now our selling point. Even though the file format is not particularly well-suited for photometry of single stars (e.g. neither the name of the star nor the exact time are stored, since the primary use case is the calibration of the field of view), we can still extract all relevant data. We determined the declination and catalog brightness of the reference stars given by the variable star observers, which allowed us to find these stars among the several thousands of entries in the reference file. Further, the time of measurement could be derived based on the time when the observation was started, and the difference of the given and the true right ascension of the star. Using a script we could extract all single measures of α COM and the reference stars from all the reference files. Figure 4 shows an example of the (log) pixel sum plot for α COM and three reference stars taken from data of Mincam1 in the morning of 2014 November 21. Since these are raw data, the result is affected by drifting cirrus clouds and other side effects.

In total we obtained 1 200 individual measurements for α COM in November, and the same order of magnitude for other reference stars. Particularly successful were the cameras Akm3, Bmh1, Hermine, Mincam5, Ro3 and Templar5. We submitted all data to the variable star observers. Even though the final result is still pending, this is already a fine example for cooperation between amateur astronomers of different disciplines.

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Table 1 – Observers contributing to 2014 November data of the IMO Video Meteor Network. Eff.CA designates the effective collection area; the overall number of nights is the number of nights with at least one camera operating, the overall observing time and number of meteors are sums over all cameras.

Code	Name	Location	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	Ludwig2 (0.8/8)	1475	6.2	3779	15	85.2	561
BANPE	Bánfalvi	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	12	49.9	153
BERER	Berkó	Ludányhalászi/HU	Hulud1 (0.8/3.8)	5542	4.8	3847	7	50.8	161
			Hulud3 (0.95/4)	4357	3.8	876	7	39.9	49
BOMMA	Bombardini	Faenza/IT	Mario (1.2/4.0)	5794	3.3	739	15	90.3	508
BREMA	Breukers	Hengelo/NL	Mbb3 (0.75/6)	2399	4.2	699	17	107.6	218
			Mbb4 (0.8/8)	1470	5.1	1208	19	108.0	240
BRIBE	Klemt	Herne/DE	Hermine (0.8/6)	2374	4.2	678	20	115.4	382
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	12	46.3	168
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	5.0	1611	13	104.6	457
			Bmh2 (1.5/4.5)*	4243	3.0	371	10	80.7	335
CRIST	Crivello	Valbrevenna/IT	Bilbo (0.8/3.8)	5458	4.2	1772	14	91.7	521
			C3P8 (0.8/3.8)	5455	4.2	1586	16	90.9	401
			Stg38 (0.8/3.8)	5614	4.4	2007	15	67.5	327
CSISZ	Csizmadia	Baja/HU	Huvcse02 (0.95/5)	1606	3.8	390	20	81.0	232
DONJE	Donani	Faenza/IT	Jenni (1.2/4)	5886	3.9	1222	16	108.3	678
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	2	17.6	64
FORKE	Förster	Carlsfeld/DE	Akm3 (0.75/6)	2375	5.1	2154	9	76.5	333
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	18	105.4	428
			Templar2 (0.8/6)	2080	5.0	1508	16	111.9	382
			Templar3 (0.8/8)	1438	4.3	571	21	123.4	203
			Templar4 (0.8/3.8)	4475	3.0	442	18	119.9	386
			Templar5 (0.75/6)	2312	5.0	2259	24	119.7	421
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	15	68.6	309
			Orion3 (0.95/5)	2665	4.9	2069	3	28.8	49
			Orion4 (0.95/5)	2662	4.3	1043	16	72.5	136
HERCA	Hergenrother	Tucson/US	Salsa3 (0.8/3.8)	2336	4.1	544	30	328.1	943
HINWO	Hinz	Schwarzenberg/DE	Hinwo1 (0.75/6)	2291	5.1	1819	22	168.2	778
IGAAN	Igaz	Baja/HU	Hubaj (0.8/3.8)	5552	2.8	403	16	80.3	149
		Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	12	64.9	124
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	19	81.9	218
		Budapest/HU	Hupol (1.2/4)	3790	3.3	475	7	39.4	39
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	16	83.0	144
KACJA	Kac	Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	8	14.7	21
		Kamnik/SI	Cvetka (0.8/3.8)*	4914	4.3	1842	6	23.7	50
			Rezika (0.8/6)	2270	4.4	840	7	29.1	129
			Stefka (0.8/3.8)	5471	2.8	379	6	15.1	25
		Kostanjevec/SI	Metka (0.8/12)*	715	6.4	640	1	8.3	49
KISSZ	Kiss	Sülysáp/HU	Husul (0.95/5)*	4295	3.0	355	12	22.8	30
KOSDE	Koschny	La Palma/ES	Icc9 (0.85/25)*	683	6.7	2951	1	4.8	97
		Noordwijkerhout/NL	Lic4 (1.4/50)*	2027	6.0	4509	17	87.8	285
LOJTO	Łojek	Grabniak/PL	Pav57 (1.0/5)	1631	3.5	269	5	53.5	76

