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Front cover photo

Samer Hobeika was photographing this nighttime scene when a fireball occurred just above the horizon. It occurred on 22 August 2020 at $04^{h}34^{m}$ UT (12:34am EST) from Dalkeith, Ontario, Canada. For more details on this particular event visit: `https://fireball.imo.net/members/imo_view/event/2020/4701`. Photo courtesy: Samer Hobeika.

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 **45:1**, 1–5, and at `http://www.imo.net/docs/writingforwgn.pdf` .

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Letter — My (first?) Corona Year

Peter C. Slansky[1]

Following the call of our IMO president in WGN journal 49:1 (2021) I want to tell you, dear IMO members and meteor observers, about my personal Corona year. (May it not be the first in a line of years – knock on wood. . .)

2020 had started quite successful with my most fruitful Quadrantids observation campaign ever. My comrade Bernd Gährken and I had gone to a mountain in South Tirol. In the night from January 3rd to 4th my Sony a7S, equipped with my new meteor universal weapon, a Sony 1.4/24 mm GM lens, recorded 308 meteors in 4:45 hours, 209 of them Quadrantids – a personal record.[a] One night later we set up our telescopes for moon impacts. Viewing our videos, we were already cheering and opening a bottle of champagne – but it turned out that, instead of lunar impacts, the cameras had captured cosmics (lots of). Driven by frustration, I set up a concept to use a cubic arrangement of three Sony a7S as an in situ particle detector. However, “3APES: Triple Atomic Particles Examination System” turned out to be quark.

That seemed an awful long time ago when my Corona year started “officially” three months later. I had just returned from my annual stay at beloved Lago Maggiore, Switzerland/Italy. In Locarno the hotel manager had come up to tell all guests that due to an agreement of the local hotel’s association they closed on Sunday, March 15th 2020. I found it quite remarkable that this step was not taken by Swiss (or Ticinese) government or at least a health organization. Oh, happy early days. . .

Back in Munich I followed the “strong suggestion” of the Federal Minister for Health to stay in quarantine at home for two weeks. At that time this was not more than a suggestion. (Oh, happy early days. . .) Fortunately/unfortunately, there were no meteor showers. So, my only escape from the quarantine was the observation of a grazing star occultation by Moon on March 31st. I was able to create a composite from two video recordings.[b]

Apart from this I spent my time writing on two scientific papers and going over the schedule of my summer semester seminar at my University (the University for Television and Film Munich). I had the imagination that a new kind of a calendar had just stated. But, of course, I did not imagine the following.

After the quarantine experience I went to my University, still in the semester vacancies. I learned that a Corona task force had been installed by our president and the chancellor that met daily (today 2 days a week). Guidelines and actions to be taken were developed before the students returned. Coloured lines were applied on the floor that formed attractive patterns, regulating the directions of movement. Every single room was calculated and indicated for its maximum number of users. Disinfectant dispensers were installed every X meters on each floor and in front of all studios and cinemas. Up until today we wear masks in our building, only to be allowed to be removed in our own office. After the second day back in office I made a general decision: Not work at home, but work in the University, as long as this was allowed. May sound strange, but that’s the way I work since that very day.

My car became my personal mobile protective shield (those of you who came to the IMC 2019 to Potsdam might know it: red 2+2-seater from Swabia, year of construction 1986. . .). Until today my red lion brings me safely from the underground carpark of my housing complex to that of my University and back on every working day. What old school, compared to all the years of using public transport. . .

My first Corona meteor observation was the Lyrids on April 22nd. According to the lock down, I stayed in my flat, just stepped out on my roof terrace. Matthias Knülle, Bernd Gährken and I had arranged a triple-station observation with camera angles aligned. From the light polluted Munich city centre my Sony a7S, equipped with a 2.8/15 mm fish eye lens, recorded 59 meteors in 3:38 hours, 41 of them Lyrids (a personal record, again).[c]

With my seminar in May/June coming closer my assistants and I developed a special setup for online teaching in our TV studio 2: `www.hff-muc.de`. We were simply fed up with images of lecturers on their sofa, the camera pointing into their nostrils and the bookshelf behind them. Our whole seminar was held online but with the very first two workshops in the presence of students. This was only possible with a nearly Kafkaesque performance of arrangements for distance keeping. But it gave the students a hope for the better. To foster their resilience at that time (that turned out later to be just the beginning) I produced a video for them from my roof terrace with a live commentary on a virtual flight over the moon surface via my 102/1100 mm refractor telescope.

Also in May, my mother passed away at the age of 95, on Mothering Sunday. Born 1925, she had been active in the war as “FLAK-Helfer” (anti-aircraft assistant) been ordered to illuminate British night bombers attacking West Germany with 1 m parabolic searchlights. Oh, unhappy old days. . . After the war she had become a textile designer. I had been incredibly happy when she was able to attend my doctoral thesis defense at the Bauhaus University in Weimar in spring 2013. I jump several things, especially the restrictions for a funeral during the pandemic. Today I think about what she could have said about the pandemic. It might sound like the title of a future James Bond movie: *“Man stirbt nicht so schnell”* (“You don’t die that fast”). In the meantime, I visited

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[a] `https://www.imo.net/members/imo_photo/view?photo_id=1408)`
[b] `http://slansky.userweb.mwn.de/bereiche/astronomie/sternesternfelder/sternbedeckungen/12-gem_31-03-2020_03.html`
[c] `https://www.imo.net/members/imo_photo/view?photo_id=1505`

her grave four times (it is 670 km from Munich). My sister and I were able to arrange very good care for my father, 96 years old.

The most spectacular observation in my Corona year came completely unplanned. On the evening of July 5th I stepped out to my roof terrace to take a last look around. For this you have to know that, from the astronomical point of view, my roof terrace is situated very badly: Facing North and pretty much in the epicenter of Munich's light pollution. But at that evening on 22:30 CEST I saw the very first Noctilucent Clouds of my life – and what a brilliant display it was! It reached from horizon to horizon from the West to the East and clearly surpassed the Munich city lighting, even that of the cathedral, which is illuminated as bright as day. It took me a while to realize that these were NLCs, so far in the South. It took me another while to get my camera and a tripod ready. But I was able to shoot my first NLC photo series. My 16 years old Canon DSLR 20Da came to service, equipped with a Sigma 3.5/10–20 mm zoom lens that gave a horizontal field of view of 83° – and the NLCs exceeded the field significantly. Was this a one-hit wonder? Well, two nights later the NLCs came back again, and even better. The icing on the cake was Comet C/2020 F3 (NEOWISE). I was prepared better, too, and was able to record a video sequence and four photo sequences with my Sony a7S. And following the call of duty, I wrote an article about it for WGN journal 48:5…

The NLCs turned out to be the basics of my presentation on the 2020 online IMC – because my 2020 Perseids campaign was a complete fail due to bad weather. (I wonder if I should submit a presentation to the next IMC with the title "The Fruits of Failure, Frustration and Fortune" – but I am not sure if the SOC would accept a topic like that…)

Summer brought a treacherous openness to traveling. I went to the Swiss Alps, again (after, of course, to my parent's home). On the Bernina Pass, at 2 300 m altitude, I shot a timer photo sequence of the sky over Piz Cambrena out of my hotel window including what turned out to be my only photo ever where I was unsure if this was a meteor or a satellite.[d]

Pandemic autumn came. Before the beginning of the winter semester, in which I have to give three seminars, a rare opportunity arose: within some consecutive nights the International Space Station ISS flew over Munich. Yes, meteors are faster. But filming a passage of the ISS is still quite a challenge. Something inside myself had smelled blood (in a scientific, or, let's say, cinematographic, sense only, of course). I took a professional digital film camera from my University that is usually used to shoot Hollywood movies. Bernd opened access to the 800/8000 mm telescope of the Munich public observatory (Volkssternwarte München). This telescope is one of the few fast enough and precise enough to follow ISS. But with a resulting field of view of only $10\overset{\prime}{.}3 \times 5\overset{\prime}{.}8$ the crucial point is, of course, the exact tracking of the ISS, which is moving with about 27 000 km/h in an altitude of 420 km. For this purpose the constructor of the telescope steering, Klaus Nagel, was engaged. On our fifth attempt on September 30th we were successful. Postproduction and sound design were made in my University. The ISS video has now received more than 3 000 clicks on vimeo: `https://vimeo.com/476651368`.

Leonids, Orionids, Northern Taurids, Alpha Monocerotids – all bad weather. But pandemic Geminids 2020 turned out to be blast. Instead of the lock down Bernd and I drove 80 km to the South East to Bayrischzell, where we had been observing several times. (We were totally legal leaving Munich before 21:00 and coming back after 05:00.) But the sky was clouded out there at the Sudelfeld Pass where we had been several times before. Fortunately, just 10 km back to the West skies were open. Above Osterhofen, at 1 200 m altitude, we setup our cameras to experience a first class night for the Geminids 2020. As it turned out, there were no fireballs or even bright meteors, neither Geminids nor others. But in 5 hours I observed 265 meteors visually, among them 230 Geminids – a personal record, again. My two Sony a7s surely would have recorded even more, but they suffered from battery weakness at the low temperatures another time. (That drives me to general improvements on my equipment.) Nevertheless, a couple of nice composite images could be created.[e]

Quadrantids 2021 were missed due to bad weather. My pandemic astronomic year finished with the observation of the occultation of mag 7.7 star HIP 61099 by minor planet 1048 Feodosia on March 20th 2021. The track of the occultation crossed the Autobahn A9 about 30 km North of Munich. While the sky over Munich remained clouded we could record the occultation on video with a duration of 5.7 s at Bernd's place and 6.3 s at my place. Of course, a report was made to IOTA.

This March, one year after the beginning of the pandemic in Germany, my University team and I had finished our three seminars in the winter semester with an incredible amount of extra work. Along the way we were able to completely renew about two thirds of our media technology installations. It had also been a year with lots of personal observational records. But another trip to Lago Maggiore is impossible. Because of the third pandemic wave, we must prepare now for another lockdown. In meteor observation – as well as in film education – we constantly feel the constraints imposed by the pandemic – like a lion grinding against the bars of his cage.

All the best to all of you – *"Bleibt gesund!"*, as we say in German!

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[d] `https://www.imo.net/members/imo_photo/view?photo_id=1655`
[e] `http://slansky.userweb.mwn.de/bereiche/astronomie/meteore/geminiden_2020_01.html`

In memoriam: Esko Lyytinen (06.11.1942 – 24.12.2020)

Peter Jenniskens[1], *Josep M. Trigo-Rodríguez*[2,3], *Maria Gritsevich*[4,5,6]

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On Christmas Eve 2020, our friend and close collaborator, Esko Lyytinen passed away. Esko was a mathematician, active amateur astronomer, and author of many scientific publications on meteor showers and meteorite falls. Esko had the unique ability to think big and dream 'out of the box' and had a great desire to help others. Hard to think of another man who would help meteor science that much and who would also, in a relatively short time after his retirement, establish effective collaborations with nearly everyone actively working in the field.

Esko was born in Helsinki, Finland, in 1942. He lived most of his childhood in Kuru, today part of Ylöjärvi. His family moved to Helsinki in the 50's, where Esko lived for the rest of his life. His father taught and worked in forestry and public administration. His mother had a Master's degree in biology and natural sciences and was a teacher for a short time, before she devoted her life to the family and bringing up the children. A deep love of nature was very much part of the family ethos.

