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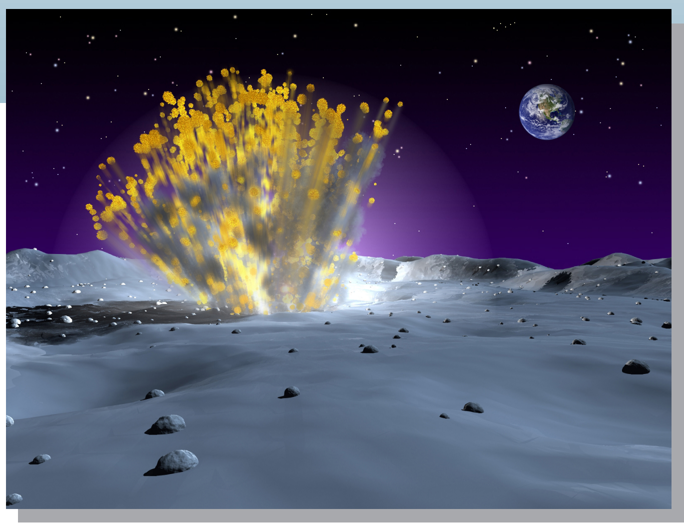

Capricornids
Meteors on the Moon
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Front cover photo

An artist's impression of an impact plume produced by a meteoroid hit upon the Moon's surface. Image courtesy of NASA. See Martin Beech's paper on page 33.

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

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

Editorial — Delays in WGN

Chris Trayner

It will be obvious to you that this issue of WGN is very late again; indeed, later than ever before. Let me make it clear that this is not the fault of anyone else in the IMO — the problem comes entirely from me as Editor. The University Department where I work has many problems at the moment, all coming from the shortage of students studying engineering in Britain. These result in staff reductions without any great reduction in workload; fewer students don't mean fewer lectures or labs. For me personally this has meant working typically a 12-hour day, which doesn't leave much space for WGN. These problems are mine not yours, but I feel I owe it to you (and to myself) to tell you why.

We will soon start the long summer vacation — not the free-and-easy time of myth and legend, but with luck things will drift down to a a 40- or 45-hour week. I therefore hope to get the June and August WGNs edited to a reasonable schedule. For this reason I am allowing the present issue to be shorter than I would like.

As you will realise, this workload is behind my decision (announced in WGN **35:6**) to resign as WGN Editor. It is to be hoped that a new Editor will be in place for the October WGN: the October term is always hectic for me. On top of this we now have the estimates for the future: due to staff cuts our University workload will be 15% more than at the moment.

One of the bad side-effects of this shortage of time for WGN has been the selection of papers to edit for each issue. Ideally everything I receive is edited ready for the issue after it is received. When WGN is running late, however, the sensible thing is to restrict myself to the papers which can be edited quickly. Unfortunately this means that the harder ones, which need a lot of email correspondence with the authors, get left for later. These harder papers are no less valuable — indeed, they are often the more important ones. But, as the English saying goes, 'needs must when the Devil drives'.

Editing WGN is a very satisfying thing to do — you feel you are making a genuine contribution to the meteor community. If you think you might be interested in editing WGN, please don't hesitate to get in contact.

IMO bibcode WGN-362-editorial NASA-ADS bibcode 2008JIMO...36...27T

Letter — Meteor electromagnetic signatures

George John Drobnock [1]

There is a renewed interest in meteor generated electromagnetic signatures. It has long been thought that a meteor creates an electromagnetic signature that can be rectified into an audible electrophonic sound, or that a meteor creates a receivable very low frequency wireless (radio) signal. There is too a controversy as to whether or not a meteor creates such a nelectromagnetic noise. Yet after years of radio observation, an electromagnetic signature has not been heard on the short-wave and higher end of the radio spectrum. Yet it is known that a meteor's trail will reflect a range of earth-bound transmitted signals.

For those beginning and conducting research may I offer the following for your consideration. These thoughts are from an unpublished paper that has undergone many revisions.

For an electromagnetic signal to be created, a resonance mechanism needs to be available, whether it is a simple Leyden jar and lecher wire with spark gap, or an oscillator consisting of a solid-state device that will allow an inductor and capacitor to be continuously charged and discharged to create a continuous wave.

For a meteor to create an individual radio frequency signature please consider the following:

1. The duration of the meteor's electromagnetic signature pulse is short. It can be anywhere from .5 sec to .001 of a second or less. The pulse being of a short time duration and it being a very long electromagnetic wave, its range for reception is possibly a few hundred kilometers or less. However, this is not to say that a fireball magnitude of -6 or greater will not create a larger signature and its range may be greater, but in general the distance of a propagated signature from a meteor of magnitude -6 or less will be 300 kilometers or less if the initial pulse from the meteor releases energy for .001 seconds or less.

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2. It is generally thought that a meteor 'noise' is alike to lightning-generated sferics, creating multiple frequencies. If I may offer the following: consider a meteor at its greatest ablation, before being extinguished, and the release of the electromagnetic pulse as being a large resonating circuit. In order for an electromagnetic signature to be created there has to be resonance.

   This is modeled as a simple resonating circuit consisting of a capacitor and inductor, a simple tuned circuit that when the energy is released from the capacitor creates a single damped wave pulse.

   The frequency generated by the meteor at the time of discharge of the electromagnetic pulse is dependent on the capacitance (in farads) created by the ablation of the minerals in the meteor and the upper atmosphere. This melting of silica, iron and low energy plasma of charged irons creates a temporary capacitor that is charged as it enters the atmosphere. The irons, siliceous materials, and plasma create the dielectric and electrode and charge of a temporary storage device. The length of the trail is a plasma capable of acting as an inductor. The length of the trail creates an antenna. The length of the trail would be an inductor measured in henries. The length of the resulting train or trail of the meteor and the capacitance created by a part of the ablation of minerals would determine the frequency created.

   The capacitor created at some point reaches a break-down point where the energy is released and resonance occurs in a given frequency of the VLF spectrum.

   As the created signal is from an antenna in free space, the electromagnetic pulse has the probability of going off into space depending on the electron density of the atmosphere above and below the meteor, or around the meteor. The signature can be propagated to follow the curvature of the earth, absorbed or attenuated by the atmosphere, and be 'heard' in a different location (then it becomes a sferic). or it can be propagated to the observer within a radius below the meteor's path.

   To support part of this please review reports of observations of the weak signal generated by sputnik I. See: Direction-Finding Observations on the 20 Mc/s Transmissions from the Artificial Earth Satellites, F. A. Kitchen, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 248, No. 1252 (1958 Oct. 28), pp. 63–68.

   The early satellite observations were on a weak continuous carrier wave, unlike a meteor generated pulse, but found to be subject to a varied propagation, unlike an earth bound and generated signature.

   With a meteor's signature being of short duration and of varied energy it is possible to exhibit the same characteristics as the early orbiting satellite.

3. The renewed interest in receiving meteor generated signatures is by using sound cards and untuned whip antennas, or the 'Inspire' designed VLF receiver, as well as others available. All rely on a random length long wire antenna. May I suggest a more refined research with a receiver having a known resonating or tunable front end. Over the years of my research it has been determined that the circuit of my research receiver is tuned to 3.2 kHz with a strong harmonic at 9.6 kHz and a weak sub-harmonic at 1.6 kHz.

   This is not to say these are the frequencies of a meteor, but if the proposed meteor model of a natural capacitor and inductor created by ablation of a meteor when the trail reaches the length to resonate at 3.2 kHz and there is a discharge of the natural capacitor then a frequency is generated that is within the capability of my receiver.

The larger fireball may create additional signatures and have a sustained signature from its size, where the small meteor may create a signature for a very short time period, therefore making the success of capturing a meteor signal from a lesser fireball more difficult.

The renewed search for the characteristics of a meteor signature is a challenge.

Conferences

International Meteor Conference 2008
September 18–21, Šachtička, Banská Bystrica, Slovakia

Stanislav Kaniansky and Daniel Očenáš

Location and period

The 2008 International Meteor Conference (IMC) will take place from September 18 to 21 in a very picturesque setting, in the town of Šachtička. Šachtička is a touristic site popular mainly for winter sports. It is 1000 m above sea level, and only 8 km away from the city of Banská Bystrica. Banská Bystrica (see `http://eng.banskabystrica.sk` for more information on the city in English) is located in central Slovakia. It is the most important historical, cultural and economic center of this part of the country. It is the capital of the Banská Bystrica Region. Banská Bystrica lies on the river Hron and is surrounding by beautiful mountains. The first written reference to the city dates back to year 1255.

Banská Bystrica used to be known as a mining town. Gold, silver, lead, and copper were mined here. Nowadays, it is a modern city with more than 80 000 inhabitants. The Vartovka Hill, very close to the city, is the location of the *Astronomical Observatory of Banská Bystrica*. In the past, Vartovka served as a watch tower.