Table 1 – Observers contributing to 2014 November data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Location	Camera	FOV [$^{\circ 2}$]	Stellar LM [mag]	Eff.CA [km^2]	Nights	Time [h]	Meteors
MACMA	Maciejewski	Chełm/PL	Pav35 (0.8/3.8)	5495	4.0	1584	9	62.8	189
			Pav36 (0.8/3.8)*	5668	4.0	1573	11	91.4	418
			Pav43 (0.75/4.5)*	3132	3.1	319	12	78.4	367
			Pav60 (0.75/4.5)	2250	3.1	281	11	89.9	548
MARGR	Maravelias	Lofoupoli-Crete/GR	Loomecon (0.8/12)	738	6.3	2698	19	123.2	241
MARRU	Marques	Lisbon/PT	Ran1 (1.4/4.5)	4405	4.0	1241	14	53.3	220
MASMI	Maslov	Novosibirsk/RU	Nowatec (0.8/3.8)	5574	3.6	773	9	68.8	432
MOLSI	Molau	Seysdorf/DE	Avis2 (1.4/50)*	1230	6.9	6152	16	102.3	735
			Escimo (0.6/130)	21	10.0	3507	2	18.9	15
			Mincam1 (0.8/8)	1477	4.9	1084	16	89.1	434
		Ketzür/DE	Remo1 (0.8/8)	1467	6.5	5491	18	107.6	742
			Remo2 (0.8/8)	1478	6.4	4778	15	105.3	600
			Remo3 (0.8/8)	1420	5.6	1967	2	15.7	114
			Remo4 (0.8/8)	1478	6.5	5358	17	112.3	721
MORJO	Morvai	Fülöpszállás/HU	Huful (1.4/5)	2522	3.5	532	16	102.5	172
MOSFA	Moschner	Rovereto/IT	Rover (1.4/4.5)	3896	4.2	1292	1	0.3	2
OCHPA	Ochner	Albiano/IT	Albiano (1.2/4.5)	2944	3.5	358	7	44.3	130
OTTMI	Otte	Pearl City/US	Orie1 (1.4/5.7)	3837	3.8	460	18	96.2	201
PERZS	Perkó	Becsehely/HU	Hubec (0.8/3.8)*	5498	2.9	460	18	110.4	574
PUCRC	Pucer	Nova vas nad Dragonjo/SI	Mobcam1 (0.75/6)	2398	5.3	2976	12	62.0	286
ROTEC	Rothenberg	Berlin/DE	Armefa (0.8/6)	2366	4.5	911	12	78.6	151
SARAN	Saraiva	Carnaxide/PT	Ro1 (0.75/6)	2362	3.7	381	10	55.7	93
			Ro2 (0.75/6)	2381	3.8	459	17	98.9	292
			Ro3 (0.8/12)	710	5.2	619	16	104.0	452
			Sofia (0.8/12)	738	5.3	907	17	77.3	173
SCHHA	Schremmer	Niederkrüchten/DE	Doraemon (0.8/3.8)	4900	3.0	409	22	109.1	409
SLAST	Slavec	Ljubljana/SI	Kayak1 (1.8/28)	563	6.2	1294	5	15.1	17
			Kayak2 (0.8/12)	741	5.5	920	3	9.3	10
STOEN	Stomeo	Scorze/IT	Min38 (0.8/3.8)	5566	4.8	3270	18	128.7	969
			Noa38 (0.8/3.8)	5609	4.2	1911	18	131.5	845
			Sco38 (0.8/3.8)	5598	4.8	3306	19	128.3	929
STRJO	Strunk	Herford/DE	Mincam2 (0.8/6)	2354	5.4	2751	19	122.0	361
			Mincam3 (0.8/6)	2338	5.5	3590	19	122.8	415
			Mincam4 (1.0/2.6)	9791	2.7	552	22	131.9	375
			Mincam5 (0.8/6)	2349	5.0	1896	19	124.4	356
			Mincam6 (0.8/6)	2395	5.1	2178	19	116.7	299
TEPIS	Tepliczky	Agostyán/HU	Huago (0.75/4.5)	2427	4.4	1036	19	78.7	282
			Humob (0.8/6)	2388	4.8	1607	17	99.9	272
TRIMI	Triglav	Velenje/SI	Sraka (0.8/6)*	2222	4.0	546	9	30.2	84
YRJIL	Yrjölä	Kuusankoski/FI	Finexcam (0.8/6)	2337	5.5	3574	2	4.7	5
ZELZO	Zelko	Budapest/HU	Huvcse03 (1.0/4.5)	2224	4.4	933	3	19.6	56
			Huvcse04 (1.0/4.5)	1484	4.4	573	1	7.6	23
* active field of view smaller than video frame						Overall	30	6 597.8	25 268

Results of the IMO Video Meteor Network — December 2014

Sirko Molau[1], *Javor Kac*[2], *Stefano Crivello*[3], *Enrico Stomeo*[4], *Geert Barentsen*[5], *Rui Goncalves*[6], *Carlos Saraiva*[7], *Maciej Maciejewski*[8], *and Mikhail Maslov*[9]

In 2014 December, 85 cameras of the IMO Video Meteor Network recorded almost 45 000 meteors in over 9 300 hours of observing time. The flux density profile is presented for the Geminids, as well as the population index profile around the maximum. A short-lasting outburst of the Ursids occurred on 2014 December 23 at 0^{h} UT that reached a flux density of 60 meteoroids per 1 000 km^2 per hour in a 30-minute interval. The annual summary of the 2014 IMO Video Meteor Network observations is presented. More than 367 000 meteors were recorded in almost 100 000 hours of observing time.