In 1972 Esko obtained a lisenciate of philosophy (MS+, a degree between master and doctorate) in Mathematics from the University of Helsinki. In his lisenciate thesis Esko studied the preservation of some classes of Riemann surfaces in quasi-conformal imaging. Prior to his retirement, he worked as a civil servant in the Finnish Ministry of Education and Culture.

After retirement, Esko was able to fully devote his attention to topics of meteor showers and meteorite falls. With a festive engagement with science and a fundamental understanding of the mathematics involved in the complex processes that govern the universe, Esko became actively involved in diverse research fields, including celestial mechanics, orbital dynamics, acoustics, seismology, meteorology, experimental physics, astronomical observations, education, and even bird migration. His life serves as a reminder that a true dedication to your ideas and dreams knows no age.

Best known for his models of meteoroid streams, Esko was a forecaster of meteor showers and a meteorite fall chaser. He was a scientist who made a difference. Esko's work contributed to a realization that meteor physics is not a fully resolved discipline from the recent past, but rather an emerging multidisciplinary science – with many openings – vitally relevant to our present time of space exploration.[a]

Figure 1 – Photo of Esko Lyytinen shortly following the recovery of the Annama meteorite in 2014. (Image credit: Emma Herranen / Tähdet ja avaruus, Ursa).

[a] A more detailed dedication will be published in the following WGN issue.

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Conferences

International Meteor Conference – September 25th/26th, 2021

The IMO Council and the IMC 2021 SOC

The International Meteor Organization organizes a two-day online IMC on Saturday September 25th and Sunday September 26th, 2021. In order to register for attendance of the online IMC, please send an e-mail to `imc2021@imo.net` before September 1st, $00^{\rm h}$ UT, mentioning your name, affiliation and country.

The online IMC 2021 will use the free Zoom software. Connection details will be communicated in due time.

To accommodate participants from Asia, Australia and New Zealand, the schedule on September 25th is from $06^{\rm h}00^{\rm m}$ UT till $15^{\rm h}00^{\rm m}$ UT. The September 26th schedule is from $10^{\rm h}00^{\rm m}$ UT until $19^{\rm h}00^{\rm m}$ UT, to allow participants from America to join part of the conference during daytime hours.

IMO's General Assembly Meeting will take place on September 25th, $14^{\rm h}00^{\rm m}$–$15^{\rm h}00^{\rm m}$ UT and is open to all interested persons.

In case you want to present a talk, please provide the author list, title, and abstract. Talks will be given by PDF/PPTs via Zoom and are 15 minutes by default, plus 5 minutes for questions. Abstracts must be submitted before July 1st, $00^{\rm h}$ UT.

We will record the entire conference and the slides will be uploaded to the IMC 2021 website. Please contact `imc2021@imo.net` if you do not want the recording and/or slides of your presentation to be distributed.

The Conference Proceedings will be published in a special section of our journal *WGN*. Proceedings papers should be submitted to WGN before October 20th, but we encourage you to submit your paper before the start of the conference if possible (contact: `wgn@imo.net` — see submission instructions for WGN at `https://www.imo.net/docs/writingforwgn.pdf`).

Further details will be published soon in the IMC 2021 website `https://imc2021.imo.net`.

We hope to meet you at the online IMC on September 25th–26th!

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Meteor science

Simultaneous estimation of ZHR and the limiting magnitude correction factor

Janko Richter [1]

This statistical model describes how a limiting magnitude correction can be applied to the analysis of visual rate observations. For this purpose, the meteor magnitudes are intentionally not used. To avoid confusion with the population index called r-value, a new correction value is introduced. The latter is used exclusively to correct the observed rates at different limiting magnitudes to determine a ZHR.

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1 Motivation

On average, we find in visual observations that more meteors are observed the greater the limiting magnitude m of the observation. Let us assume, that two visual observations were made under the same conditions, but with different limiting magnitudes m (see Table 1). In this example it can be seen that $f = 1.5$ times more meteors were observed in observation B than in observation A. Hence, the factor f describes the amount of increase of the rate with the limiting magnitude.

Table 1 – Two visual observations made under the same conditions, but with different limiting magnitudes m

Observation	m	n
A	5.5	20
B	6.5	30

In the following thought experiment, we assume that a third observation would have been made under the same conditions, but at a limiting magnitude of $m = 5.7$. How many times more meteors would be observed on average if the limiting magnitude is $m = 6.7$? Intuitively one would answer that also $f = 1.5$ times more meteors would be observed than at a limiting magnitude of $m = 5.7$. With $q = \ln(f)$ we can express this with the following equation:

$$\mathrm{E}[n] \propto \; e^{q \cdot m} \, \frac{1}{t_{\text{eff}}} \; . \tag{1}$$

Here $\mathrm{E}[n]$ is the mean expected number of observable meteors and E is the symbol for the expected value. The operator $\propto$ expresses that the number of observable meteors still depends on the activity of the meteor shower and the observation conditions. In the previous example, we assumed that the activity of the meteor shower and the observation conditions were the same. Equation (1) is a stochastic model because the actual observable meteor count depends on chance.

This model can be used to estimate the ZHR of an observation:

$$\mathrm{ZHR} = c \cdot e^{q \cdot (6.5 - m)} \cdot \frac{n}{t_{\text{eff}}} \; , \tag{2}$$

where n is the observed count of meteors and c is a correction factor expressing all other known observational conditions. To estimate the ZHR, the limiting magnitude correction factor q must be known. As shown in the example, the q-value can be estimated with $q = \ln(f)$. This results in two problems. How can the q-value be estimated for more than two visual observations? What is the uncertainty of the q-value? Therefore, a general method is needed to estimate the q-value.

2 The linear regression

In this section we describe the mathematical principles for estimating the q-value and the activity of the meteor shower. Let t be the waiting time for a meteor, where corrections such as the altitude of radiant have already been applied. The waiting time for a randomly observed meteor is stochastically independent and memoryless. This means that the waiting time for a certain meteor does not depend on how much time has already passed or how long we have waited for the previous meteor. From this follows that

$$P(T > t) = e^{-\lambda \; t} \; , \tag{3}$$

where $P(T > t)$ is the probability to wait longer than t for the next meteor and λ is the rate parameter. The rate parameter is usually given in meteors per hour. For example, it means that at an average rate of 6 meteors per hour ($\lambda = 6$) we can expect an average waiting time of 10 minutes for each meteor. Note here the difference in notation between t and T. In probability theory, capital letters are used for random variables. Lower case letters are used for variables that do not depend on random. This includes also measured values, as they are in the past. Therefore, $P(T > t)$ is the probability that the waiting time T for a meteor is greater than any given waiting time t.

Next, we use Equation (2) to create a stochastic model. We obtain the nonlinear model

$$\mathrm{E}[T_m] = \mathrm{E}\left[\frac{1}{\lambda_m}\right] \; , \tag{4}$$

$$= e^{\,-a - q \cdot (m - m_0)} \; . \tag{5}$$

where $\mathrm{E}[T]$ is the expected value of T and intuitively the arithmetic mean of a large number of of independent observed waiting times for a meteor. The variables a

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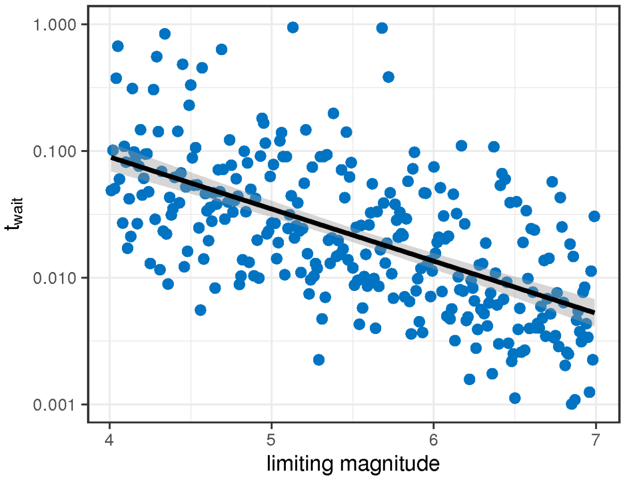

Figure 1 – Gumbel distributed linear regression using the example of waiting time for a meteor. Used values are $q = 1.0$ and a rate of 10 meteors per hour at a limiting magnitude of $m = 4.0$.

and q are parameters of the model and m_0 a predefined scale parameter. Consequently, in Equation (2) $m_0 = 6.5$. For $m = m_0$ we get the meaning of the parameter a: $\exp(a)$ is the expected mean rate for the limiting magnitude of m_0. To obtain a linear model we use the logarithm of the waiting time for a meteor. From Equation (5) it follows that

$$\mathrm{E}[\ln(T_m)] = \mathrm{E}[-\ln(\lambda_m)] \ , \tag{6}$$
$$= -a - q \cdot (m - m_0) \ . \tag{7}$$

Suppose we have observed a waiting time t_k for a meteor of observation k. All observations must have different limiting magnitudes and we still assume that the ZHR is the same for all observations. According to Equation (7), then there is a correlation between the waiting time t_k for a meteor and the limiting magnitude m_k of the kth observation (see Figure 1). With a newly defined random variable

$$U := \ln(T) + \gamma \tag{8}$$

and consequently the observable value

$$u_k = \ln(t_k) + \gamma \tag{9}$$

we obtain from Equation (7)

$$u_k = -a - q \cdot (m_k - m_0) - \delta_k \ , \tag{10}$$

where δ_k is a random error term and $\gamma \approx 0.5772$ is the Euler–Mascheroni constant. The Definition (8) of the random variable U considers that we must ensure that the sum of all residuals is 0:

$$\sum_{j=1}^{n} \delta_j = 0 \ . \tag{11}$$

The correlation is homoscedastic (homogeneity of variance) so that its random error terms have the same finite variance.