Venue

The conference will take place in *Hotel Šachtička*. For more information in English, please visit `http://www.sachticka.sk/index_en.html`. There are double rooms and double rooms with an extra bed. Each room has toilet, shower, and TV.

The main conference room can seat 136 people, and is also suitable for posters. There are also smaller conference rooms. They are equipped with a sound system, TV, video, flipcharts, overhead projectors, silver screens, data projectors, DVD players, microphones, internet access, and similar amenities.

How to get there

Banská Bystrica can be reached from the Slovak capital of Bratislava by plane, train or bus. There is an airline connection between Bratislava and Sliac Airport, located 15 km from the city. Train and bus connections between Bratislava and Banská Bystrica are direct, i.e., they do not require a transfer. From Banská Bystrica, a short car ride will take you to your hotel.

To give you an idea, we calculated the distances from some major, capital cities in Central Europe to Šachtička:

Budapest–Šachtička	187 km
Bratislava–Šachtička	200 km
Vienna–Šachtička	282 km
Prague–Šachtička	541 km
Warsaw–Šachtička	554 km

Local Organization

This year, the Local Organization is in the hands of the Maximilián Hell District Observatory and Planetarium at Žiar nad Hronom, and the Observatory of Banská Bystrica. It is co-organized by the Department of Astronomy, Physics of the Earth and Meteorology of the Faculty of Mathematics, Physics and Informatics of the Comenius University at Bratislava, and by the Slovak Central Observatory at Hurbanovo. The Local Organizing Committee (LOC) is composed as follows:

Daniel Očenáš, Observatory of Banská Bystrica;
Stanislav Kaniansky, Maximilián Hell District Observatory and Planetarium;
Juraj Tóth, Comenius University, Bratislava;
Teodor Pintér, Slovak Central Observatory.

IMO bibcode WGN-362-kaniansky-imcann NASA-ADS bibcode 2008JIMO...36...29K

Registration fee

The registration fee amounts to 150 EUR. If you book no later than June 30, 2008, however, you get a 10 EUR deduction, and you pay only 140 EUR. In this amount is included:

- a parking place for those coming by car;
- general conference materials and a 2008 IMC T-shirt;
- accommodation for 3 nights;
- all meals (from dinner of Thursday, September 18, up to lunch on Sunday, September 21);
- refreshments during coffee breaks;
- the conference excursion and barbecue;
- the proceedings.

We also encourage you to give a presentation of your results or the results of your group. Make sure your registration as well as the abstract of the talk(s) you intend to give before August 31, 2008. However, we strongly advise you not to wait that long and register at your earliest convenience.

Practical information

To register, please visit `http://www.imo.net/imc2008` and fill out the registration form that you will find there by following the appropriate link. Alternatively, you can fill out the paper registration form you find here and send it to *Marc Gyssens, IMO Treasurer, Heerbaan 74, B-2530 Boechout, Belgium.* **However, please use the webform if you can!** The paper form is intended only for those having no easy access to the internet.

For your registration to remain valid, the IMO excepts to receive either the full sum of 140 EUR (early)/150 EUR (late) or a prepayment of at least 70 EUR **within two weeks after registration**. If you have registered electronically, you will be automatically directed to the page with payment information. For those who cannot register electronically, the paper form contains this info as well. Electronic registrants get automatic confirmation emails for both receipt of their registration and receipt of (each) payment. If you only make a prepayment, you can pay the balance at a later data or at the conference itself.

Contact information

For more information, check the IMC 2008 website at `http://www.imo.net/imc2008`.

For further questions regarding registration and payment, please contact the IMO Treasurer, Marc Gyssens, via email at `treasurer@imo.net` or write to him—Marc Gyssens, Heerbaan 74, B-2530 Boechout, Belgium.

For all other questions, contact the LOC via e-mail at `imc2008@imo.net` or write to them—Stanislav Kaniansky, Krajská hvezdáreň a planetárium M. Hella, Duklianskych hrdinov 21, SK-965 01 Žiar nad Hronom, Slovakia. This is in particular the case for those needing a formal invitation to obtain a visa. Notice that such invitations will be supplied only to serious applicants known to the international meteor community.[1]

[1] It is the participant's responsibility to obtain all documents required to enter Slovakia. Failure to do so does not constitute a valid reason for full or partial reimbursement of the registration fee or prepayments thereof.

International Meteor Conference
Šachtička, Banská Bystrica, Slovakia, 2008 September 18–21
Registration form

Do not use if you have internet access! Please register electronically on `http://www.imo.net/imc2008` if you can. If you have **no** internet access, fill out one form for each individual participant should fill return it to Marc Gyssens, IMO Treasurer, Heerbaan 74, B-2530 Boechout, Belgium, as soon as possible. Registration will be guaranteed only after Marc Gyssens has received either the full registration fee of 140 EUR (up to June 30)/150 EUR (from July 1 onward) or a pre-payment of at least 70 EUR. We expect this payment to arrive within two weeks after the form.

Name: ______________________________ Address: ______________________________

____

____

Phone: ______________ Fax: ______________ E-mail: ______________

- I wish to register for the IMC 2008 from September 18 to 21.
- I intend to travel by ________, together with ______________________________
- I want to share a room with ______________________________
- T-shirt: Size (S-M-L-XL): ________ Gender: ________ (included in fee)
- I am vegetarian.

For participants wishing to contribute to the program:

Lecture: ______________________________

Requirements: ______________________________

Duration: ________ minutes

Workshop: ______________________________

Poster(s): ______________________________ Space: ________ m^2

Comments:

- I am paying the entire registration fee of 140 EUR (early)/150 EUR (late)
- I am paying the advance (70 EUR) now, the remainder later
- I want a single room (add 30 EUR to the registration fee).

The indicated amount should be sent to IMO Treasurer, Marc Gyssens. The following payment options are available:

- **International bank transfer** to the International Meteor Organization, Mattheessensstraat 60, B-2540, Hove, Belgium, IBAN account number: BE30 0014 7327 5911, BIC bank code: GEBABEBB (Fortis Bank, Belgium). This is recommended for people living in the European Union, as it is no more costly than a domestic bank transfer when done correctly.
- **PayPal payment** to `payment@imo.net`. In that case, we must ask you to add the costs involved in the transaction (3.4% of the total sum, plus 0.35 EUR).
- **Other arrangements**. Please contact the IMO Treasurer for information.

Financial support for IMC2007 participants

Jürgen Rendtel

As during previous years, *IMO* is making limited funds available to support participation in the *IMC* 2008. To apply for support, please do the following:

1. E-mail your application to *IMO* President Jürgen Rendtel, at `president@imo.net`. Include the word 'Meteor' in the subject line to get round the anti-spam filters. *IMO* cannot be held responsible for applications which are lost or arrive late. The application must be submitted by an *IMO* member, but may also request support for other meteor workers. The proposal must state that all the candidates are committed to attend the *IMC* (except for unforeseen circumstances) if the requested support is granted in full.
2. Complete an *IMC* Registration Form (preferably electronically) for everyone seeking support (unless already done before).
3. Include a brief curriculum vitae of everyone seeking support, focusing on aspects relevant to meteor work. Supported participants are expected to present either a talk or a poster at the *IMC*. (Indicate and detail this on the Registration Form.)
4. The application must explain the motivation for participating in the *IMC* and the importance of this participation it to the person or group of persons requesting support.
5. Include a budget for travel costs and registration, and the amount of support requested. Other sources of external support, or their absence, must be mentioned. The proposal must indicate to what extent *IMO* support is essential to attend the *IMC*.
6. The applications should reach the President no later than 2008 June 20. The decision of the *IMO* Council will be made as soon as possible, probably within two weeks after this deadline. If the support is granted in full, the registration form becomes final. If the requested support is not granted, or only partially granted, the candidates should inform the President within three weeks after notification of the *IMO* Council's decision if they want to sustain or withdraw their registration. The support granted will be paid in cash at the *IMC*. Any unpaid registration fees will be deducted from the amount paid to the candidates.

Should the application be turned down, the standard conference fee (i.e., €140, without the surcharge for a late application) will still apply. We strongly encourage all meteor workers who want to attend the *IMC* 2008, but who are prevented from doing so by financial considerations, to apply for support.

IMO bibcode WGN-362-rendtel-imcsupport NASA-ADS bibcode 2008JIMO...36...32R

Ongoing meteor work

Meteors over the Moon

Martin Beech [1]

There is a high degree of probability that in the relatively near future, on a timescale of perhaps several hundreds of years, the Moon will be engineered to support a substantial atmosphere. Once the mass of any artificial lunar atmosphere exceeds some 10^8 kg, it will be both long-lived and dynamically maintainable. One of the key advantages of producing a lunar atmosphere will be that it will provide protection to ground-living communities against meteoroid impacts as well as solar and cosmic radiation. We find that a lunar atmosphere with a mass in excess of 10^{11} kg will provide ground protection against even the highest possible velocity (that is for bound solar system orbits) kilogram-mass meteoroids.