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1 Introduction

With respect to the weather conditions, December started as bad as November had finished. Fortunately the situation improved towards the middle of the month, so that 65 cameras were in operation during the Geminids maximum on December 13/14. However, the waning Moon affected the display significantly. In the following days the weather was mediocre, whereby observers in northern Europe experienced larger observing breaks which are typical for this time of year, whereas observers in southern Europe experienced many clear nights in a row. 27 of the 85 cameras in operation observed in twenty or more observing nights, all five Templar cameras from Rui Goncalves even in 29 or 30 nights. With over 9 300 hours, the effective observing time fell a few percent short of the result from 2013, as did the overall number of meteors with almost 45 000 recorded (Table 4 and Figure 1). The outcome was clearly better than in earlier years, though, which secured another record in the long-term IMO Network statistics.

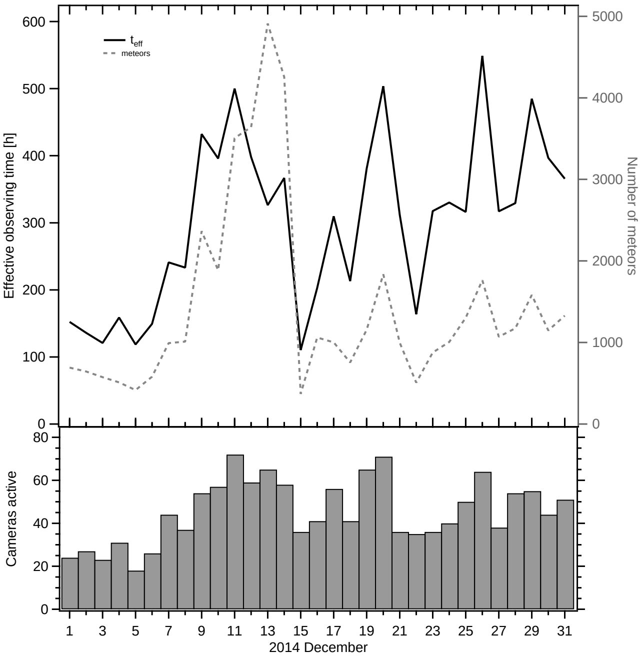

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2014 December.

2 Geminids

The most important shower of December is also the strongest annual shower – the Geminids. Their maximum does not last as long as the Perseid peak, though, and both showers give a different visual impression, since the Geminids are slower than the Perseids. A bigger particle density is necessary to obtain the same number of visual meteors. Figure 2 compares the Geminids flux density profile of the past three years at a resolution of 30 minutes per bin. It is remarkable that the data sets fit perfectly at the ascending and descending branch, but there are significant fluctuations at the peak between 261°.75 and 262°.4 solar longitude. If we neglect some outliers, the flux density reaches values of 80 meteoroids per 1 000 km^2 per hour. For comparison: Perseids and Quadrantids only yield fluxes of the order of 50.

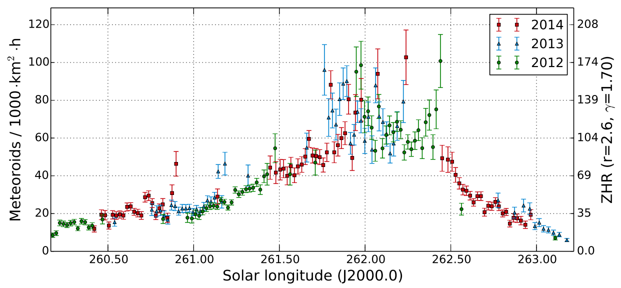

Figure 2 – Activity profile of the Geminids, derived from data of the IMO Video Meteor Network 2012–2014.

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NASA-ADS bibcode 2015JIMO...43...62M

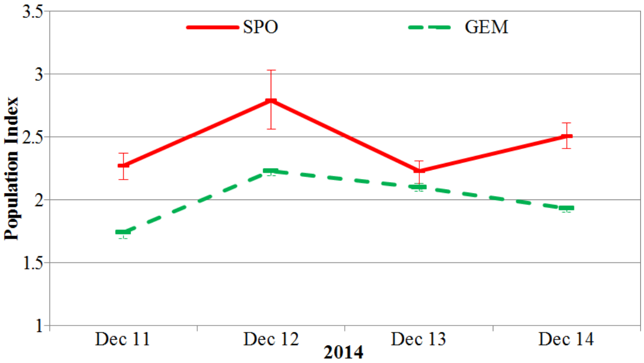

Figure 3 – Population index of the Geminids and sporadic meteors during the Geminid maximum in 2014.