Proof. With the Equation (6) and Equation (10) we get

$$\delta_k = -a - q(m_k - m_0) - u_k \ , \tag{12}$$
$$= -a - q(m_k - m_0) - \ln(t_k) - \gamma \ , \tag{13}$$
$$= -\ln(\lambda_k) - \ln(t_k) - \gamma \ , \tag{14}$$
$$= -\ln(\lambda_k \ t_k) - \gamma \tag{15}$$

and finally

$$e^{-\delta_k - \gamma} = \lambda_k \ t_k \ . \tag{16}$$

Let Δ be the random variable of the observable error value δ. Because of Equation (3) the probability

$$P(\Delta < \delta) = e^{-e^{-\delta-\gamma}} \ . \tag{17}$$

is Gumbel distributed (see, Wikipedia, Gumbel distribution). From this it follows that $\mathrm{E}[\Delta] = 0$. This satisfies the requirement of Equation (11). From the Gumbel distribution we also get

$$\mathrm{Var}[\Delta] = \mathrm{E}[(\Delta - \mathrm{E}[\Delta])^2] \ , \tag{18}$$
$$= \frac{\pi^2}{6} \ . \tag{19}$$

Because $\mathrm{Var}[\Delta]$ is constant for all δ, it follows that the correlation is homoscedastic. □

Since the conditions of the Gauss–Markov theorem are now fulfilled, we can use the ordinary least squares estimator (OLS). It is the best linear unbiased estimator (BLUE) of the coefficients $\hat{a}$ and $\hat{q}$. In other words, $\hat{a}$ and $\hat{q}$ solve the following minimization problem:

$$Q(a,\ q) = \min_{a,\ q} \sum_{k=1}^{n} \delta_k^2 \tag{20}$$
$$= \min_{a,\ q} \sum_{k=1}^{n} (-u_k - a - q(m_k - m_0))^2 \ . \tag{21}$$

To obtain the estimates of the coefficients $\hat{a}$ and $\hat{q}$, the following system of linear equations must be solved:

$$\frac{\partial Q(a,\ q)}{\partial a} = 0 \ , \tag{22}$$
$$\frac{\partial Q(a,\ q)}{\partial q} = 0 \ . \tag{23}$$

The solution of these equations is the same as for the simple linear regression, which we will not discuss further here. Using this and with

$$m_0 = \overline{m} = \frac{1}{n} \sum_{j=1}^{n} m_j \tag{24}$$

we get with Equation (9)

$$\hat{a} = -\frac{1}{n} \sum_{j=1}^{n} u_j, \tag{25}$$

$$s_{m,u} = \sum_{j=1}^{n} (m_j - \overline{m})(u_j - \hat{a}), \tag{26}$$

$$s_m^2 = \sum_{j=1}^{n} (m_j - \overline{m})^2, \tag{27}$$

$$\hat{q} = -\frac{s_{m,u}}{s_m^2} \tag{28}$$

$$\tag{29}$$

and also

$$\widehat{\sigma}^2 = \mathrm{Var}[\epsilon] = \frac{\pi^2}{6} \;, \tag{30}$$

$$\widehat{\sigma_a}^2 = \mathrm{Var}[a] = \frac{\widehat{\sigma}^2}{n} \;, \tag{31}$$

$$\widehat{\sigma_q}^2 = \mathrm{Var}[s] = \frac{\widehat{\sigma}^2}{s_m^2} \;. \tag{32}$$

3 Visual observations

Waiting times of meteors are not measured during visual meteor observation. Instead, we wait for meteors in a predetermined period of time. The count of observed meteors n is then a random variable and is Poisson distributed per observation. This follows from the assumption made earlier in Equation (3).

For the estimation of the parameter q introduced in Section 1, we first assume that in the same interval k observations are made with different limiting magnitudes m_k. Instead of assuming that the observations are made at the same time, we can also assume that the ZHR is the same for all observations. The effective observation time of all meteors is t_k, where all known corrections (e.g., radiant height) have already been applied to t_k. From Equation (2) follows the probability $P(M = m_k)$ that an observer k sees a meteor at a limiting magnitude m_k:

$$P(M = m_k) \propto t_k \; e^{q \cdot m_k} \;. \tag{33}$$

Now it is possible to build an a priori distribution for the random variable M for k stochastically independent observations with known parameter q:

$$F(q) = \sum_{k=1}^{K} t_k \; e^{q \cdot m_k} \;, \tag{34}$$

$$P(M = m_k) = F(q)^{-1} \; t_k \; e^{q \cdot m_k} \;. \tag{35}$$

The expected value $\mathrm{E}[M]$ and the variance $\mathrm{Var}[M]$ follow from equation (35):

$$\mathrm{E}[M] = F(q)^{-1} \; \sum_{k=1}^{K} m_k \; t_k \; e^{q \cdot m_k} \;, \tag{36}$$

$$= \widetilde{m} \;, \tag{37}$$

$$\mathrm{Var}[M] = F(q)^{-1} \; \sum_{k=1}^{K} (m_k - \widetilde{m})^2 \; t_k \; e^{q \cdot m_k} \;. \tag{38}$$

With this probability distribution, we can now obtain an unbiased estimator for q. Applying the maximum likelihood method, it follows that the mean limiting magnitude $\overline{m}$ is an unbiased estimator for q. If n_k is the count of observed meteors of an observation k, then:

$$N = \sum_{k=1}^{K} n_k, \tag{39}$$

$$\overline{m} = N^{-1} \sum_{k=1}^{K} n_k m_k \;. \tag{40}$$

We get the unknown parameter q by solving Equation (36). To do this, we apply, for example, Newton's method for finding roots and obtain:

$$\hat{q}_0 = 0, \tag{41}$$

$$\hat{q}_{j+1} = \hat{q}_j + \frac{\overline{m} - \widetilde{m}(\hat{q}_j)}{\mathrm{Var}[M](\hat{q}_j)} \;. \tag{42}$$

The estimator for a follows from the Poisson distribution and is a Bayesian estimator that assumes no prior knowledge about the rate:

$$\hat{a} = -\ln\left(\frac{1}{N+1} \; \sum_{k=1}^{K} t_k \; e^{\hat{q} \cdot (m_k - \overline{m})}\right) \;. \tag{43}$$

Corresponding to the Equations (30) to (32), we obtain the variances of the estimated parameters:

$$\widehat{\sigma}^2 = 1 \;, \tag{44}$$

$$\widehat{\sigma_a}^2 = \mathrm{Var}[a] = \frac{1}{N} \;, \tag{45}$$

$$\widehat{\sigma_q}^2 = \mathrm{Var}[q] = \frac{1}{N \, \mathrm{Var}[M]} \;. \tag{46}$$

4 Prediction of the ZHR

So far, we have estimated only the rate $\lambda(\overline{m}) = exp(\hat{a})$ at the limiting magnitude $\overline{m}$. However, we can estimate from our model what the rate $\lambda(m)$ would be at a limiting magnitude of m. For this purpose, we use the linear regression prediction model.

First, we determine the mean logarithmic waiting time $\widehat{u}(m)$ for a meteor and the corresponding variance $\widehat{\sigma_u}^2(m)$ for the limiting magnitude m:

$$\widehat{u}(m) = -\hat{a} - \hat{q} \cdot (m - \overline{m}), \tag{47}$$

$$\widehat{\sigma_u}^2(m) = \mathrm{Var}\left(-\hat{a} - \hat{q} \cdot (m - \overline{m})\right), \tag{48}$$

$$= \widehat{\sigma_a}^2 + \widehat{\sigma_q}^2 \cdot (m - \overline{m})^2. \tag{49}$$

For $m = 6.5$ we obtain the confidence interval for the ZHR based on the variance:

$$\ln(\widehat{\mathrm{ZHR}}) = \hat{q} \cdot (6.5 - \overline{m}) + \hat{a} \pm \sqrt{\widehat{\sigma_a}^2 + \widehat{\sigma_q}^2 \cdot (6.5 - \overline{m})^2}. \tag{50}$$

5 Example Perseids 2015

We will now analyze data of the Perseids of 2015 as an example. Please note that this is not a detailed analysis of the meteor shower. For example, we do not consider here the magnitude distribution of the meteor shower. Of special interest here is only the answer to the following questions:

- What is the *average* value of the Perseids q-value?
- How much can we trust our stochastic model?

To answer these questions, 3633 intervals totalling 1452 hours and 34291 PER were analyzed. In all observations the radiant was at least 15.0 degrees above the horizon. The sun was at least 12.0 degrees below the

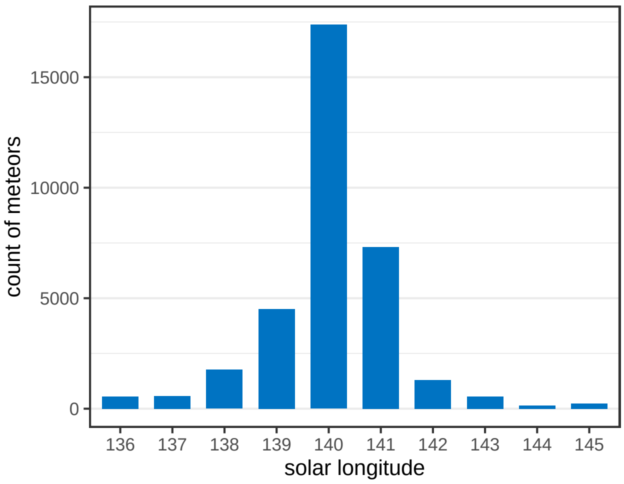

Figure 2 – Observed solar longitude spectrum.

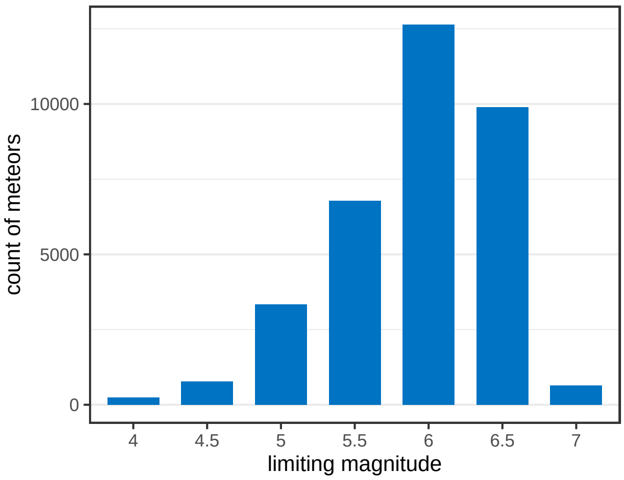

Figure 3 – Observed limiting magnitude spectrum.

horizon and also the moon was below the horizon. This high number of meteors allows us to make more precise analyses, which is not always possible. Figure 2 and Figure 3 shows the distribution of observed meteors by solar longitude and limiting magnitude. Of particular interest here is the limiting magnitude, since it is used to determine the q-value. The limiting magnitude for these data is 5.9 on average. It is worth noting here that to estimate the ZHR we are actually interested in the rate at a limiting magnitude of 6.5. This means that we have to predict the ZHR. For the analysis, we sort the observations by solar longitude and group them to contain approximately 300 of meteors per interval (see Figure 4). However, this then also leads to the fact that each interval has a different width. But the advantage is that each interval has approximately the same measurement accuracy. For each of these groups, the ZHR and q-value were estimated. The result can be seen in Figure 5 and in Figure 6. It can be clearly seen that most of the estimated q-values are greater than 0.0. This was an expected result. Moreover, most of the estimated q-values are less than $q = 0.8$.

We now want to test whether the q-value is not correlated with the solar longitude. Since the measured values have different qualities, we must use the standard score z, which is defined for as follows:

$$z = \frac{x - \mathrm{E}[X]}{\sqrt{\mathrm{Var}[X]}}, \tag{51}$$

where x is any measured value. This process of converting is called standardizing or normalizing. The result of the transformation can be viewed in Figure 7. Because of standardization, error bars can be omitted, unlike Figure 6. We can conclude that the q-value is not correlated with the solar longitude. Therefore, it is possible to estimate a mean q-value. The variance of the measured values is about 50% higher than we would theoretically expect (dashed red lines). Due to the expected inaccuracies (e.g. sky conditions) in visual observations, this variance is within an expected range. Applying the measured variance, we can assume a constant q-value of $q \approx 0.35 \pm 0.2$ for our data.