1 Introduction

Current NASA plans call for the return of astronauts to the Moon by 2020, and the eventual establishment of a permanently staffed Moon-base over the ensuing decades. The problem of building structures on the Moon's surface is accordingly an area of great current interest, and concomitant to this is the interest in making such structures as safe as is reasonably possible from meteoroid impacts (Benaroya & Bernold, 2008). Indeed, the habitable structures will need to shelter humans from meteoroid impacts, cosmic rays, solar radiation, and the extremes of temperature experienced on the Moon. One of the most commonly discussed methods of structural shielding is regolith enshrouding. In this scenario a layer of lunar soil, several meters thick, is built-up around and over a building thereby providing a 'natural' barrier with which to absorb meteoroid impact energy and radiation – additionally, the regolith is also readily available without the need for any substantial transportation costs. The debate on building construction and protection is far from complete, and will certainly develop and change over the next many years (Figure 1).

For individual, relatively small structures impact protection by regolith covering is certainly a reasonable approach to adopt. The situation is less clear in the deeper future, however, when the large scale, cityscape inhabitation of the Moon is in full progress (Landis, 1990). Under these circumstances it might make more sense to try and construct an artificial lunar atmosphere. Such an atmosphere might provide the entire Moon with a natural protective barrier from small meteoroids as well as protection from harmful solar and cosmic radiation. By the construction and maintenance of a lunar atmosphere we are not specifically invoking the idea of terraforming (Beech, 2008; Fogg, 1995), but rather we envision an entirely un-breathable atmosphere made predominantly of (perhaps) industrial waste gases and directed out gassing. Indeed, on the Moon we potentially have the enviable situation where the more industrial pollution generated the better, a circumstance that will not, of course, please lunar astronomers, but by the time such developments are likely to take place the Moon will probably no longer be an ideal location for making observations anyway.

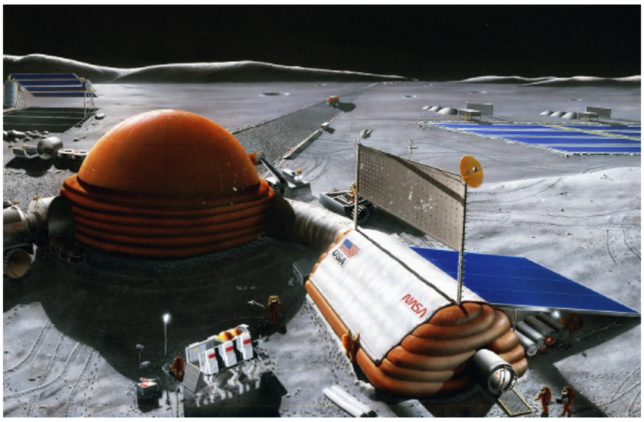

Figure 1 – An early concept design for an inflatable Moon dome, power generation plant and surface vehicle maintenance yard. NASA graphic number S89-26097 (1989 March).

2 An artificial lunar atmosphere

The Moon has no natural, long-lived atmosphere, its surface gravity is simply too low to constrain in place any gas with the characteristic temperature of a body at 1 AU from the Sun (Hughes, 1978). The present lunar exosphere has a measured surface density of about 10^{10} particles per meter cubed and a total instantaneous mass of about 10^4 kg. Such conditions indicate that the exosphere is collision-less with the constituent atoms moving along ballistic trajectories. The loss of material from the Moon's exosphere is therefore a thermal process such that any atom of mass m having a velocity $V_{\text{thermal}} = [2kT/m]^{1/2} > V_{\text{escape}} = 2.38$ km/s, where T is the Moon's surface temperature and k is the Boltzmann constant, will soon, on a timescale of order hundreds to thousands of years, be lost into space.

In addition to the thermal loss process, a highly efficient mass removal mechanism related to the solar wind also operates on the Moon. In this case atmospheric ions produced through interactions with solar UV radiation become entangled within the electric field pro-

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NASA-ADS bibcode 2008JIMO...36...33B

duced by the motion of the solar wind past the Moon. In this manner, it turns out, half of the ions are driven into outer space and half are driven back to the Moon's surface. In this situation the mass loss rate is controlled by the ionization lifetime which is typically of order a few tens to perhaps a hundred days – this is a timescale many orders of magnitude smaller than the thermal mass loss mechanism. Richard Vondrak (1974) has studied the ionization mass loss mechanism in some detail and finds that a critical mass loading of the solar wind occurs at a mass flux of about 0.03 kg/s. Here then lies the possibility for producing a lunar atmosphere. Detailed calculations indicate that if gases are released from the Moon's surface with a mass flux in excess of about 50 kg/s, then an atmosphere can be built up with the exosphere being pushed upwards and away from the lunar surface. Vondrak (1974, 1992) finds that a long-lived (that is on a timescale of thousands of years) lunar atmosphere can be created once its total mass exceeds 10^8 kg — this corresponds to a four orders of magnitude increase in the mass of the present lunar exosphere.

The Moon is certainly rich in resources that might in principle be mined, and/or vaporized to produce, and then feed the artificial atmosphere. The challenge to produce such a mass increase, however, is formidable. If we take Vondrak's (1992) estimate of about 50 kg/s of out gassing being required to produce an artificial lunar atmosphere, and also assume that it should be in the form of oxygen then of order 50 million metric tons of regolith would need to be mined per year (Taylor, 1992) – this calculation assumes a 5% efficiency in extracting oxygen from regolith material containing 5% ilmenite = iron titanium oxide: $FeTiO_3$. This number perhaps sounds large, and of course economically speaking it is, but it is actually 100 times smaller than the current annual coal extraction rate on Earth (`http://www.worldcoal.org`).

3 Meteoroid filtration

The surface pressure P_S that results from an atmosphere of mass M_{atm} is given by the relationship

$$P_S(\text{Pascal}) = (5.31 \times 19^{-12})(M_P/R_P^4)M_{atm}, \quad (1)$$

where M_P and R_P are the mass and radius of the host planet / moon. For the Moon we have

$$P_S = (4.28 \times 19^{-14})M_{atm}(\text{kg}). \quad (2)$$

At height h above the Moon's surface the pressure

$$P(h) = P_S \exp(-h/H) \quad (3)$$

where $H = kT/mg$, where H is the pressure scale height, k is Boltzmann's constant, T is the temperature, m is the mass of the representative atmospheric atom, and g is the gravitational acceleration at the Moon's surface. For a perfect, isothermal gas, the pressure can be related to the temperature and pressure via the relationship $P = (R/\mu)\rho T$, where R is the gas constant and μ is the mean molecular weight of the representative atmospheric atom/molecule. In the calculations that follow

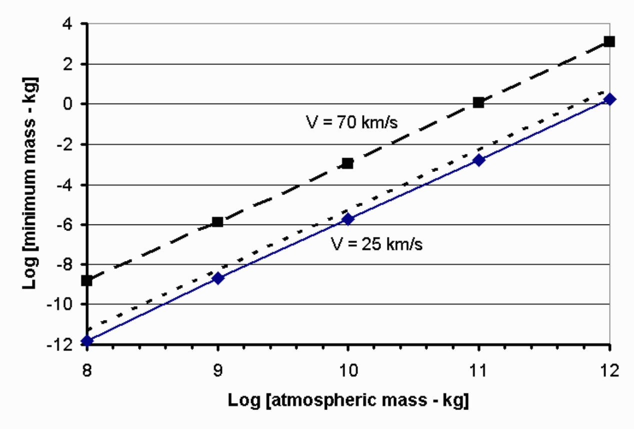

Figure 2 – Minimum impact mass for a meteoroid encountering an artificial Moon atmosphere of mass M_{atm} (kg). The upper line corresponds to an encounter velocity of 70 km/s and the lower line to an encounter speed of 25 km/s when the zenith angle is $Z = 0°$. The short-dashed line corresponds to an encounter velocity of 25 km/s, but with a zenith angle of entry of 45 degrees.

we take $\mu = 32$, technically this value corresponds to an oxygen atmosphere although our intention here is to use this purely as a representative number. Different composition atmospheres will produce either higher or lower values for the mean molecular weight term and correspondingly lower or higher pressure scale heights.