In the nights of highest activity (>1 000 shower meteors for analysis), the population index of the Geminids was typically about 0.5 smaller than the r-value of the sporadic meteors (Figure 3).

3 Ursids

Just before Christmas, the Ursids have repeatedly surprised the observers with rates well above their long-term average. 2014 was no exception – on the contrary: this year the shower presented a short but particularly strong outburst just at midnight UT of the night of December 22/23 (270°85 solar longitude). Unfortunately the weather was not so good which is why the data set is more sparse than for other showers, but the smaller the selected bin size, the more prominent becomes the peak. In Figure 4 there are at least 10 Ursids per bin.

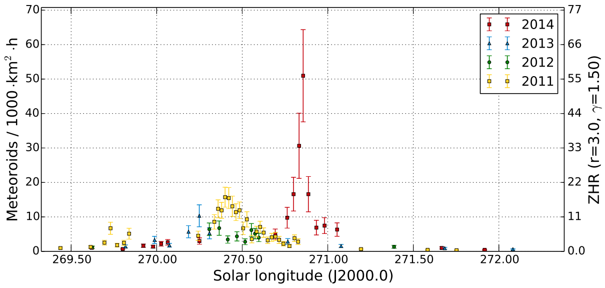

Figure 4 – Activity profile of the Ursids, derived from data of the IMO Video Meteor Network 2011–2014.

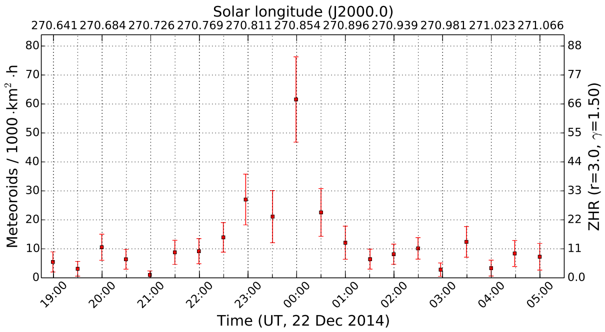

Figure 5 – Detailed profile of the Ursids on 2014 December 22/23, with a fixed bin size of 30 minutes. The outburst occurred almost exactly at midnight UT.

To double-check the result, we created another flux density profile of the peak night 2014 with a fixed resolution of 30 minutes per bin (Figure 5). The peak is very prominent here as well. For a few minutes, the flux density was as high as during the Perseid peak! That will delight our meteor shower modelers, which had indeed expected enhanced rates due to the dust trails of comet 8P/Tuttle from 1392 and 1405. Esko Lyytinen predicted a peak for 23:38 (Jenniskens, 2006), Mikhail Maslov for 23:54 (Maslov, 2014) and Jeremie Vaubaillon for 00:40 UT (McBeath, 2013). A quick Google search led to a post of Tony Markham (2014), who came to the same preliminary conclusion about the Ursids based on visual observing reports: there was a brief peak on 2014 December 23 at 00^{h} UT (±30 minutes) with an equivalent ZHR of up to 50.

With $r = 1.7$ the population index of the Ursids was clearly smaller than the sporadic values of the same night ($r = 2.9$), but both values are based on only about a hundred meteors.

4 Small showers of December

Another outburst was predicted for the December Phoenicids. However, that shower is so far south that there are no sensible data from the IMO Network available (0 to 4 PHO per night).

The flat activity profile of the σ-Hydrids is somewhat boring, but not so the profile of the Monocerotids. They show a gentle increase of the flux density throughout the December, which suddenly doubles just before the end the activity. This peak between 261° and 262° solar longitude can be noticed in every of the four years, but it is best visible in the combined profile, of course (Figure 6).

5 2014 summary

Finally, we will present as always a summary of the observing results from the previous year. In the 16th year of the IMO Video Meteor Network, the weather was mainly sympathetic to the observers. It was remarkable that in the first half of the year northern observers often enjoyed better weather conditions than their colleagues in southern Europe. The moon hampered some of the major showers, but the favourable observing conditions continued well into late fall. Only November brought us back to the ground.

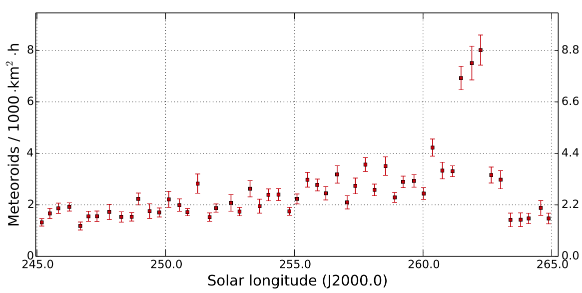

Figure 6 – Activity profile of the Monocerotids, averaged over the data sets 2011–2014.

Table 1 – Monthly distribution of video observations in the IMO Network 2014.