After that we want to check our assumed model. To do this, we estimate the mean ZHR with a given q-values for the intervals. Then the total rate $\lambda(m)$ is calculated for the respective limiting magnitude m. This rate expresses how many meteors could have been observed on average with the given q-value. Observations having similar limiting magnitudes are merged for this purpose. Using the standard score, the values are then compared to the observed meteor total count n. In this case, the standard score for the Poisson distribution is calculated as follows:

$$z = \frac{n - \lambda}{\sqrt{\lambda}}. \tag{52}$$

We begin first with our estimated q-value of $q = 0.35$. In Figure 8 it can be seen that the standard rate score does not correlate with the limiting magnitude. We can therefore assume that our model works well with the estimated q-value. More precisely, there is no reason not to use this model with the q-value of 0.35.

For comparison, we now consider the q-value with the values $q = 0.0$. In Figure 9, the rate correlates significantly with the limiting magnitude. Observers with a higher limiting magnitude observe more meteors than those with a lower limiting magnitude. This is an expected result, since $q = 0.0$ is equivalent to not having applied any limiting magnitude correction. As a consequence, this means that we have to apply a limiting magnitude correction.

We want to test the same for a q-value of $q = 0.8$. We get a similar result as for a q-value of 0.0, but exactly opposite (see Figure 10). Therefore, with a q-value of 0.8, the rate observations are overcorrected.

6 Discussion and Conclusion

We will now discuss the relationship of this model to the model of the magnitude distribution of the meteor shower. The most important parameter of the magnitude distribution of the meteor shower is the population index named r-value. The r-value is defined as follows

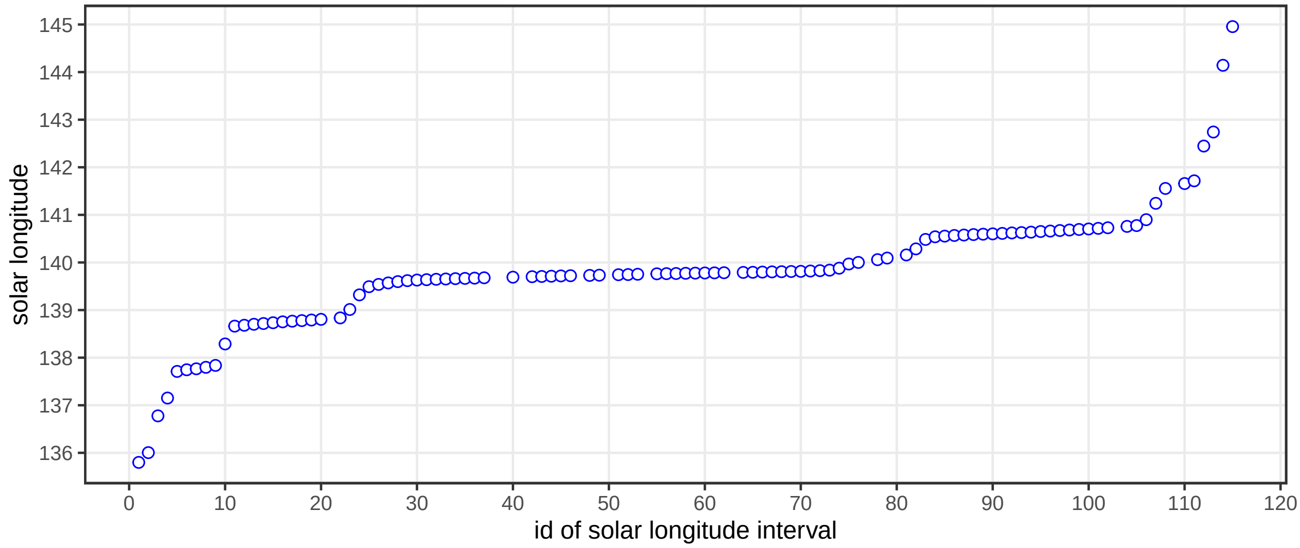

Figure 4 – The solar longitude for each interval of observations.

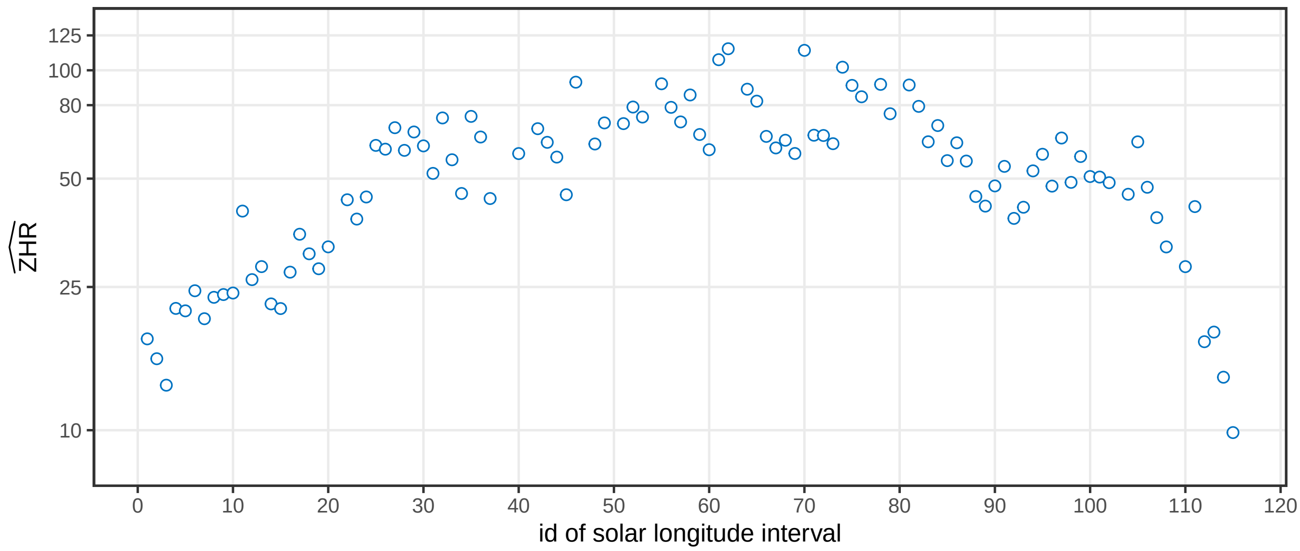

Figure 5 – Estimated ZHR ordered by solar longitude. No error bars are used because each group has approximately the same count of meteors. All values therefore have the same weights and variances.

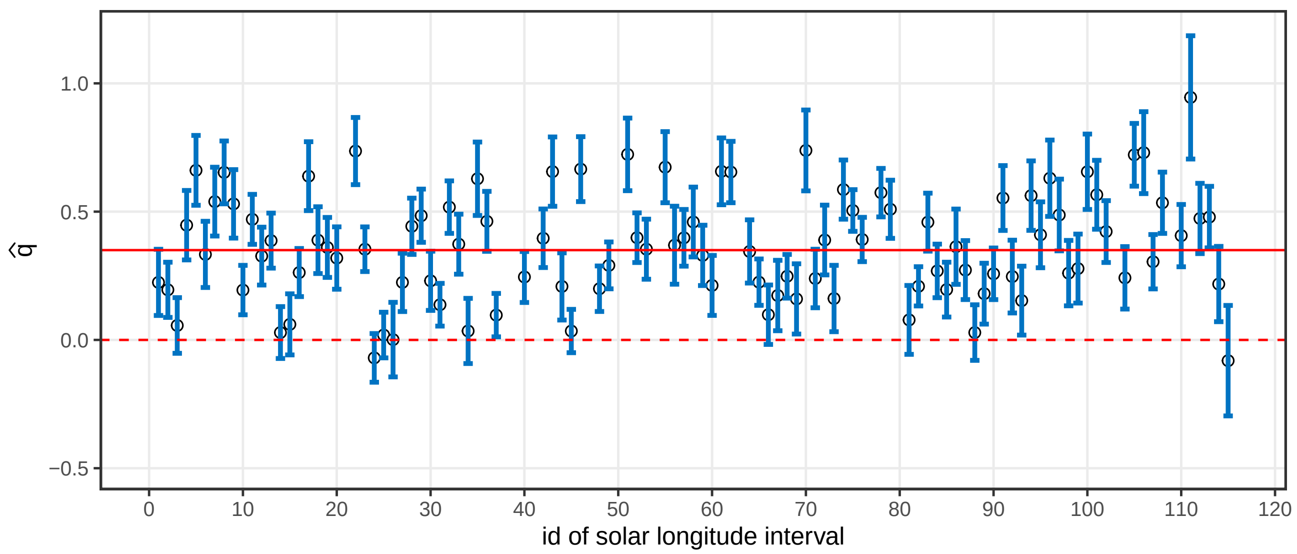

Figure 6 – Estimated q-values ordered by solar longitude. The error bars represent the expected variance of the estimate of the q-value. In addition to the count of meteors, the variance also depends on the limiting magnitudes of the observations in each interval. The red line marks the average q-value, the red dashed line the q-value of $q = 0.0$.

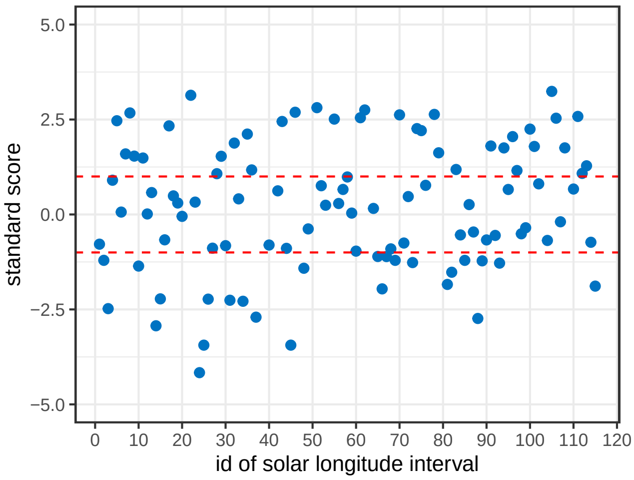

Figure 7 – Standard score of q-value ordered by solar longitude.

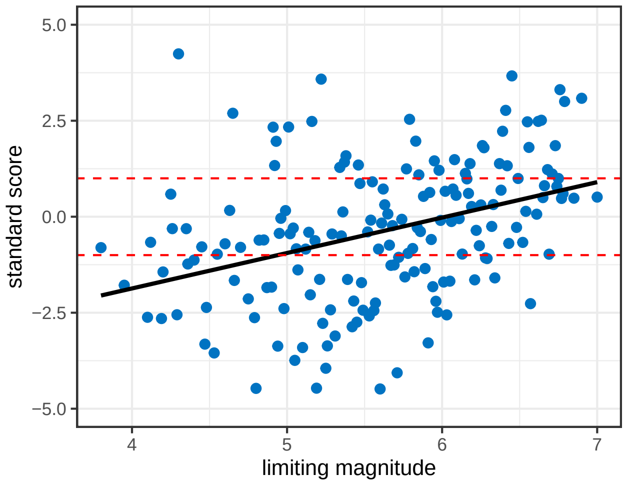

Figure 9 – Standard score of observed rates ordered by limiting magnitude for $q = 0.0$.