With the above isothermal, atmospheric model being described we are in a position to consider meteoroid ablation in an artificial lunar atmosphere of total mass M_{atm} (kg). The calculations to be discussed here simply solve for the deceleration and mass loss equations describing the ablation of a solid-body meteoroid. For the sake of argument we assume a vertical impact ($Z = 0$, although see Hughes, 1993), a meteoroid density of 3000 kg/m^3 and an ablation coefficient of $\sigma = 8 \times 10^{-8} m^2/s$ (characteristic of stony material). Two encounter velocities, $V = 25$ km/s and 70 km/s, will be considered. The larger velocity is the 1 AU limit for a meteoroid to remain bound to the solar system, while the smaller is representative of the typical sporadic meteoroid encounter speed at the Earth's orbit. We are not specifically interested in the trail length and or lunar meteor brightness in this study; rather it is the evaluation of the surface impacting mass for a given atmosphere. Accordingly, we are looking to determine the meteoroid, with an initial encounter mass of $m(h \approx \infty)$, that has a vanishing mass at the Moon's surface: $m(h = 0) = 0$. The results of our calculations are shown in Figure 2. As one would expect, the more massive the lunar atmosphere, so the larger is the minimum meteoroid mass required to satisfy the $m(h = 0) = 0$ condition. For a lunar atmosphere mass of 10^8 kg, the least massive meteoroid capable of just reaching the Moon's surface has a mass of 1.4×10^{-9} kg (dia. = 100 microns). The least massive meteoroid capable of just reaching the Moon's surface when the lunar atmosphere has a mass 10^{11} kg and the encounter velocity is 70 km/s is 1.2 kg (dia. = 9.3 cm). For an encounter velocity of 25 km/s, the least massive meteoroid capable of reaching the Moon's surface is 1.7 grams (dia. = 1.0 cm), when the atmospheric mass is 10^{11} kg. For meteoroids having zenith

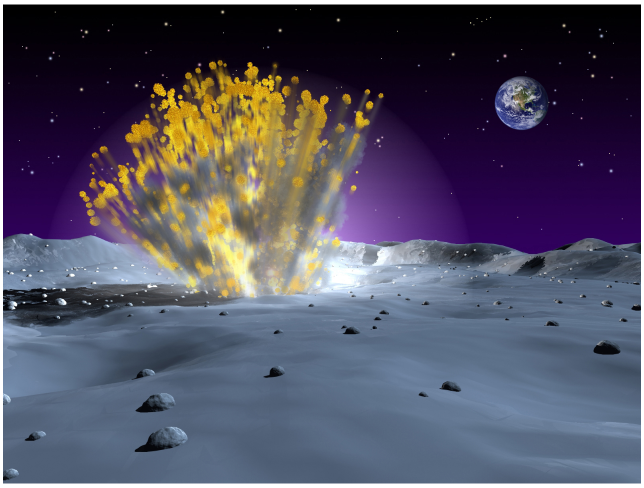

Figure 3 – An artist's impression of an impact plume produced by a meteoroid hit upon the Moon's surface. Image courtesy of NASA. Further details at:
`http://www.nasa.gov/offices/meo/home/index.html`.

angles greater than the vertical impacts considered here (i.e., $Z > 0$), the minimum mass limits for ground impact will increase above those derived for $Z = 0$ – as indicated by the short-dashed line in Figure 2.

The observed peak of the meteoroid influx at 1 AU occurs at a mass of about 10^{-8} kg (Love & Brownlee, 1993), and accordingly protection from the majority of small mass meteoroids at 1 AU from the Sun can be achieved on the Moon once the lunar atmospheric mass exceeds $\sim 10^9$ kg.

4 Discussion

There has been a long history of visual observers apparently seeing meteors in a supposed lunar atmosphere (Beech & Hughes, 2000), but in more recent times there has been the very definite detection of seismic events and surface impact flashes (Figure 3) caused by meteoroid strikes (Oberst and Nakamura, 1991; Dunham et al., 2000; and see the review article by Bellot Rubio, Ortiz and Sada, 2000). Cooke et al., (2007) find the lunar impact rate for 1 kg-class sporadic meteoroids to be about one per 11 hours. During the time of maximum activity associated with Earthly meteor showers the lunar impact rate of 1 kg-class meteoroids might increase to as high as 1 per hour. To provide lunar surface module protection against the direct impact of 1 kg-class initial mass meteoroids an artificial lunar atmosphere with a total mass between 10^{11} and 10^{12} kg would need to be generated.

If a regolith mined oxygen out-gassing rate of 100 kg/s can be realized then a 10^{12} kg lunar atmosphere might be developed within perhaps 300 to 500 years. This end might be achieved on a more rapid time scale if nuclear mining is exploited. Ehricke (1974) has estimated that a 1 kt nuclear device, if embedded and then detonated within the lunar mantle, might produce some 10^7 kg of oxygen. The detonation of 100 000 such devices, by no means a passive release of energy, would then produce the required amount of oxygen to produce an initial, 10^{12} kg lunar atmosphere. The atmosphere would then need to be maintained, at a lower material input rate, through non-nuclear regolith mining. Fogg (1995) has questioned Ehricke's assumptions, however, and suggests that the oxygen release rate per kt of explosive energy is more like 10^5 kg indicating that nuclear mining might not be the easiest or most cost effective way of producing a lunar atmosphere. A pure water-ice cometary nucleus with a diameter of 1.5 km technically contains enough oxygen to 'seed' an initial 10^{12} kg lunar atmosphere – the tricky engineering part, however, would be to release all the oxygen in a non-explosive manner. Simply allowing the entire cometary nucleus to crash into the Moon's surface would produce a much too dissipative impact. If the nucleus can be fragmented into numerous components prior to impact, however, a controlled out-gassing might just be possible. This latter scenario would also result in enhanced regolith degassing, similar in manner but on a much larger scale to the sodium enrichment of the Moon's exosphere observed during the Leonid meteor storm in 1998 (see e.g., Smith et al., 1999).

It has been speculated by Chernyak (1978) that the Moon might have supported various transient atmospheres throughout most of its history. His argument is based upon the detailed study of lunar regolith core samples gathered by the Russian Space Agency's Luna and NASA's Apollo mission astronaut explorations conducted during the 1970s. Specifically, Chernyak argues that on the basis that the Moon's regolith is produced by meteoritic bombardment then the relative depletion of very small mass particles might be explained by their ablative destruction in a lunar atmosphere. Indeed, Chernyak suggests that the Moon must have had, on at least one occasion during the past 100 Ma, an atmosphere with a total mass of order 5×10^{11} kg to explain the relative depletion of small particles in the lunar regolith samples.

In a solar system full of natural resources there seems to be no reason to doubt that an artificial lunar atmosphere won't eventually be engineered within the next several centuries (Beech, 2008). James Oberg (1981) goes even further and argues, 'Because of the Moon's proximity to Earth, it should be considered as an early terraforming project' Indeed, a lunar atmosphere will provide a natural filter against the surface impact of small meteoroids, and for Earth-based observer's there will be the added pleasure of seeing meteors fall across the Moon's disk. Not only will such an atmosphere provide lunar inhabitants with impact protection it will also, if the appropriate chemical composition is maintained (e.g., the emplacement of an upper ozone layer), provide them with protection against short-wavelength solar radiation and cosmic rays.

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The Capricornids in 1984

Koen Miskotte [1] *and Carl Johannink* [2]

Dutch observations of the Capricornids from 1984 to 2003 are presented and analysed. It is concluded that the 1984 Capricornids were brighter and more numerous than the other years.

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1 Introduction

In 1984 three meteor observers of the Dutch Meteor Society, Carl Johannink (JOHCA), Koen Miskotte (MISKO) and Bauke Rispens (RISBA) stayed in Puimichel, Southern France from 22 July until 5 August. It was the very first observing project for which Dutch observers travelled to a region with more favourable weather than what they were used to in the Netherlands. They stayed at the holiday observatory of Danny Cardoen and Arlette Steenmans in those days. Considerable numbers of meteors were observed at that place according to Dutch standards. In about ten nights of clear sky over 4000 meteors were raked in. Most striking then were the Capricornids: with a maximum ZHR of about 10 and a good number of bright shower members absolutely worth the efforts. As it was the very first time that this shower was observed by DMS members from more southern latitudes, Rudolf Veltman (1984) assumed this was a normal Capricornid display. However, later observations from southern locations in 1985, 1986, 1990, 1991, 1993, 1994, 2001 and 2003 indicate that in 1984 there was something unusual happening. Koen Miskotte observed this shower from even more southern latitudes than in Puimichel, like the Greek islands Chios (2001) and Crete (2003). Furthermore Carl Johannink observed end July in 1994 and 2001 from Toscana, Italy. At these later returns only a fraction of the 1984 Capricornid numbers was recorded. When this article was written some more data turned up with the observations of Paul Roggemans of July 1984. The ZHR values calculated for these observations were used in this paper too.

Since Koen proclaims since years that the 1984 Capricornids were very special, although never documented with facts, it is time to take a closer look.