Month	Observing Nights	Eff. Observing Time	Meteors	Meteors / Hour
January	31	6 027.2	18 367	3.0
February	28	6 966.3	14 569	2.1
March	31	11 891.1	20 351	1.7
April	30	7 773.9	16 353	2.1
May	31	7 490.0	18 249	2.4
June	30	6 602.3	18 690	2.8
July	31	6 789.2	30 949	4.6
August	31	9 762.9	70 819	7.3
September	30	9 448.3	36 518	3.9
October	31	11 199.1	51 979	4.6
November	30	6 597.8	25 267	3.8
December	31	9 331.7	44 925	4.8
Overall	365	99 879.8	367 036	3.7

The IMO Network grew only to a minor extend in 2014. 48 observers (2013: 49) from 15 countries (2013: 16) contributed with 92 meteor cameras (2013: 88) to the Network. The ranking by country is clearly lead by Germany with 21 cameras, followed by Hungary (16), Italy (13), Slovenia (12) and Portugal (11). Further cameras were operated in Poland (5), the Netherlands (3), Spain, US and the Czech Republic (all 2) as well as Australia, Belgium, Greece, Finland and Russia (all 1).

In 365 observing nights (2013: 365) and 99 880 observing hours (2013: 86 637) we recorded a total of 367 036 meteors (2013: 350 003). Thus, we barely missed the 100 000 observing hours and surpassed the result of the two previous years by over 10 000 meteors. For the first time in the history of the IMO Network, more than 1 000 meteors were recorded on average every night! With 3.7 meteors per hour, the average hourly outcome was similar to 2012 (3.8) and slightly below the level of last year (4.0).

Table 1 gives the distribution of observations over the months. In March and October we collected more than 11 000 hours of effective observing time, whereas it was less than 7 000 hours in January, February, June, July and November.

The number of observers that obtained 300 and more observing nights increased from five in the previous year to seven in 2014. Due to technical problems with one camera on the Canaries, Detlef Koschny was barely beaten with his 329 observing nights by two other observers. In the end, Sirko Molau (331) and Carl Hergenrother (330) had a shade more on their accounts. Behind the trio we find Rui Goncalves (324), Antal Igaz (308), Stefano Crivello (303) and Enrico Stomeo (300). Twenty more observers reported 200 and more observing nights, and another fifteen observers more than 100 observing nights.

Nothing has changed in the TOP-3 ranking with respect to the effective observing time. Rui Goncalves could defend his top position by increasing his outcome of 2013 significantly to over 9 500 observing hours. Also second-ranked Sirko Molau and third-ranked Carlos Saraiva obtained personal records with over 8 100 and 6 800 hours, respectively.

Finally Sirko Molau could prove that six sensitive cameras (mainly Mintrons) are sufficient to beat the output of the two image-intensified cameras on the Canaries. With 43 000 meteors he recorded more meteors than anyone else in a single year before. With over 32 500 meteors, Detlef Koschny ranked "only" second, followed by Rui Goncalves with over 30 000 meteors.

In the long-term statistics, Sirko Molau passed the mark of 4 000 and Jörg Strunk of 3 000 observing nights. Javor Kac, Flavio Castellani and Bernd Klemt all have more than 2 000 nights on their account, and another twenty observers have more than 1 000 nights.

Table 2 summarizes the details for all active observers of the IMO Video Meteor Network. The number of cameras and stations refers to the majority of 2014.

The list of the ten most successful video systems reflects the high degree of automation and success of many video systems. For the first time ever there are two cameras with over 300 observing nights. To enter the TOP-10 at all, a camera had to provide at least 280 observing nights, whereas in the year before 260 nights were sufficient. Once more the list does not contain the cameras with highest meteor count: Icc9 (17 129), Icc7 (12 221), Avis2 (9 948) and Jenni (9 836).

The complete data set of the IMO Video Meteor Network including the 2014 data is available online at the IMO network homepage `http://www.imonet.org`. At the time of submission the database contains exactly 2 133 934 meteors from 512 494 hours effective observing time in 5 373 nights.

As always, we would like to thank the many observers, whose passion is a guarantor for the success of the IMO Network. Special thanks Stefano Crivello, Enrico Stomeo, Rui Goncalves, Carlos Saraiva, Maciej Maciejewski and Mikhail Maslov, who check together with Sirko Molau every month the consistency of the data set and ensure the high quality of the database.

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Table 2 – Distribution of video observations over the observers in 2014.