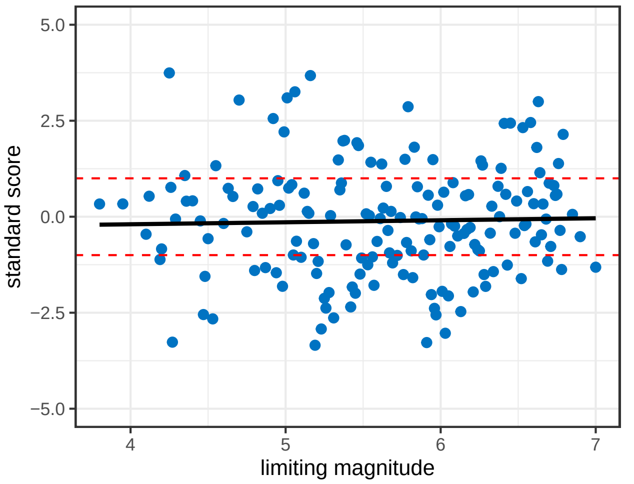

Figure 8 – Standard score of observed rates ordered by limiting magnitude for $q = 0.35$.

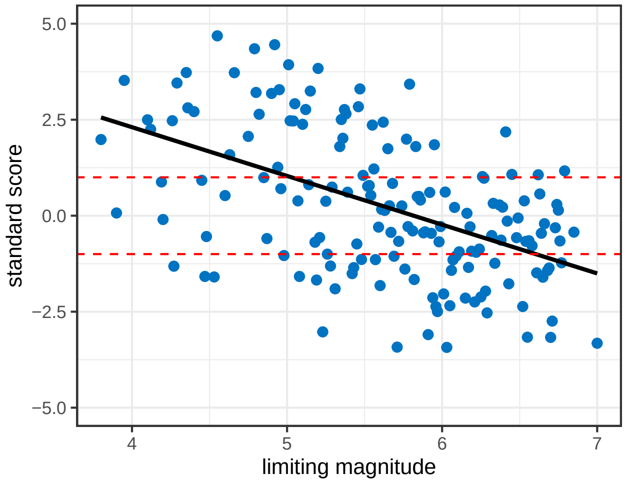

Figure 10 – Standard score of observed rates ordered by limiting magnitude for $q = 0.8$.

(see Rendtel J. and Arlt A., 2017):

$$r = \frac{n(m+1)}{n(m)} \ . \tag{53}$$

With this, it follows in analogy to Equation (2):

$$\mathrm{ZHR} = c \cdot r^{6.5-m} \cdot \frac{n}{t_{\mathrm{eff}}} \ , \tag{54}$$

This equation bases on following assumptions:

i. The population index r is constant for the visual range 0^m ... 7^m,

ii. Limiting magnitudes for stars and for meteors are reduced by the same value.

From (i) follows that the magnitude distribution is exponential for all visible magnitudes. The assumption (i) is fulfilled in most cases. Due to physiology of human visual perception the assumption (ii) is rather rough approximation, especially with bad limiting magnitudes under illuminated skies. If assumptions (i) and (ii) are valid we find $q = \ln(r)$.

The method presented here does not require the assumptions (i) and (ii) to estimate the ZHR. From this, it is clear that there are significant differences between the q-value and the r-value. The r-value is a parameter of the magnitude distribution of the meteor shower. In contrast, the q-value describes the inclination of the rate in relation to the limiting magnitude. Thus, the q-value is used to correct the limiting magnitude for the estimate of the ZHR. If the increase in the count of meteors per magnitude is to be measured, the r-value must be used.

In our example in Section 5, it follows with $q = \ln(r)$ that $q = 0.35$ corresponds to an r-value of $r = 1.4$. For the Perseids, the population index of $r = 2.2$, corresponding to $q = 0.8$, was determined using different methods. The large difference between $q = 0.35$ and $q = 0.8$ is a strong indication that at least one of assumption (i) or (ii) is not valid (see Figure 10).

The method described here has the disadvantage that it does not take into account the magnitude distribution of the meteors. A large number of observed meteors at different limiting magnitudes is necessary to reliably determine the q-value. Thus, this method is difficult to apply to meteor showers with low activity.

List of symbols and abbreviations

E[X] Expected value of X (mean).

Var[X] Expected variance of X.

$\hat{x}$ Estimated value of x.

u Natural logarithm of the waiting time for an meteor.

δ Residual (difference between actual and predicted values of a dependent variable).

ln Natural logarithm, i.e., with basis the number $e = 2.71828\ldots$

λ Rate parameter of poisson distribution.

m Limiting magnitude of an observation.

P Probability.

σ Standard deviation.

t Waiting time for a meteor. Corrections such as the altitude of radiant have already been applied.

Acknowledgments

The author would like to thank all the observers whose observations made these results possible. Special thanks to Dr. Ralf Koschack and Dr. Jürgen Rendtel for the many comments and hints.

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Ongoing meteor work

Ten years of fireballs and video meteors observations

Vladimír Bahýl [1]

This paper presents review of our ten years effort in the bright fireballs and video meteors observations. All our data have been paired and stored in the EDMOND and CEMeNt video meteors databases. In addition, all our data are obtained through the UFO Capture system and there are at the disposal for anybody who is working in the video meteors pairing process or other kind of research in the field of the scientific branches of the video meteors and bright fireballs.

Received 2021 February 8

1 Introduction

Our scientific research focused on a bright fireball watch program initiated in the year 2011. In the beginning we have had at our disposal very simple classical camera PRAKTICA MTL 5B with the all-sky fish eye lens BELOMO EWP MC3.5/8A and we utilized a series of approximately 60 minutes exposures for all of the nights with the clear sky of that time. This equipment was used on every clear sky night up to the year 2015. That year we terminated this particular scientific program. Our results, observation technology and methods of processing the obtained data are described in detail in the article Bahýl and Gajtanska (Bahýl & Gajtanska, 2016). Therefore, we will not pay more attention to these observations and their methodology. But in Figure 1, we present the camera system and one of the results, for illustrative purposes only. In addition, we also mention here that we found/registered 166 clear fireballs in this project.

In this paper, we would like to focus on the results obtained in the process of video meteor observations, which we started in August 2012 independently on the photographic observations. In short, nine years of observations are presented here. Very similar research has been done by Tóth et al. (2011). Their research inspired us to prepare this article in order to first of all inform about the data we obtained and also, of course, about the results that can be achieved on their basis.

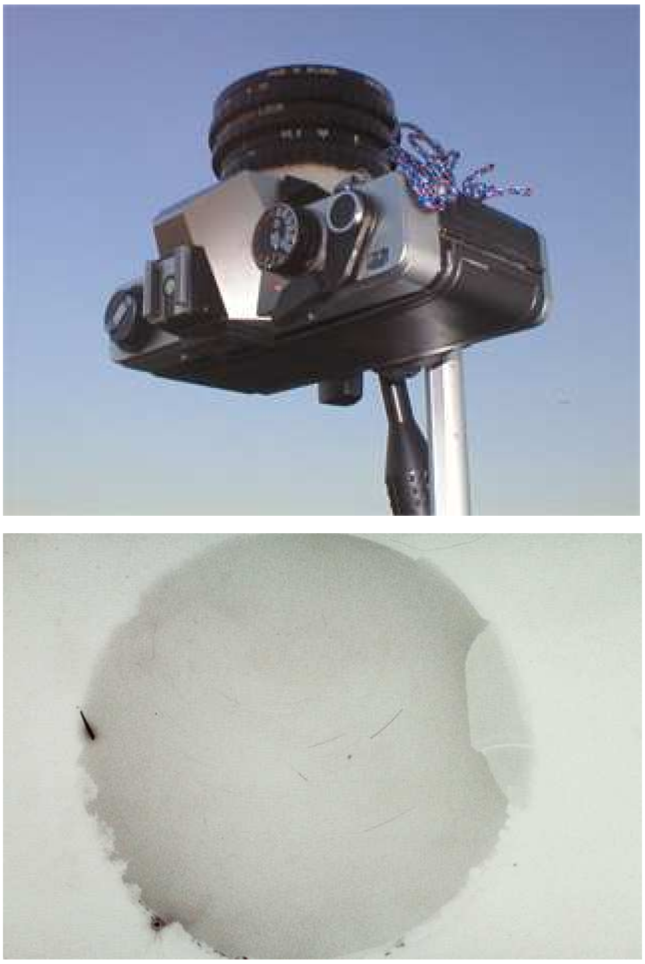

Figure 1 – Top: PRAKTICA camera with the fish eye lens BELOMO. Bottom: One of obtained pictures with bright fireball trace. Left down the bright trace is the Moon. The fireball is in the middle of the picture.

2 Observation

In 2012, we supplemented our observational program “Bright fireball watch” with the video meteor observation and recording. We started in August 2012 and we have been continuing the program until now. And, of course, we hope that we will continue to do so in the future years too.

Our observatory “Júlia” is located on the GPS position 19.2568 east and 48.5645 north in Central Slovakia, Europe and at present we have the video camera KPF 131 HR 1/3” (the chip SONY SUPER HAD II) at our disposal. The camera is oriented almost directly to the south with altitude $h = 70$ degrees above the horizon. The detection area (field of view) is 105 degrees in declination and 90 degrees in right ascension. The resolution is 720×576 pixels and the objective is Tokina $f = 3$–8.5 mm, light gathering power $F = 0.98$. All software which we are using is of the SonotaCo (SonotaCo, 2009) origin.

All our data has been entered into the CEMeNt database, where they are stored and available to anyone. Over the years, we have found more than 9500 video meteors tracks. Our annual totals are shown in Table 1. In the first three years, we only learned how

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NASA-ADS bibcode 2021JIMO...49...42B

to observe the video meteors. But in our opinion, the main impact on the number of registered video meteors over the last six years of our observations was only due to the climatic conditions in our locality i.e. if we have had or if we have not had the clear sky.

Table 1 – Detected video meteors since 2012.

year	video meteors
2012	515
2013	453
2014	592
2015	1176
2016	1823
2017	1304
2018	1248
2019	1568
2020	855

3 Results and processing

It is possible to realise the basic statistical treatment of our data if we take into account our single station observations only. This research has been done using the Statistica software package [a]. Illustratively, we insert Figure 2 into this work, where the basic results are shown in this sense. However, if we want to go further, we must process our observations in UFO Analyzer and UFO Orbit software. The UFO Analyzer (SonotaCo, 2009) is of course valuable and usable for one station as well. After master it, we have treated all our data with the UFO Analyzer program. We thus obtained basic information regarding the quality of our data. In this context, we can state that our data and our results in this respect are as accurate and reliable as similar data from any station. We are presenting in Figure 3 our records from November 2015. It is one common result from our 92 months of observations. It is possible to see that we are able to register meteors falling far above the Adriatic Sea (approximately from 700 to 800 km away from us).

After we have treated all our data in the UFO Analyzer package, we started the process of pairing them with the data from other stations near to us as they are working in the frame of the CEMeNt project. J. Srba (private communication) from the Observatory in Valašské Meziříčí provided us with selfless and invaluable help in our work. He not only offered help and assistance, but also provided data from other stations for us to use. So we have been able to pair our data with that of other nearby stations and to plot the orbits of the observed meteoroids caught by multiple stations. All our data (paired and unpaired) and the common results are stored in the database CEMeNt now, of course and they are accessible to anybody. Again, for illustrative reasons, we present in Figure 4 which provides results of the 2019 Perseids, documenting the quality of our results.