2 Summary of observations of past decades

2.1 1984

In 1984, three observers managed to observe the Capricornids in the period 22 July till 5 August. Most remarkable were the number of bright Capricornids, including some beauties of −4, −4, −5 and −8! Especially the −8 fireball was spectacular. This moved from the constellation Aries slowly to the Pleiades where it disappeared after a bright −8 end flare. Especially the build-up towards the maximum attracted attention as it was rich in (sometimes very) bright meteors. After the maximum the shower was to some extent less abundant in bright meteors. During the same year Paul Roggemans observed two nights at the Keys in Florida, USA. Although the sky conditions for these observations were less good as for those made in Puimichel, Southern France, they fit well together. At the same time several bright Capricornids were reported from the Netherlands and Belgium. Unfortunately the radiant remains too low above the horizon seen from these countries and therefore the correction factors are too large for the ZHR calculations.

Figure 1 – The Dutch observers in Southern France July 1984: from left to right Carl Johannink, Marcel Lücht, Koen Miskotte and Bauke Rispens.

2.2 1985

Encouraged by the success of 1984 the complete meteor observing team ‘Delphinus’ from Harderwijk, the Netherlands, landed in Puimichel in 1985: Arjen Grinwis (GRIAR), Robert Haas (HAARO), Koen Miskotte and Bauke Rispens. Between 6 and 22 August over 8000 meteors were counted. Most nights were clear, but some were a bit hazy. Because these observations were made after the maximum of the Capricornids, these datasets were not included in this analysis. Compared to 1984 the number of Capricornids was very disappointing. At that time we attributed this to the fact that we were observing far too long after the maximum.

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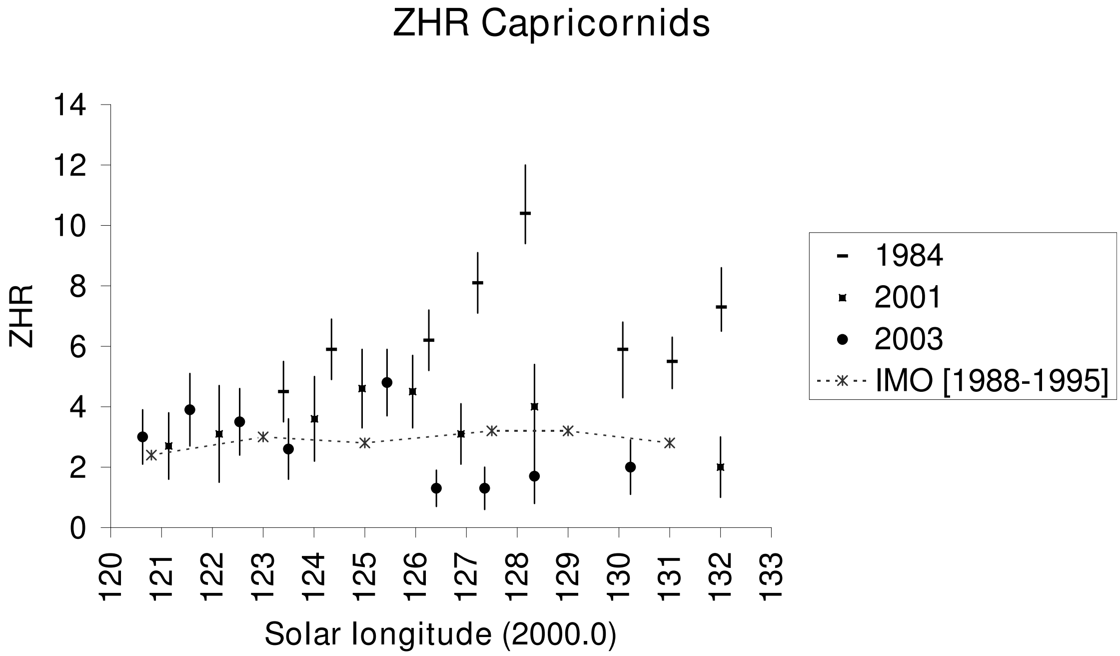

Figure 2 – Capricornid ZHRs for the years 1984, 2001 and 2003.

2.3 1986

The same goes for 1986 when MISKO and RISPA visited Puimichel again, then between 3 and 16 August. Also that year disappointing numbers of Capricornids were recorded. Also the observations of the Belgian meteor observer Paul Roggemans done from 25 July onwards that year listed very few Capricornids.

2.4 1990, 1991

Marco Langbroek (LANMA) visited Puimichel in 1990 and 1991. During the nights of 20, 21, 22 and 25 July 1990 some 6.5 hours were observed with as few as 3 Capricornids as a result. Unfortunately this is too few data for any serious analyses. In the period of the nights of 4–5 until 12–13 August 1991 Marco observed 8 Capricornids with a mean magnitude of 2.80, the brightest one being +2. Note that these observations were done after the maximum and the number of meteors is too small to enable any valid statistics.

2.5 1993

Rognes, Provence, Southern France. Because of the expected Perseid outburst on 11 August the observations took place in Southern France. Between 7 and 14 August very little was seen of the Capricornids. Also these observations are not included in the analyses.

2.6 1994

Toscana, Italy. JOHCA observed a few nights end of July and begin of August and recorded almost no Capricornids. Unfortunately too few Capricornids were seen to get any reliable data.

2.7 2001

In 2001 MISKO made observations on the Greek island Chios between 22 and 31 July. During 8 nights over 800 meteors were recorded. The Capricornids displayed a low activity and only few bright shower members were seen (the brightest was −2). JOHCA also observed that year again from a southern observing site (Toscana, Italy) and recorded low numbers too. From both observers data was used in this analysis.

2.8 2003

In 2003 MISKO observed from Southern Crete. Between 22 July and 3 August well over 1400 meteors were seen. It was noticeable that during the build up towards the maximum some more bright Capricornids were seen (just like in 1984) but the activity level didn't get up to the 1984 level.

3 Comparing ZHRs of 1984 with 1994, 2001 and 2003

In this analysis the observations of 1984 were reconsidered. This was done before by Rudolf Veltman (1984), but at that time the personal perception coefficient cp of the observers wasn't yet taken into account and the observations of Carl Johannink weren't included in the analyses. The ZHR was determined with the method described in the DMS visual book 1988. The standard deviation of the individual ZHR values was derived as $\mathrm{ZHR}/\sqrt{n}$ From the magnitude distribution of the meteors observed by MISKO, RISBA and JOHCA population index values r of respective 2.40 , 2.59 and 2.53 were derived. For the ZHR calculations of the Capricornids in 1984 the r-value was assumed to be 2.50. This is also the value mentioned in the handbook for visual observations of IMO (Rendtel et al., 1995). The computed ZHR values are reproduced in Table 1. Table 2 lists the results for ROGPA from the Florida Keys (USA). These values agree very well with the results from Southern France, except for one data point. His magnitude distributions show that relatively many bright shower mem-

Table 1 – 1984 Capricornid ZHRs for MISKO, RISBA and JOHCA.

$\lambda_\odot$ (eq. 2000)	ZHR Mean	σ
120.00	2.0	1.0
123.40	4.5	1.0
124.34	5.9	1.0
126.26	6.2	1.0
127.22	8.1	1.0
128.16	10.4	1.6
130.08	5.9	0.9
131.05	5.5	0.8
132.02	7.3	1.3

Table 2 – 1984 Capricornid ZHRs for ROGPA.

$\lambda_\odot$ (eq. 2000)	ZHR Mean	σ
123.67	10.8	4.4
123.74	7.7	3.4
126.51	11.5	3.3
126.62	3.2	1.9

bers were recorded (+2 or brighter up to −4).

For comparison the ZHR values of the Capricornids according to IMO based on 1625 observations from the period 1988 – 1995 are listed in Table 3 (Rendtel et al., 1995).

Table 3 – 1988–1995 Capricornid ZHRs according to IMO.

$\lambda_\odot$ (eq. 2000)	ZHR Mean	σ
120.8	2.4	0.3
123.0	3.0	0.3
125.0	2.8	0.2
127.5	3.2	0.2
129.0	3.2	0.2
131.0	2.8	0.2

It occurs immediately that the ZHR values recorded in Puimichel in 1984, are about twice as high as the averaged ZHRs of IMO for the entire observing interval. The ZHR values for the observations of 2001 and 2003 by MISKO from Crete and the 2001 observations of JOHCA from Toscana are also calculated. These are listed in Table 4 for 2001 and in Table 5 for 2003. It is clear that a maximum ZHR of about 5 is found, about half of the value for 1984!

For all ZHR values of the years 1984, 2001 and 2003 as well as for the average ZHR values of the IMO a graph has been created (Figure 2). This shows in one view that the Capricornids in 1984 were an exceptional appearance.

For the datasets of 1984, 2001 and 2003 magnitude distributions were derived. For the years 2001 and 2003 only data for MISKO was used because JOHCA recorded rather too few Capricornids these years. The magnitude distributions were limited to the interval −2, +5, the observing conditions were compatible (Table 6).

Table 4 – 2001 Capricornid ZHRs for MISKO and JOHCA.