Observer	Country	Observing Nights	Eff. Observing Time [h]	Meteors	Meteors / h	Cameras (Stations)
Sirko Molau	Germany	331	8 169.6	43 032	5.3	6 (2)
Carl Hergenrother	USA	330	2 818.4	6 266	2.2	1 (1)
Detlef Koschny	Netherlands	329	4 488.6	32 567	7.3	3 (3)
Rui Goncalves	Portugal	324	9 556.4	30 344	3.2	5 (1)
Antal Igaz	Hungary	310	4 010.6	7 213	1.8	4 (3)
Stefano Crivello	Italy	303	4 648.5	20 291	4.4	3 (1)
Enrico Stomeo	Italy	300	4 178.7	25 713	6.2	3 (1)
Jörg Strunk	Germany	293	6 215.0	19 048	3.1	5 (1)
Carlos Saraiva	Portugal	288	6 822.5	16 649	2.4	4 (1)
Hans Schremmer	Germany	286	1 411.5	5 264	3.7	1 (1)
Bernd Klemt	Germany	285	2 541.6	6 996	2.8	2 (2)
Istvan Tepliczky	Hungary	281	2 612.4	7 378	2.8	2 (1)
Jenni Donati	Italy	277	1 749.3	9 836	5.6	1 (1)
Rainer Arlt	Germany	272	1 413.9	7 751	5.5	1 (1)
Flavio Castellani	Italy	271	2 837.8	9 427	3.3	2 (1)
Maciej Maciejewski	Poland	270	4 478.3	17 055	3.8	4 (1)
Martin Breukers	Netherlands	261	2 582.9	5 195	2.0	2 (1)
Mitja Govedič	Slovenia	259	2 896.8	9 447	3.3	3 (1)
Mario Bombardini	Italy	253	1 424.2	8 292	5.8	1 (1)
Mike Otte	USA	238	1 296.3	3 122	2.4	1 (1)
Karoly Jonas	Hungary	235	1 327.5	2 583	1.9	1 (1)
Zsolt Perkó	Hungary	231	1 371.8	6 464	4.7	1 (1)
Javor Kac	Slovenia	227	3 295.7	12 038	3.7	5 (3)
Fabio Moschini	Italy	227	651.2	2 771	4.3	1 (1)
Szabolcs Kiss	Hungary	212	969.9	1 045	1.1	1 (1)
Mikhail Maslov	Russia	203	823.1	4 214	5.1	1 (1)
Rok Pucer	Slovenia	200	1 004.0	3 162	3.1	1 (1)
Maurizio Eltri	Italy	199	1 103.4	4 335	3.9	1 (1)
Mihaela Triglav	Slovenia	192	684.3	2 027	3.0	1 (1)
Eckehard Rothenberg	Germany	184	1 053.6	2 172	2.1	1 (1)
Paolo Ochner	Italy	170	863.8	2 060	2.4	1 (1)
Wolfgang Hinz	Germany	164	843.1	4 212	5.0	1 (1)
Erno Berkó	Hungary	160	1 729.5	6 311	3.6	2 (1)
Péter Bánfalvi	Hungary	158	458.5	1 788	3.9	1 (1)
József Morvai	Hungary	153	1 018.0	1 334	1.3	1 (1)
Szilárd Csizmadia	Hungary	150	426.7	1 869	4.4	1 (1)
Grigoris Maravelias	Greece	149	1 001.8	2 357	2.4	1 (1)
Kevin Förster	Germany	141	702.5	2 988	4.3	1 (1)
Tomasz Lojek	Poland	133	738.8	1 221	1.7	1 (1)
Leo Scarpa	Italy	130	547.1	1 701	3.1	1 (1)
Ilkka Yrjölä	Finland	128	730.5	2 025	2.8	1 (1)
Stane Slavec	Slovenia	112	570.2	986	1.7	1 (1)
Rui Marques	Portugal	97	772.2	3 200	4.1	1 (1)
Zoltán Zelko	Hungary	68	456.1	1 215	2.7	2 (1)
Karl-Heinz Gansel	Germany	51	340.7	553	1.6	1 (1)
Steve Kerr	Australia	19	53.1	271	5.1	1 (1)
Rosta Štork	Czech Republic	10	102.2	1 200	11.7	2 (2)
Luc Bastiaens	Belgium	3	17.4	11	0.6	1 (1)

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Handling Editor: Javor Kac

Table 3 – The ten most successful video systems in 2014.

Camera	Location	Observer	Observing Nights	Eff. Observing Time [h]	Meteors	Meteors / h
Salsa3	Tucson (US)	Carl Hergenrother	330	2 818.4	6 266	2.2
Templar5	Tomar (PT)	Rui Goncalves	306	1 915.4	6 777	3.5
Sco38	Scorze (IT)	Enrico Stomeo	292	1 472.4	9 724	6.6
Templar3	Tomar (PT)	Rui Goncalves	287	1 872.6	3 433	1.8
Doraemon	Niederkrüchten (DE)	Hans Schremmer	286	1 411.5	5 264	3.7
Remo1	Ketzür (DE)	Sirko Molau	285	1 480.4	9 776	6.6
Remo4	Ketzür (DE)	Sirko Molau	283	1 567.1	8 674	5.5
Bilbo	Valbrevenna (IT)	Stefano Crivello	281	1 571.7	7 095	4.5
Noa38	Scorze (IT)	Enrico Stomeo	281	1 405.0	7 511	5.3
Min38	Scorze (IT)	Enrico Stomeo	280	1 301.3	8 478	6.5

Figure 7 – Sporadic fireball recorded with Templar5 on 2014 December 2 at $01^{h}23^{m}55^{s}$ UT. Photo courtesy: Rui Goncalves.