[a]Statistica 2020, `http://www.tibco.com`, `http://www.statsoft.com`

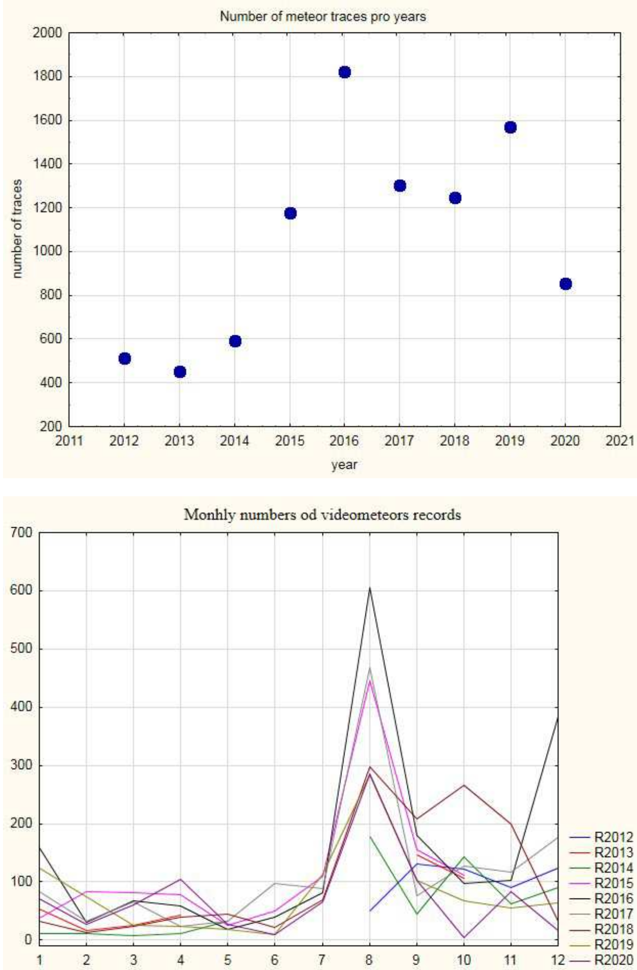

Figure 2 – Top: Numbers of video meteors (the values on abscissa are from the Table 1) detected in the whole year. Bottom: Numbers of video meteors in individual months for all year of observations showing the dominance of Perseids.

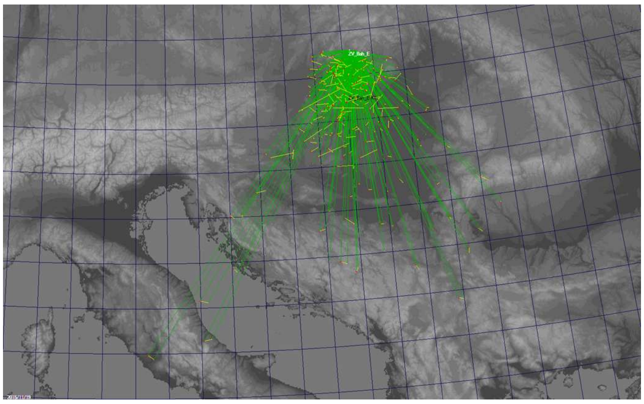

Figure 3 – Our result from UFO Analyzer obtained in November 2015.

Conclusions

Our results are based on three pillars. These are UFO Capture, UFO Analyzer and UFO Orbit, provided by SonotaCo. The results from UFO Capture are very large, especially "avi" files. They are not so easy to archive, let alone send somewhere via the internet. The results of the UFO Analyzer and UFO Orbit software packages are significantly smaller and

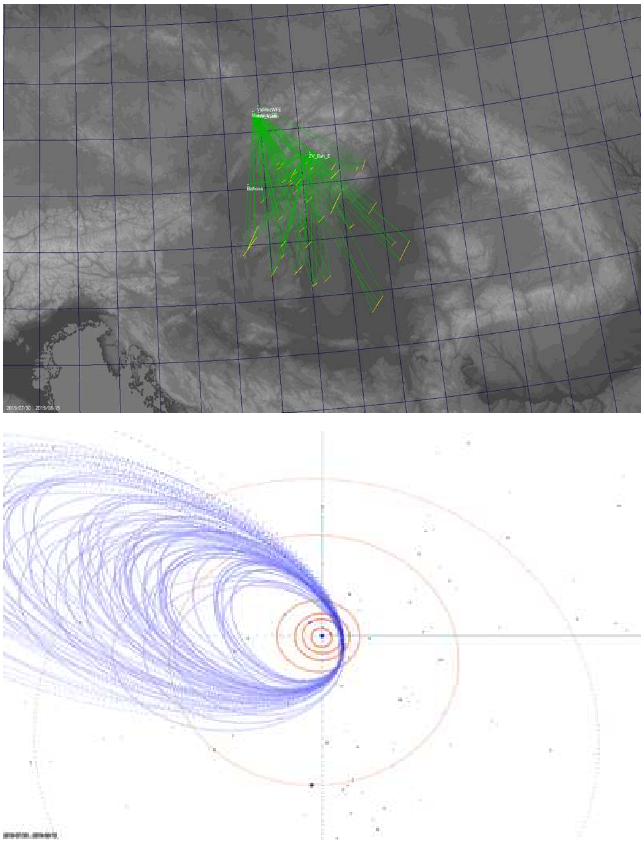

Figure 4 – Top: Paired our data and Valašské Meziříčí data for Perseids 2019. Bottom: The orbits of our detected Perseids in the year 2019.

are based on "csv" files. These are easily portable and archiveable. All our results for all years of observation are stored in the CEMeNt database and, of course, with us. They are also available either directly or from us via E-mail and for free!

Our results are available from the EDMOND international database and we are sure that they will serve for the future deep and comprehensive study of such small bodies of the Solar system. Moreover, although it is well known, meteor research is a matter for collectives. An individual can do nothing worthwhile, no matter how long they have been collecting data. Therefore, it is important to organize networks of observers and store data in generally accessible databases. And observe, observe for years and decades. We hope that our results will be an encouragement for "meteor lovers" to observe them for years to come and to share their results with other similarly oriented astronomers.

The science of meteors is deep, interesting and exciting, especially if there are nice, beautiful glowing fireballs crossing the clear night sky. However, these smallest parts of our solar system, which meet the Earth's atmosphere, are not just beautiful theater only. They are also a very important source of knowledge, so it is necessary and useful to study them. We consider this to be the main result of our more than ten-year effort, when we carefully collected all the data obtained into the relevant database. They are ready for anyone. As a representation of our data, we offer our results of the

Table 2 – Perseids and sporadic meteors on 2018 August 13/14 (UFO Analyser Report).

hour(UT)	Perseids	Sporadics
19	5	/
20	7	1
21	7	3
22	6	/
23	5	3
00	23	3
01	25	4
02	11	2

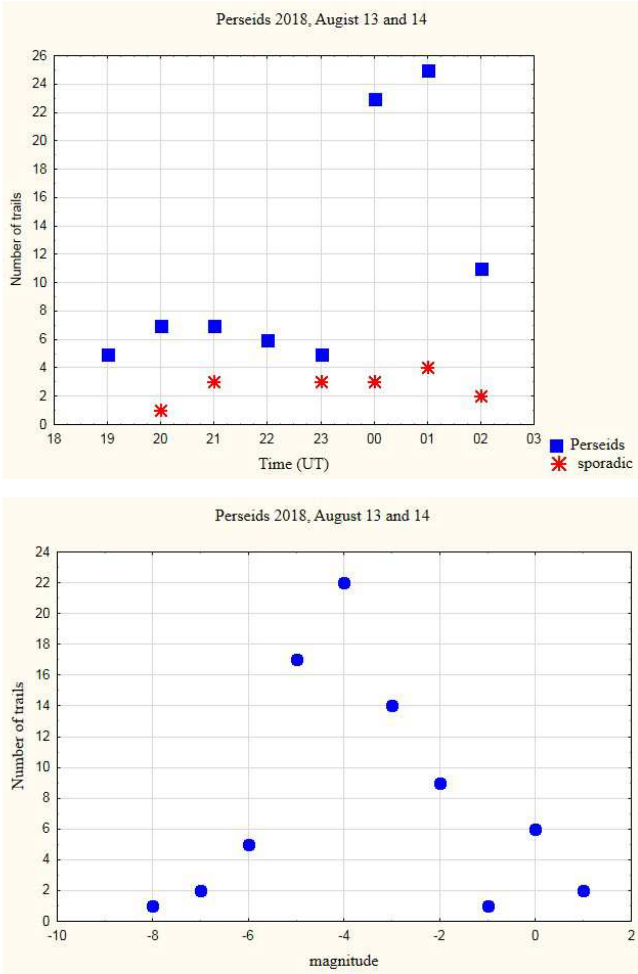

Figure 5 – Top: The number of Perseids and sporadic meteors on 2018 August 13/14. Bottom: Magnitude distribution of the Perseids during 2018 August 13/14.

2018 Perseids. These data are summarized in Table 2. The results are shown graphically in Figure 6.

Observation of the video meteors is not only a science, but also excitement and joy. Especially if more than one trail appears in one image. In Figure 6 top, two Perseids and one sporadic meteor are clearly visible. The stars of the constellations Pegasus and Pisces are visible in the upper and middle part. Stars Deneb Kaitos and Fomalhaut are also visible. Figure 6 bottom, shows the result of the UA2 analyzer. Interestingly, even if there is depicted only the treatment of the greatest trail there are treated all three trails. The brightest meteor's magnitude is -0.7.

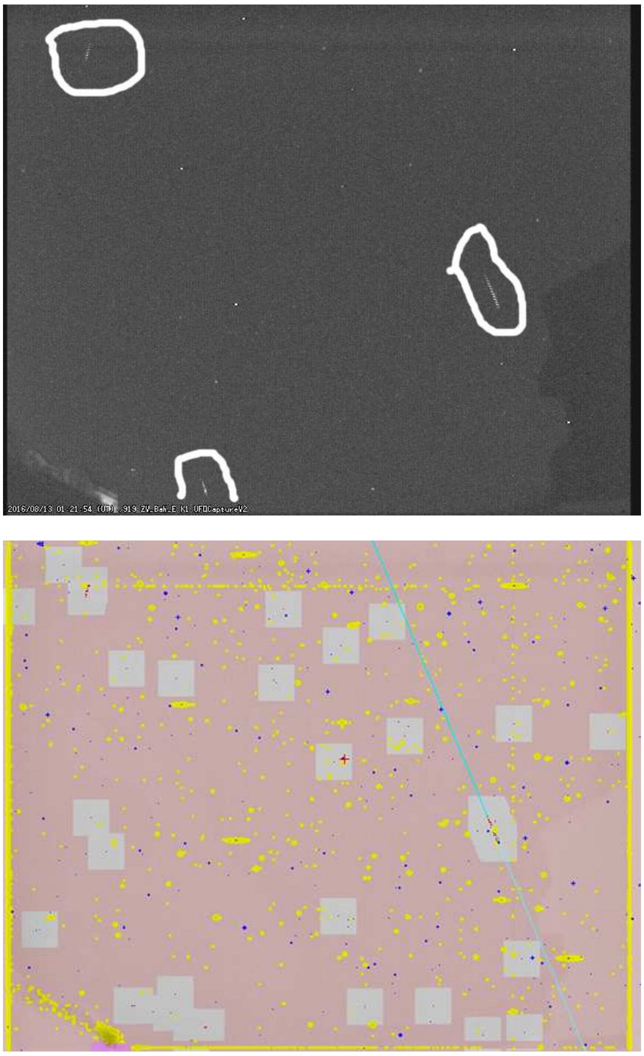

Figure 6 – Top: Three trails during Perseid shower. Bottom: UA2 analyse result.