$\lambda_\odot$ (eq. 2000)	ZHR Mean	σ
120.10	4.0	1.3
121.14	2.7	1.1
122.13	3.1	1.6
124.01	3.6	1.4
124.95	4.6	1.3
125.94	4.5	1.2
126.89	3.1	1.0
128.34	4.0	1.4
132.00	2.0	1.0

Table 5 – 2003 Capricornid ZHRs for MISKO.

$\lambda_\odot$ (eq. 2000)	ZHR Mean	σ
120.63	3.0	0.9
121.56	3.9	1.2
122.54	3.5	1.1
123.50	2.6	1.0
125.44	4.8	1.1
126.41	1.3	0.6
127.36	1.3	0.7
128.34	1.7	0.9
130.23	2.0	0.9
132.00	2.0	1.0

4 Conclusion

From these data it is obvious that the average magnitude of the Capricornids varies from one year to the other. Of these three years 1984 shows the brightest average magnitude. Furthermore the meteor shower displayed most of the meteors brighter than −2 in 1984. The conclusion therefore is that this meteor stream outnumbered other years in quantity but also surpassed them in quality.

Acknowledgements

We thank the observers for using their data and Paul Roggemans for translating this article into English.

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Table 6 – Magnitude distributions for 1984, 2001 and 2003.

Year	Averaged Capricornid magnitude
1984	2.84
2001	3.36
2003	3.01

Preliminary results

Results of the IMO Video Meteor Network — December 2007

Sirko Molau [1]

The year 2007 finished with true meteor fireworks. The weather was less co-operative than in 2006, so that the monthly totals summed to 'only' 1 600 hours of observing time and nearly 9 500 meteors. That was sufficient, though, to ensure the first place for 2007 in the annual statistics.

In the first December days weather was particularly good for a winter month, but right in time for the Geminids the situation became worse. At the maximum night December 12/13 it was better again, but there was hardly an observing site with truly clear skies. Often the observation was hampered by cirrus clouds or fog. Bob Lunsford was in the best position of all — he had moved for three nights into the Californian desert with pristine skies. On December 14/15 he broke all records by capturing over 700 meteors in eight hours of observing time. That result was only topped during the Leonid storms. In subsequent nights, the weather allowed one or the other observation. However, just in time for the eagerly awaited Ursid maximum it deteriorated again and improved only slightly towards the end of the year.

Now for the highlights of the month. At first I would like to mention a sporadic meteor of first magnitude that I captured on the morning of December 14 at 04^h14^m UT. What's so special about it? It's the 100 000th meteor that I observed by video and analysed with MetRec! Ok, to be perfectly honest, the one shown here (Figure 1) is meteor no. 99 999. The real jubilee meteor was much less attractive. ;-)

Back to the real highlights of the last month. First of all, the Geminids have to be mentioned. Contrary to the previous year, there was no single camera in 2007 with permanently clear skies on December 13/14 and 14/15. For that reason, the activity graph had to be combined from time intervals with clear skies from the individual cameras. Unfortunately I could not use the data sets of the image-intensified cameras AVIS2 and BOCAM. That was a particular pity, because the American data would have extended the profile quite a bit. However, whereas all the other Mintron and Watec cameras have in the first order similar recordings properties, the two intensified cameras record much more meteors. The meteor counts would have to be scaled down, but the scaling factor is not easily determined. The resulting activity profile from the other cameras shows rising Geminid activity in the evening of December 13 until about midnight. From there on, it stays at a high level until dawn, and by the evening of December 14 the rates are falling again. The second highlight of December was the Ursids, which were supposed to show enhanced rates in 2007. Just days before the maximum, Peter Jenniskens, Esko Lyytinen and other renowned outburst specialists published a paper in WGN. They had studied the development of dust trails from the parent comet 8/P Tuttle in the last 2000 years. It was concluded that on December 22 between 20^h and 22^h UT ZHRs between 40 and 80 could have been expected, much more than the usual maximum rate of about 10. Already at previous returns of the short periodic parent comet, the Ursids had occasionally shown enhanced rates, which could be explained more or less well by the dust trail simulations.

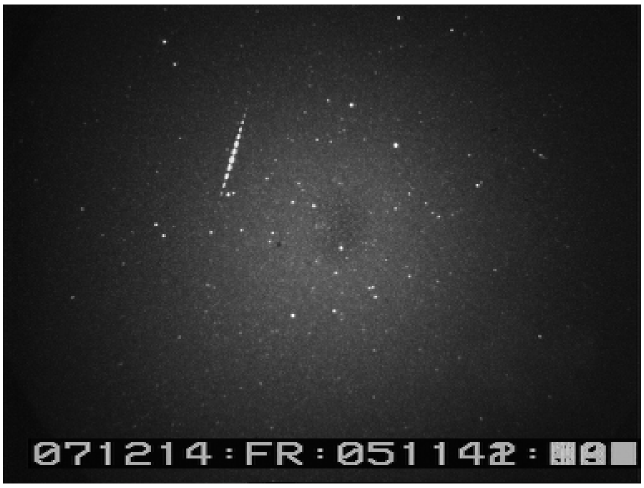

Figure 1 – Sirko Molau's jubilee meteor no. 99,999.

Unfortunately, the weather was hardly co-operative in the night in question, and the full moon was high in the sky. So only three cameras (Mincam2, Mincam3, Hermine) in the Ruhr area in Germany and one (Finexcam) in Finland were able to provide useful data sets. Mincam5 was blinded for a longer time period by the full moon, RF1 suffered from clouds drifting through the field of view, and at other sites skies cleared only later at night. The four cameras recorded 93 Ursids and 42 sporadic meteors between December 22, 15^h30^m UT and December 23, 01^h UT. From the first look it was obvious that Ursid rates were high right from the beginning of observation until about 23^h UT, and broke down dramatically thereafter. For the analysis, meteors were summed up in 30 minute intervals and corrected for the radiant altitude. In addition, an empirical correction factor was applied for those time intervals where the full moon disturbed the field of view. In the end, the data from the four cameras were averaged resulting in an activity profile that shows enhanced activity between 17^h and 23^h UT.

But was that indeed the expected outburst? Fortunately, there was already special interest in the Ursids before, so I had done an analysis of the shower with the same method in the previous year based on five data

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NASA-ADS bibcode 2008JIMO...36...40M

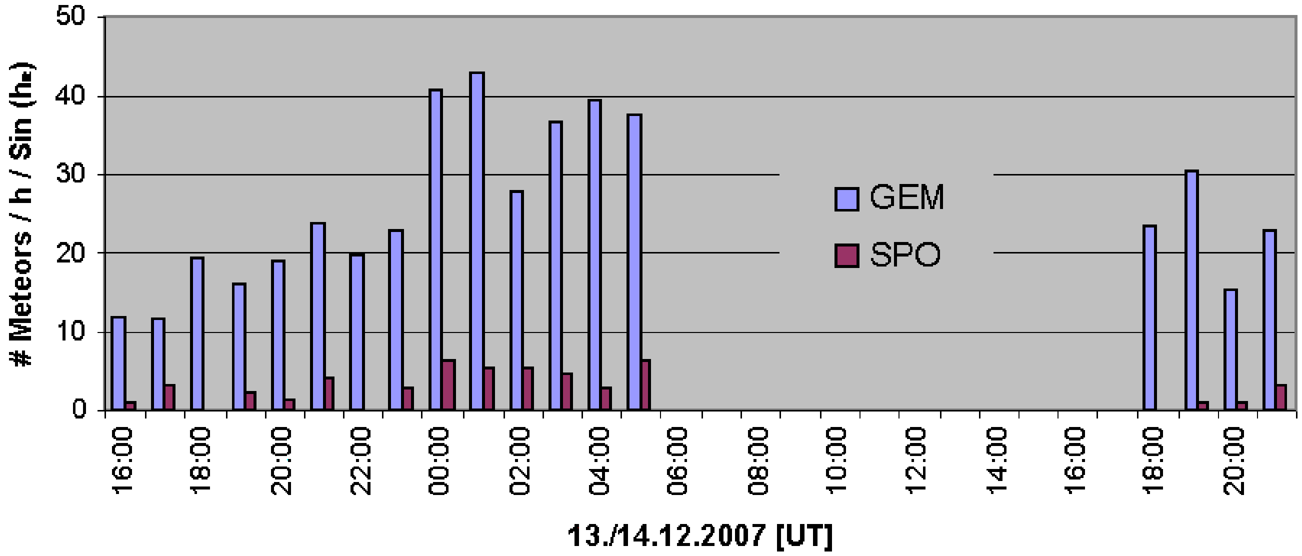

Figure 2 – Activity graph of the Geminids on 2007 December 13/14. The plot shows the number of Geminids recorded per hour, corrected for the radiant altitude. For comparison, the sporadic hourly rate is given as well.