Figure 8 – Sporadic fireball recorded with Templar5 on 2014 December 6 at $05^{h}52^{m}09^{s}$ UT. Photo courtesy: Rui Goncalves.

Figure 9 – Sporadic fireball recorded with Templar4 on 2014 December 19 at $22^{h}33^{m}20^{s}$ UT. Photo courtesy: Rui Goncalves.

Figure 10 – Sporadic fireball recorded with Mincam6 on 2014 December 28 at $01^{h}47^{m}54^{s}$ UT. Photo courtesy: Jörg Strunk.

Table 4 – Observers contributing to 2014 December data of the IMO Video Meteor Network. Eff.CA designates the effective collection area; the overall number of nights is the number of nights with at least one camera operating, the overall observing time and number of meteors are sums over all cameras.

Code	Name	Location	Camera	FOV [$^{\circ 2}$]	Stellar LM [mag]	Eff.CA [km^2]	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	Ludwig2 (0.8/8)	1475	6.2	3779	20	106.0	639
BANPE	Bánfalvi	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	9	39.0	194
BASLU	Bastiaens	Hove/BE	Urania1 (0.8/3.8)*	4545	2.5	237	3	17.4	11
BERER	Berkó	Ludányhalászi/HU	Hulud1 (0.8/3.8)	5542	4.8	3847	12	87.2	613
			Hulud3 (0.95/4)	4357	3.8	876	12	74.8	163
BOMMA	Bombardini	Faenza/IT	Mario (1.2/4.0)	5794	3.3	739	14	82.4	851
BREMA	Breukers	Hengelo/NL	Mbb3 (0.75/6)	2399	4.2	699	17	80.9	174
			Mbb4 (0.8/8)	1470	5.1	1208	11	60.0	149
BRIBE	Klemt	Herne/DE	Hermine (0.8/6)	2374	4.2	678	13	49.4	201
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	10	50.3	256
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	5.0	1611	21	184.0	873
			Bmh2 (1.5/4.5)*	4243	3.0	371	24	214.0	705
CRIST	Crivello	Valbrevenna/IT	Bilbo (0.8/3.8)	5458	4.2	1772	25	158.7	937
			C3P8 (0.8/3.8)	5455	4.2	1586	27	140.2	614
			Stg38 (0.8/3.8)	5614	4.4	2007	22	161.1	1475
CSISZ	Csizmadia	Baja/HU	Huvcse02 (0.95/5)	1606	3.8	390	14	99.1	349
DONJE	Donani	Faenza/IT	Jenni (1.2/4)	5886	3.9	1222	13	91.1	851
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	12	80.5	482
FORKE	Förster	Carlsfeld/DE	Akm3 (0.75/6)	2375	5.1	2154	5	31.2	153
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	30	299.0	1249
			Templar2 (0.8/6)	2080	5.0	1508	30	308.9	1287
			Templar3 (0.8/8)	1438	4.3	571	30	302.3	762
			Templar4 (0.8/3.8)	4475	3.0	442	30	300.3	1190
			Templar5 (0.75/6)	2312	5.0	2259	29	298.1	1448
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	18	154.4	1368
			Orion3 (0.95/5)	2665	4.9	2069	20	150.0	572
			Orion4 (0.95/5)	2662	4.3	1043	20	146.7	745
HERCA	Hergenrother	Tucson/US	Salsa3 (0.8/3.8)	2336	4.1	544	30	259.9	795
HINWO	Hinz	Schwarzenberg/DE	Hinwo1 (0.75/6)	2291	5.1	1819	10	57.9	348
IGAAN	Igaz	Baja/HU	Hubaj (0.8/3.8)	5552	2.8	403	9	69.5	418
		Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	18	121.4	403
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	18	70.9	312
		Budapest/HU	Hupol (1.2/4)	3790	3.3	475	18	122.6	128
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	20	141.0	399
KACJA	Kac	Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	15	75.4	225
		Kamnik/SI	Cvetka (0.8/3.8)*	4914	4.3	1842	12	71.3	481
			Rezika (0.8/6)	2270	4.4	840	12	82.2	698
			Stefka (0.8/3.8)	5471	2.8	379	12	72.9	398
		Kostanjevec/SI	Metka (0.8/12)*	715	6.4	640	1	10.1	33
KISSZ	Kiss	Sülysáp/HU	Husul (0.95/5)*	4295	3.0	355	19	104.3	136
KOSDE	Koschny	La Palma/ES	Icc9 (0.85/25)*	683	6.7	2951	21	164.4	1515
		Noordwijkerhout/NL	Lic4 (1.4/50)*	2027	6.0	4509	14	69.0	432
LOJTO	Łojek	Grabniak/PL	Pav57 (1.0/5)	1631	3.5	269	1	2.7	3