Figure 7 – The fireballs and the Moon. Top: 2017 August 11, $20^{h}41^{m}30^{s}$ UT. Bottom: 2019 September 21, $01^{h}12^{m}39^{s}$ UT.

A very special problem are the observations of meteors at the time when the Moon is shining. If we do not observe in this time, we lose not only weaker trails, but also beautiful trails of fireballs. Therefore, with or without the Moon, it is necessary to observe! See e.g. Figure 7. This result refutes the relatively widespread view that meteor observations at a time when the Moon is shining are scientifically of little value.

Another and very interesting result of the presented 10-year observation period of meteors and video meteors is their structure over time as annual, monthly, but especially night variation. Of course, we have meteor showers during the year. The most remarkable are, of course, the Perseids, see Figure 2 on the bottom. The monthly variations are also interesting for the presence of smaller showers. But from the point of view of our 10-year observations of video meteors, the most interesting and scientifically open ones for us appear to be the variations of the so called sporadic meteors. Of course, we have in mind those outside the activities of individual well-known showers.

Antihelion radiant is clearly detectable. Here we see the space for further, deeper study of the structure of meteoroid streams surrounding the Earth. It is, of course, a very challenging problem that requires not only further observations but also new, special methodologies and methods. We would like to focus our scientific effort in this direction in the future. Without stopping to adding our data to the CEMeNt database of course.

Acknowledgement

Before all we thank to Mr. Dipl. Ing. Jiří Srba for kind teaching us to work with the UFO Analyser and UFO Orbit software and for kind access to the data from the EDMOND and CEMeNt databases.

We thank also to Dr. M. Husárik and to Dr. Leonard Kornoš for valuable advices, help and assistance with a preparation of the article in LaTeXenvironment.

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Preliminary results

Result of the IMO Video Meteor Network – Second Quarter 2019

Sirko Molau [1], Stefano Crivello, Rui Goncalves, Carlos Saraiva, Enrico Stomeo, Jörg Strunk, and Javor Kac

The IMO Video Meteor Network cameras recorded over 18 000 meteors in more than 8 000 observing hours during 2019 April, fewer than 12 500 meteors in 5 725 observing hours during 2019 May, and almost 20 000 meteors in nearly 8 000 observing hours during 2019 June. Flux density profiles are presented for the Lyrids, the η-Aquariids and the η-Lyrids. Flux density profile is also presented for the Antihelion meteors during the second quarter of the year.

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1 Introduction

As in the previous months, about 80 video cameras were active in the IMO Network in the second quarter of 2019. The weather was mediocre (Figure 1): phases with very good observing conditions and just over 70 active meteor cameras (e.g. between April 15 and 21) interleaved with phases, where less than half of this number of cameras was in operation. The lowlight was April 12/13, when 18 cameras detected no more than 125 meteors in nearly 50 observing hours.

With more than 8 000 observing hours and 18 000 meteors, the April output was close to the average of the previous years. There have been better years such as 2015 with nearly 11 000 observing hours and 26 000 meteors (Molau et al., 2015), but also worse ones.

May 2019 was really poor. Not even 12 500 meteors could be recorded – the last time we gathered so little data was 2010, when the network was only half of today's size.

June, on the other hand, was far better than average. Nearly 8 000 observing hours are more than we have ever recorded in this monthand, with regards to the number of meteors, the month ranks second after 2016.

Looking at the number of recorded meteors per hour (Figure 2), the Lyrids around April 22 are clearly visible, with the average meteor rate doubling. Away from that, the values scatter around the minimum of two meteors per hours. The η-Aquariids in early May leave no imprint, because they are visible for only a short interval in the morning hours. Only in the last third of June is the average rising to three meteors per hours – the spring minimum of meteor activity had passed.

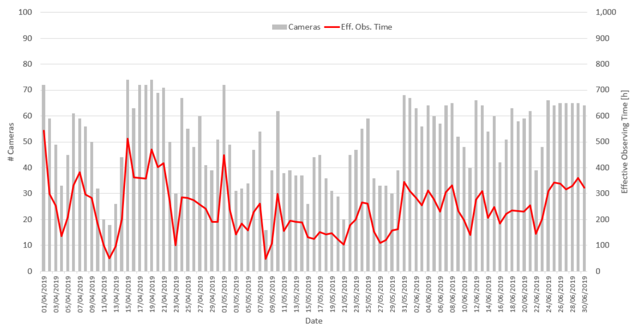

Figure 1 – Number of active cameras per night (grey bars) and effective observing time of these cameras (red line) in the second quarter of 2019.

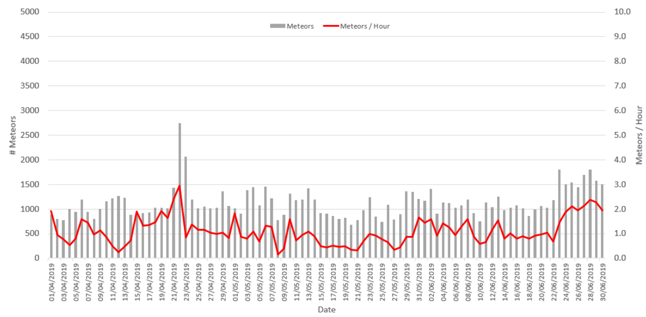

Figure 2 – Average number of meteors per hours (grey bars) and number of recorded meteors per night (red line) in the second quarter of 2019.

2 Lyrids

Let us have a look at the meteor showers which were active in the second quarter.

Figure 3 compares the activity profile of the 2019 Lyrids with the average during 2011 to 2018.

Before and after the peak the values match well, and with five meteoroids per 1 000 km^2 per hour, the height of the peak is also nearly identical, but the time of maximum differs. Whereas the long-term average peak time from our video data is $32\overset{\circ}{.}18$ solar longitude, we measured peak activity in 2019 at $32\overset{\circ}{.}37$ solar longitude, which is more than four hours later. In addition, rates where still higher than usual during the next night.

Unfortunately, this result cannot be confirmed by data of IMO, because the number of visual observations was too low. Highest zenithal hourly rate during the few observing intervals was reached near midnight UT of April 22/23, which translates to $32\overset{\circ}{.}30$ solar longitude (International Meteor Organization, 2019). However, the error bars are quite large.

According to the IMO Meteor Shower Calendar (Rendtel, 2018), the long-term average of the Lyrid peak from visual data occurs at $32\overset{\circ}{.}32$ solar longitude, i.e. closer to the value we determined for 2019. It is

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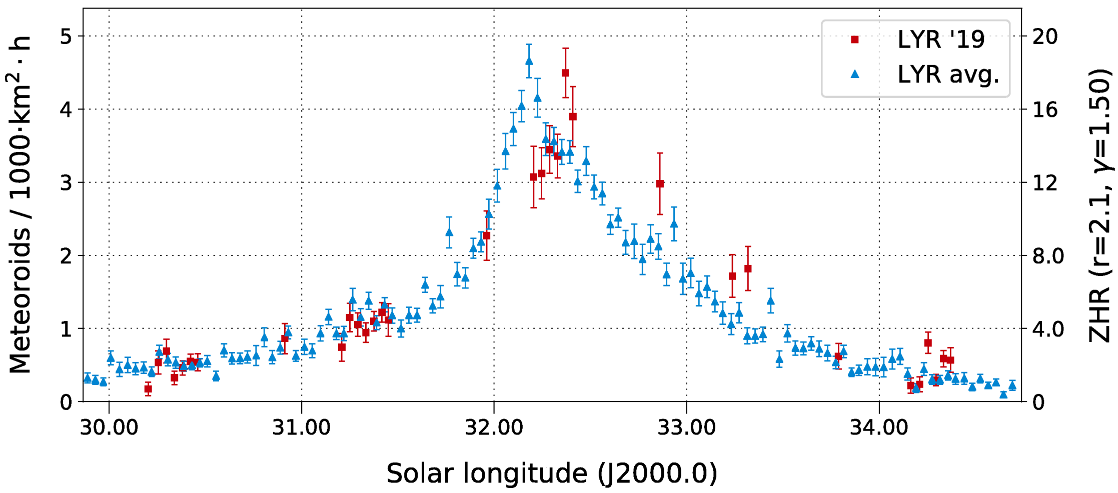

Figure 3 – Flux density of the Lyrids in 2019 (red) as well as in the average of the years 2011–2018 (blue), derived from observations of the IMO Network.

pointed out that the peak time may vary between $32\overset{\circ}{.}00$ and $32\overset{\circ}{.}45$. It is also believed that Lyrid peaks near the average are stronger than those farther away from the average. Unfortunately, our video data are not (yet) sufficient to verify that, because we only cover the European night time hours sufficiently and, thus, catch a maximum only every four years.

3 η-Aquariids

For the η-Aquariids, we had to reduce the resolution of the activity profile strongly, because the weather was particularly poor in the first few days of May. Figure 4 shows a comparison between the activity profile of 2019 (one value per night) and the average of the years 2011–2018. The only thing we can derive from it is, that the peak time at 46° solar longitude is confirmed and that the activity was lower than in the long-term average.

4 η-Lyrids

The η-Lyrids in mid-May did not play a role for visual observers so far because of their low activity level. Still, we can regularly confirm them in our video data. Also here we compare a lower-resolution activity profile of 2019 with a higher resolution long-term profile of the years 2011 to 2018. We find that they are in excellent agreement. The peak flux density is only two meteoroids per 1 000 km^2 per hour, which is also the peak ZHR (Figure 5). This explains, why the shower is not a favourite of visual meteor observers.

5 June Bootids

The June Bootids of 2019 also did not rise significantly from the sporadic background.

6 Antihelion

Finally, we have a look at the Antihelion source (Figure 6), which is active all year round and is replaced by the Taurids only in autumn. In the second quarter of 2019 we see a tendency for increasing activity from less than two to over three meteoroids per 1 000 km^2 per hour. Further details cannot be derived from the plot with a resolution of two days per data point for 2019 one day per data point for the long-term profile.

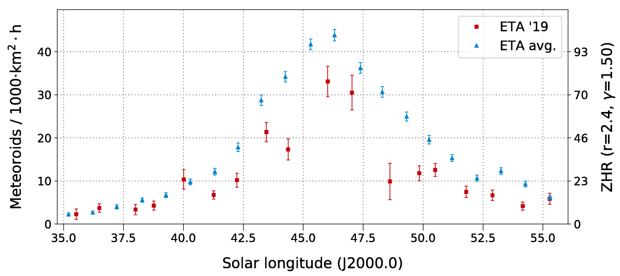

Figure 4 – Flux density of the η-Aquariids in 2019 (red) as well as in the average of the years 2011–2018 (blue), derived from observations of the IMO Network.