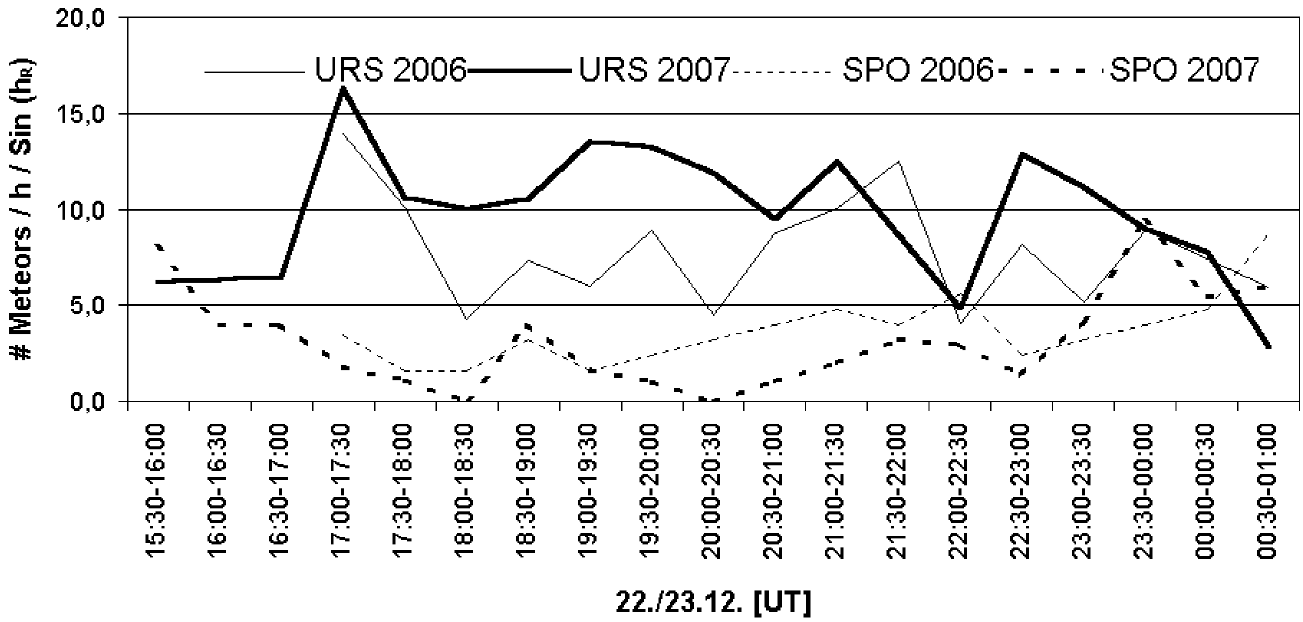

Figure 3 – Comparison of the Ursid activity on December 22, 2006 and 2007. The plot shows the number of Ursids recorded per hour, corrected for the radiant altitude. For comparison, the sporadic hourly rate is given as well.

sets. That could now be used for comparison. It became clear that the activity profile in 2007 was quite similar to the one of 2006, and rates were only slightly higher. Since the profile of sporadic meteors looked the same as well it can be ruled out that this is only due to different observing conditions (limiting magnitude, field of view). If there was indeed an outburst, it must have consisted mainly of faint meteors — too faint to be recorded by non-intensified cameras in a moonlit night. It remains to be mentioned that the highest Ursid activity was observed in both years in the evening of December 22, i.e. at a different solar longitude.

Let's now come to the annual statistics for 2007. In the last year, 22 observers (2006: 19) from 9 countries (2006: 6) have participated in the IMO Video Meteor Network with 30 (2006: 28) distinct camera systems. With respect to the number of observers, Germany (7) and Italy (5) are on top, followed by Slovenia (3). All observers but Bob Lunsford (USA) are based in Europe. The slightly increased interest in the camera network is reflected also in the observation results. Even though we 'only' got 364 observing nights this time (May 28/29 was the only night with no observation in the last two years), the overall effective observing time increased from nearly 15 000 hours in 2006 to nearly 17 000 hours in 2007, and also the meteor number increased from 70 000 to 75 000. Averaging over all cameras and nights, we recorded 4.4 meteors per hour — slightly less than in the year before (2006: 4.7).

Once more, August, October and December were particularly successful months. Whereas most observing time was collected in October, we could record for the first time more than 15 000 meteors a month in August. April is also worthwhile to be mentioned, since this typically very poor month yielded perfect observing conditions in 2007, in contrast to the two following months.

Looking at the complete video meteor database, we now collected between 10 000 (May) and 53 800 (October) meteors per month. The data set has almost doubled since the last extensive meteor shower analysis in 2006, which is why I intend to repeat the analysis this year.

In the last year, six (2006: 5) observers managed to take the magic hurdle of 200 observing nights. In fact, what seemed to be almost impossible before — I myself collected even well above 300 nights improving the record from last years by 36 nights. Javor Kac, Flavio Castellani, Bernd Brinkmann, Mihaela Triglav-Čekada and Joerg Strunk follow in the statistics. It should be mentioned that Sirko Molau, Javor Kac and Joerg Strunk usually operate three cameras in parallel.

It remains to explain how a single observer can collect 324 observing nights in central Europe. The answer has two aspects: On the hand hand, my cameras are installed at two observing sites at a distance of about 500 kilometers. If it is clouded at one site, there are still chances for a cloud gap at the second. On the other hand, both observing sites seem to be well suited for central European circumstances. Both camera systems are operated fully autonomously and run stably such that they do not miss the slightest cloud gap. The statistics of the ten most successful cameras show REMO1 in Ketzuer in first and MINCAM1 in Seysdorf in second place.

All observations from 2007 are checked for consistency and inserted into the video meteor database. They will be made available in PosDat format for download at `www.imonet.org`.

Finally, I'd like to thank all observers in the camera network for the good co-operation in the previous year, and to wish all of us a happy and successful new observing year.

Results of the IMO Video Meteor Network — January 2008

Sirko Molau [1]

The year 2008 started in a successful way. In particular in Germany the weather was unusually good, so that several observers got more than 20 observing nights. At other sites, the weather was mediocre, but an overall of 1200 hours of observing time and 4 500 meteors are a decent result for January. It remains to add that the data of SRAKA is not yet included (Mihaela is about to finish her PhD — good luck!).

With respect to meteor activity, the Quadrantids were the only noticeable shower. In the beginning it looked as if they would become a victim of poor weather again, but right at the maximum skies cleared over eastern and southern Germany, so that maximum activity could be covered by a number of video cameras.

Figure 3 (next page) shows the activity profile of the shower as derived from data of AKM2, MINCAM1, REMO1, ARMEFA and FINEXCAM. The data set (274 QUA, 81 SPO) was split into 1/2 hour intervals, corrected for the radiant altitude, and averaged over all five cameras. Interestingly, the Quadrantid activity was almost constant between 01^h00^m and 04^h30^m UT, and increased only between 04^h30^m and 05^h30^m.

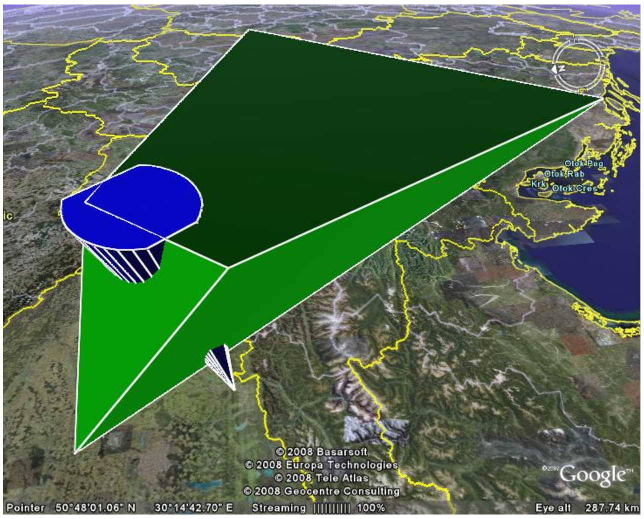

Figure 1 – Fields of view of MINCAM1 and AKM2 displayed in Google Earth.

Some weeks ago, Geert Barentsen wrote how to use Google Earth for the visualization of the cameras fields of view. He wrote a little web application that takes the position of the camera and the coordinates of the borders of FOV as input, and creates a KML file required for Google Earth. Based on this, I provided a small tool that creates the input for his web application based on a MetRec reference star file. Depending on the camera, either the full rectangular field of view is used, or you can mark the borders of the real field of view in a comfortable way (e.g. in case of an image-intensified camera with a circular FOV). Currently, Geert and I are still optimizing the result, but later the KML code generation shall be integrated directly into the MetRec tool.