Table 4 – Observers contributing to 2014 December data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Location	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Meteors
MACMA	Maciejewski	Chełm/PL	Pav35 (0.8/3.8)	5495	4.0	1584	12	52.8	171
			Pav36 (0.8/3.8)*	5668	4.0	1573	16	74.1	370
			Pav43 (0.75/4.5)*	3132	3.1	319	10	49.6	140
			Pav60 (0.75/4.5)	2250	3.1	281	12	56.5	274
MARGR	Maravelias	Lofoupoli-Crete/GR	Loomecon (0.8/12)	738	6.3	2698	27	163.7	477
MARRU	Marques	Lisbon/PT	Cab1 (0.8/3.8)	5291	3.1	467	17	88.4	413
			Ran1 (1.4/4.5)	4405	4.0	1241	30	281.9	1124
MASMI	Maslov	Novosibirsk/RU	Nowatec (0.8/3.8)	5574	3.6	773	11	45.4	362
MOLSI	Molau	Seysdorf/DE	Avis2 (1.4/50)*	1230	6.9	6152	13	59.3	580
			Escimo (0.6/130)	21	10.0	3507	2	14.1	15
			Mincam1 (0.8/8)	1477	4.9	1084	13	49.9	384
		Ketzür/DE	Remo1 (0.8/8)	1467	6.5	5491	19	106.9	838
			Remo2 (0.8/8)	1478	6.4	4778	18	79.4	614
			Remo3 (0.8/8)	1420	5.6	1967	17	98.2	501
			Remo4 (0.8/8)	1478	6.5	5358	18	114.4	811
MORJO	Morvai	Fülöpszállás/HU	Huful (1.4/5)	2522	3.5	532	21	130.9	340
MOSFA	Moschner	Rovereto/IT	Rover (1.4/4.5)	3896	4.2	1292	25	92.6	546
OCHPA	Ochner	Albiano/IT	Albiano (1.2/4.5)	2944	3.5	358	3	14.5	46
OTTMI	Otte	Pearl City/US	Orie1 (1.4/5.7)	3837	3.8	460	12	79.2	188
PERZS	Perkó	Becsehely/HU	Hubec (0.8/3.8)*	5498	2.9	460	18	158.6	1378
PUCRC	Pucer	Nova vas nad Dragonjo/SI	Mobcam1 (0.75/6)	2398	5.3	2976	17	95.3	333
ROTEC	Rothenberg	Berlin/DE	Armefa (0.8/6)	2366	4.5	911	12	56.2	123
SARAN	Saraiva	Carnaxide/PT	Ro2 (0.75/6)	2381	3.8	459	29	273.3	978
			Ro3 (0.8/12)	710	5.2	619	28	280.5	1236
			Sofia (0.8/12)	738	5.3	907	28	246.0	699
SCHHA	Schremmer	Niederkrüchten/DE	Doraemon (0.8/3.8)	4900	3.0	409	17	90.5	710
SLAST	Slavec	Ljubljana/SI	Kayak1 (1.8/28)	563	6.2	1294	10	62.3	164
			Kayak2 (0.8/12)	741	5.5	920	12	85.4	162
STOEN	Stomeo	Scorze/IT	Min38 (0.8/3.8)	5566	4.8	3270	25	111.3	835
			Noa38 (0.8/3.8)	5609	4.2	1911	24	111.8	837
			Sco38 (0.8/3.8)	5598	4.8	3306	24	118.8	954
STRJO	Strunk	Herford/DE	Mincam2 (0.8/6)	2354	5.4	2751	14	61.3	212
			Mincam3 (0.8/6)	2338	5.5	3590	13	59.1	210
			Mincam4 (1.0/2.6)	9791	2.7	552	15	49.1	253
			Mincam5 (0.8/6)	2349	5.0	1896	12	53.5	243
			Mincam6 (0.8/6)	2395	5.1	2178	13	56.0	216
TEPIS	Tepliczky	Agostyán/HU	Huago (0.75/4.5)	2427	4.4	1036	20	130.2	757
			Humob (0.8/6)	2388	4.8	1607	13	106.4	610
TRIMI	Triglav	Velenje/SI	Sraka (0.8/6)*	2222	4.0	546	16	76.6	291
YRJIL	Yrjölä	Kuusankoski/FI	Finexcam (0.8/6)	2337	5.5	3574	10	46.8	127
ZELZO	Zelko	Budapest/HU	Huvcse03 (1.0/4.5)	2224	4.4	933	10	45.0	187
			Huvcse04 (1.0/4.5)	1484	4.4	573	11	43.5	181
* active field of view smaller than video frame						Overall	31	9 331.7	44 925

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Fireballs of 2015 April from Slovenia

Sporadic fireball on 2015 April 10 at $21^{\mathrm{h}}36^{\mathrm{m}}49^{\mathrm{s}}$ UT recorded on two consecutive exposures (notice the break) of the allsky camera of Rezman Observatory, Slovenia. This fireball showed multiple fragments at the end of its flight. Photo courtesy: Javor Kac / Rezman Observatory.

Sporadic fireball on 2015 April 23 at $23^{\mathrm{h}}27^{\mathrm{m}}10^{\mathrm{s}}$ UT recorded by the allsky camera of Rezman Observatory, Slovenia. This fireball lasted for more than 10 seconds, glowing greenish-white, and fragmented in the last part of its flight. Photo courtesy: Javor Kac / Rezman Observatory.