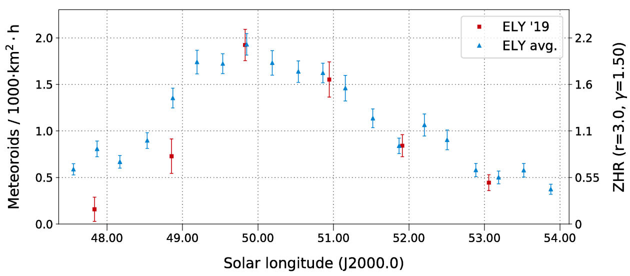

Figure 5 – Flux density of the η-Lyrids in 2019 (red) as well as in the average of the years 2011–2018 (blue), derived from observations of the IMO Network.

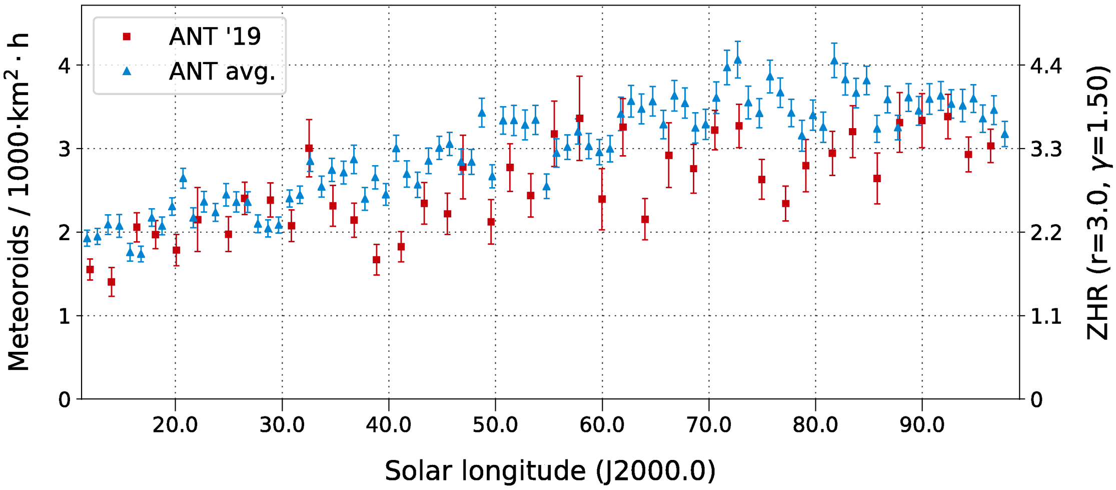

Figure 6 – Flux density of the Antihelion source in second quarter 2019 (red) as well as in the average of the years 2011–2018 (blue), derived from observations of the IMO Network.

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Table 1 – Observational statistics for second quarter of 2019.

Code	Name	Place	Camera	April			May			June		
				Nights	Time [h]	Meteors	Nights	Time [h]	Meteors	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	LUDWIG2	25	140.7	412	21	82.9	237	27	82.5	426
BERER	Berkó	Ludanyhalaszi/HU	HULUD1	4	18.5	41	2	13.1	33	—	—	—
BIATO	Bianchi	Mt. San Lorenzo/IT	OMSL1	20	87.0	112	7	26.7	37	27	153.3	271
BOMMA	Bombardini	Faenza/IT	MARIO	25	120.5	249	19	97.3	295	28	156.1	458
BRIBE	Klemt	Herne/DE	HERMINE	20	118.1	286	24	90.0	167	24	87.2	218
		Berg. Gladbach/DE	KLEMOI	18	96.8	216	18	77.8	150	25	89.6	210
CARMA	Carli	Monte Baldo/IT	BMH2	16	89.9	266	12	58.8	186	26	134.9	520
CASFL	Castellani	Monte Baldo/IT	BMH1	15	95.3	128	10	49.7	89	21	127.6	193
CINFR	Cineglosso	Faenza/IT	JENNI	24	135.6	241	19	105.0	214	28	169.2	389
CRIST	Crivello	Valbrevenna/IT	ARCI	24	120.2	238	19	82.5	193	27	149.1	403
			BILBO	21	120.8	215	13	60.7	157	29	157.1	407
			C3P8	21	106.5	164	18	55.5	96	24	109.5	232
			STG38	20	40.3	118	17	20.7	68	18	74.4	303
ELTMA	Eltri	Venezia/IT	MET38	18	64.4	131	11	33.4	69	29	108.6	242
FORKE	Förster	Carlsfeld/DE	AKM3	24	153.5	371	17	67.0	140	15	53.5	171
GONRU	Goncalves	Tomar/PT	TEMPLAR1	23	149.1	365	28	196.7	574	28	168.0	507
			TEMPLAR2	27	154.2	266	28	194.4	447	26	165.9	405
			TEMPLAR3	25	140.4	103	27	178.3	170	26	147.9	148
			TEMPLAR4	25	124.5	249	28	188.7	375	26	159.1	371
			TEMPLAR5	27	126.5	199	28	176.6	386	27	155.8	359
GOVMI	Govedič	Središče ob Dr./SI	ORION2	21	108.3	175	14	57.0	68	25	111.1	205
			ORION3	20	109.0	69	13	50.4	41	24	125.3	108
			ORION4	19	56.5	72	9	16.3	32	26	109.4	98
HINWO	Hinz	Schwarzenberg/DE	HINWO1	27	181.0	352	19	83.9	123	24	97.9	264
IGAAN	Igaz	Hodmezovasar./HU	HUHOD	17	107.3	96	5	25.0	20	—	—	—
		Budapest/HU	HUPOL	7	37.3	21	—	—	—	9	31.0	22
JONKA	Jonas	Budapest/HU	HUSOR2	16	90.5	85	14	60.6	64	27	130.4	147
KACJA	Kac	Kamnik/SI	CVETKA	10	53.4	135	6	27.6	80	21	93.9	284
			REZIKA	11	49.8	175	6	29.5	146	21	92.1	366
			STEFKA	11	54.5	104	6	24.9	40	21	96.2	202
		Kostanjevec/SI	METKA	19	107.9	122	7	36.1	57	—	—	—
		Ljubljana/SI	SRAKA	13	63.1	103	10	23.8	58	26	94.9	214
KOSDE	Koschny	La Palma/ES	ICC7	—	—	—	—	—	—	14	55.2	125
			ICC9	27	160.0	595	11	59.7	287	—	—	—
			LIC1	—	—	—	—	—	—	15	50.0	194
			LIC2	27	186.6	1513	—	—	—	—	—	—
KWIMA	Kwinta	Krakow/PL	PAV06	16	77.3	43	3	5.6	3	20	76.4	62
			PAV07	19	105.4	72	5	14.9	9	18	73.8	68
			PAV79	20	123.4	152	6	21.9	23	21	85.2	174
MACMA	Maciejewski	Chelm/PL	PAV35	21	85.2	148	17	45.3	52	17	49.8	86
			PAV36	23	127.6	232	19	63.4	100	16	68.9	100
			PAV43	21	136.2	205	18	70.1	70	15	66.1	79
			PAV60	23	145.6	353	19	71.2	152	15	71.7	195
MARRU	Marques	Lisbon/PT	CAB1	27	168.9	334	28	198.4	409	28	175.1	339
			RAN1	25	134.5	196	25	165.9	237	24	138.1	184
MISST	Missiaggia	Nove/IT	TOALDO	13	69.5	168	8	26.1	46	22	80.9	252
MOLSI	Molau	Seysdorf/DE	AVIS2	24	138.4	509	20	79.6	339	28	91.9	549
			DIMCAM2	24	130.2	821	21	80.8	583	27	109.5	1135
			ESCIMO2	23	137.6	183	4	22.4	37	—	—	—
			ESCIMO3	—	—	—	16	60.0	287	28	107.3	648
		Ketzür/DE	REMO1	26	131.5	443	23	77.0	248	20	61.9	362
			REMO2	27	150.1	514	25	92.0	370	25	83.0	402
			REMO3	25	166.0	545	25	106.4	299	27	95.6	402
			REMO4	26	164.4	657	26	98.8	422	25	91.4	518
MORJO	Morvai	Fülöpszallas/HU	HUFUL	21	137.0	102	13	68.5	50	26	138.8	120
MOSFA	Moschini	Rovereto/IT	ROVER	16	22.0	64	9	27.7	53	25	108.4	121
NAGHE	Nagy	Budapest/HU	HUKON	17	35.9	191	11	54.1	87	15	18.5	131
		Piszkestetö/HU	HUPIS	23	109.7	216	16	63.7	133	26	113.3	266
		Zamardi/HU	HUZAM	21	101.3	141	14	34.0	67	3	2.3	15
OTTMI	Otte	Pearl City/US	ORIE1	15	13.9	48	8	6.9	20	—	—	—
PERZS	Perkó	Becsehely/HU	HUBEC	17	104.1	165	17	69.7	123	25	123.7	294
ROTEC	Rothenberg	Berlin/DE	ARMEFA	20	119.7	173	15	66.5	97	11	33.6	54
SARAN	Saraiva	Carnaxide/PT	RO1	2	8.1	11	27	186.5	191	29	197.9	214
			RO2	—	—	—	27	181.0	355	30	184.0	366
			RO3	1	7.4	55	27	188.0	402	30	200.8	498
SCALE	Scarpa	Alberoni/IT	LEO	17	51.1	43	15	36.4	42	26	118.7	92
SCHHA	Schremmer	Niederkrüchten/DE	DORAEMON	21	111.1	238	20	90.7	178	24	79.9	142
SLAST	Slavec	Ljubljana/SI	KAYAK1	13	68.8	61	10	47.6	101	26	114.5	196
			KAYAK2	13	92.0	64	10	53.6	50	24	126.7	98
STOEN	Stomeo	Scorze/IT	MIN38	20	93.9	259	15	42.2	134	28	109.3	451
			NOA38	20	113.4	197	12	39.0	124	28	130.5	306
			SCO38	18	79.0	226	17	33.0	122	30	125.2	396
STRJO	Strunk	Herford/DE	MINCAM2	25	140.7	472	24	102.0	279	25	90.5	270
			MINCAM3	23	138.0	188	24	99.5	127	24	83.7	129
			MINCAM4	23	113.3	136	19	82.5	75	22	82.1	93
			MINCAM5	23	137.7	183	20	94.6	114	23	84.4	110
			MINCAM6	23	134.1	246	22	92.7	159	25	78.5	144
TEPIS	Tepliczky	Agostyan/HU	HUAGO	21	130.0	195	16	80.0	95	24	115.3	183
			HUMOB	18	93.8	151	13	66.7	70	26	116.3	200
WEGWA	Wegrzyk	Nieznaszyn/PL	PAV78	23	116.1	143	15	22.3	49	14	32.2	50
YRJIL	Yrjölä	Kuusankoski/FI	FINEXCAM	22	116.7	204	9	19.9	36	—	—	—
ZAKJU	Zakrajšek	Petkovec/SI	PETKA	20	103.2	298	13	65.3	254	29	144.1	540
			TACKA	15	101.4	97	11	60.0	48	28	136.1	167
Sum				30	8352.2	18 119	31	5725.0	12 420	30	7952.6	19 664

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Composite image created from 55 video composite images, recorded on 2020 December 13/14 from Osterhofen bei Bayrischzell, Bavaria, Germany. Sony a7S at 25 fps, $\frac{1}{25}$ s exposure time, ISO 81 000, with Sony GM 1.4/24 mm lens at $F = 1.4$. Image courtesy: Peter C. Slansky. See also author's letter on page 31.