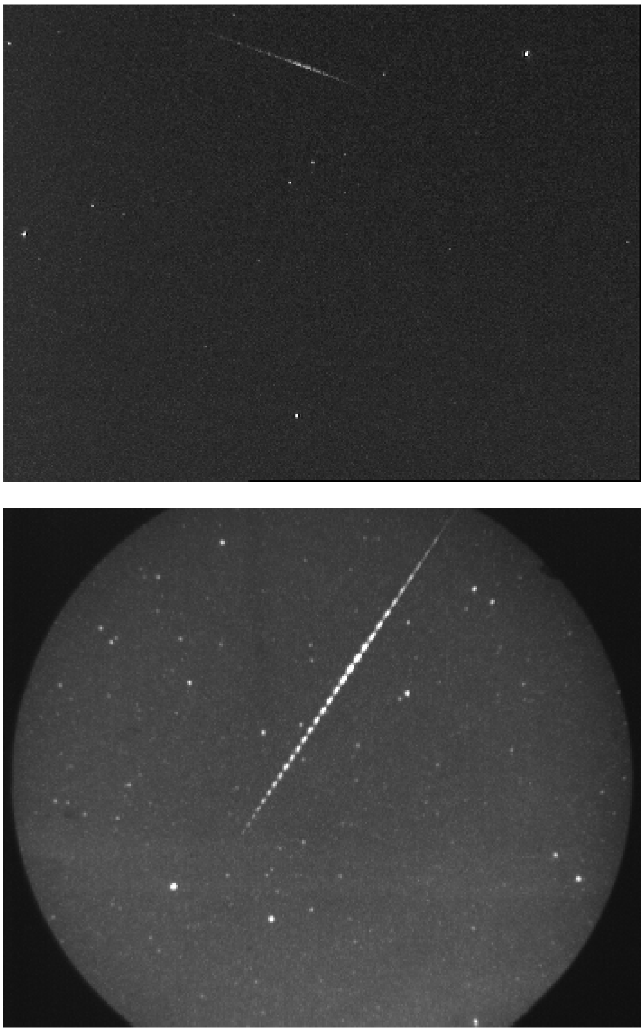

Figure 2 – A meteor recorded by MINCAM1 (top) and AKM2 (bottom) on 2008 Jan 3, $22^h42^m49^s$ UT.

To show the ability of Google Earth I measured the fields of view of all IMO network cameras and supplied the resulting KML file at `www.imonet.org` for download. Figure 1 shows the conditions over southern Germany as an example. It is easy to recognize that the field of view of MINCAM1 (Seysdorf, green) and AKM2 (Brannenburg, blue) overlap partly. A meteor pair recorded by both cameras on January 3 confirms the result (Figure 2).

Google Earth is well suited to align cameras in a double-station setup. Further areas of application (e.g. the spatial visualization of meteor trails) are currently under investigation.

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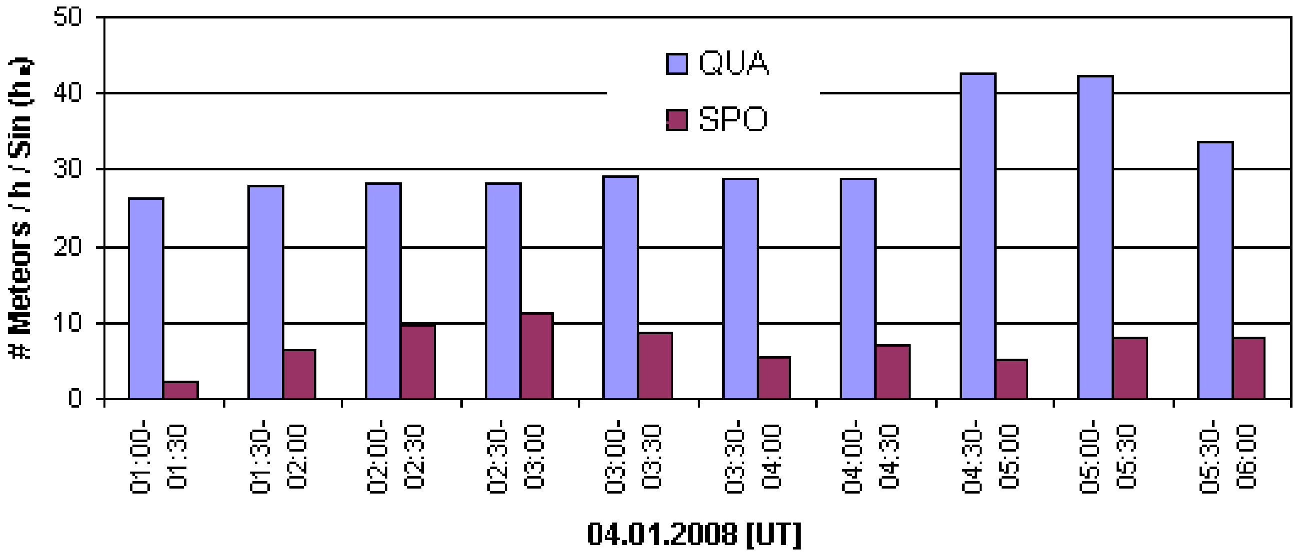

Figure 3 – Activity profile of the Quadrantids on the morning of 2008 January 4.

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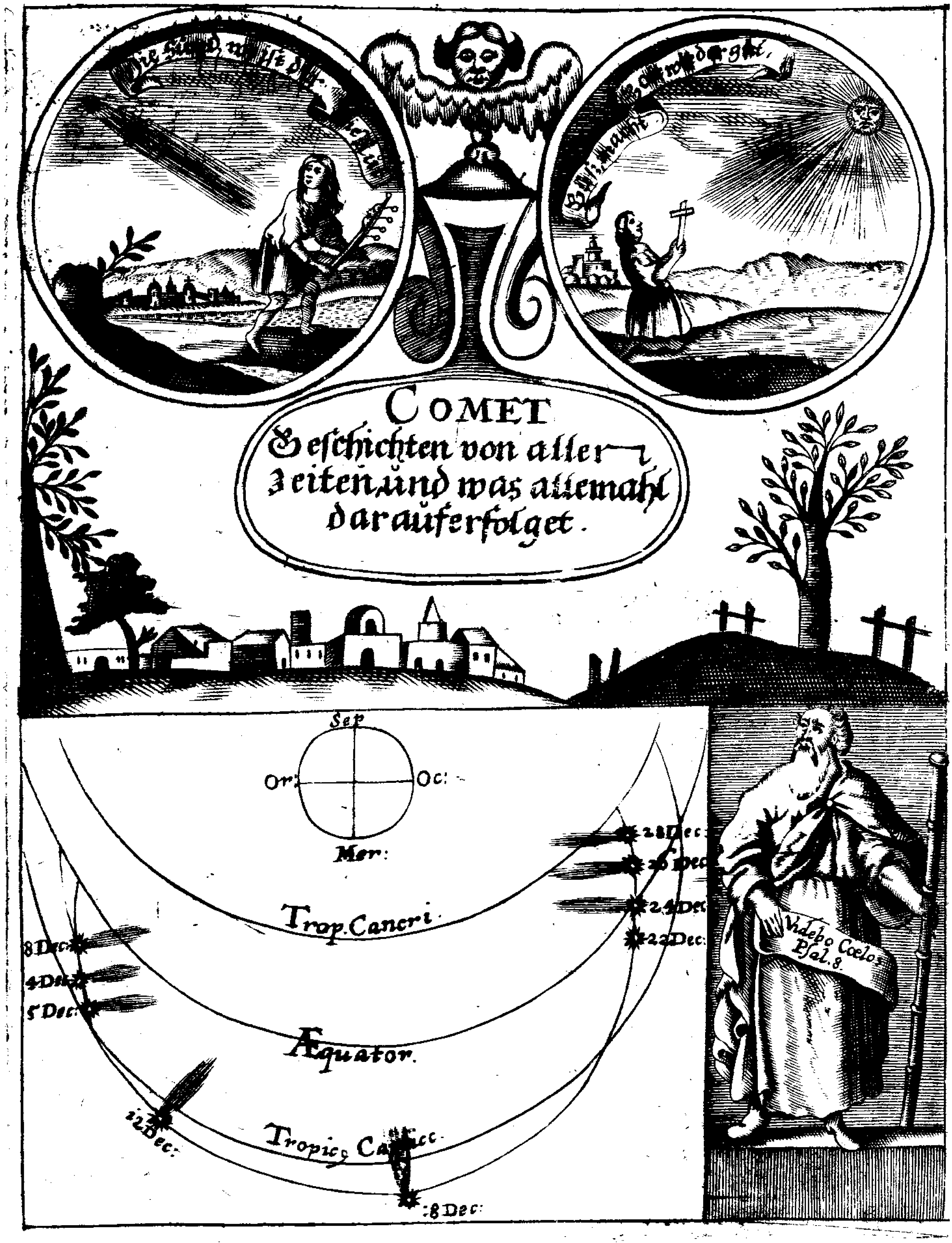

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See page 37 for comments on the Capricornids
and page 33 for speculations on meteors on the Moon.