journal of the international meteor organization

WGN

50:5
october 2022

IMC 2022 report and IMC 2023 first announcement
Flux density algorithms in MetRec and MeteorFlux
Possible meteor shower of 45P/Honda-Mrkos-Pajdušáková
Piscis Austrinids not traced in modern data
Hyperbolic meteors: is CNEOS 2014-01-08 interstellar?
Observations during a road trip in the Australian Outback

ISSN 1016-3115

WGN Vol. 50, No. 5, October 2022, pp. 109 – 146

Administrative

Conferences

Ongoing meteor work

Front cover photo

This impressive fireball was captured from near Bishop, CA, USA on 2022 July 1 at $04^{h}51^{m}$ UT. Image courtesy: Roger Craig Smith.

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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Guest Editorial

Marc Gyssens

In this issue, you can read more about the very successful IMC 2022 in Poroszló, Hungary. We chose for a hybrid format and, besides the 104 online participants, there were 52 meteor enthousiasts who chose to be part of this event on-site. While this number is significantly lower than what were used to before the corona crisis, it is important to observe that it has been three years ago that such an international party met physically at an IMC. Further on in this issue, Felix Bettonvil together with some first-time attendees gives you all the details about this IMC, so I will endeavor not to repeat him here. What I want to focus on here is that the spirit so typical of an IMC was present literally from the first hour onward as if corona had never existed. Perhaps this felt so special because the three-year interruption made us realize that the atmosphere characterizing an IMC was not be taken for granted, but I was nevertheless deeply moved by this experience (and with me, I am sure, many more long-time participants), and this emotion that kept raging through me throughout the conference. Surely, the International Meteor Organization has seen many defining milestones during its history of more than 30 years, but the IMC 2022 as the first physical meeting of the meteor community since the corona pandemic organized at the IMO's initiative was definitely one of them. Please allow me to digress on why I feel this way.

When I was a student, we promoted meteor astronomy as one of the few branches of astronomy in which amateurs can do meaningful observations which professionals can use. The foundation of the IMO was in part motivated by the need to reinforce this. Too many amateurs at that time were only concerned with the observations made by their group, regional, or national association, and were insufficiently aware that meaningful conclusions could only be drawn if meteor activity was monitored around the clock—that is, if a sufficient range of longitudes around the globe was covered. Achieving internationalization and common standards—more specifically for visual observations, by far the most prevalent type of observing at that time—-was therefore the main focus during the years that led up to the formation of the IMO. Through the subsequent IMCs, amateurs came to actually *know* the professionals, and some of them decided to study astronomy or a related subject, do a PhD with one of these professionals they got acquainted with, and even become professionals themselves. In this way, the meteor scene evolved from a group of amateurs and a group of professionals which were on speaking terms with each other to a very closely knit community in which the boundary between amateurs and professionals had faded completely. Instead, we now have a spectrum going from amateurs *pur sang* to full-time professionals with every thinkable combination of these two extremes in between. We have to realize, though, that the platform that is the annual International Meteor Conference, is to a large degree responsable for this evolution.

The strong interconnectedness of the international meteor community is not its only remarkable feature, however. What I heard from several young first-time participants is that they were surprised by the wide variety of topics within meteor astronomy that were covered at the IMC. There has been a time that amateur meteor enthousiasts seemed to be obsessed by identifying as many minor meteor showers as possible, but these times are way behind us. Due to the interaction with professional meteor astronomers and the example they have set, every aspect of the meteoric phenomenon is now within grasp of amateurs and professionals alike, so the international meteor community is not only a spectrum from amateurs to professionals but also a spectrum in which every aspect of the meteoric phenomenon is represented.

Last, but certainly not least, the international meteor community is a community of *friends*. Of course, if you go to professional conference, you see again many colleagues you have met several times before and you meet new colleagues as well. You will have interesting conversations with a lot of them, some purely professional, some more personal, and, with some of them, you even may have lunch or dinner. While this is certainly one of the more pleasurable aspects of the international conferences I have attended, the experience has never come even close to what I have experienced time and again at the International Meteor Conference, the IMC 2022 being no exception. The only explanation I can offer for this is that the international meteor community is a community of *friends*, in the full sense of the word. It is moreover a very open community. For instance, it was obvious that, at the last evening of the IMC 2022, first-time attendees were completely part of the group, as if they were already in it for years!

Of course, all the characteristics of the international meteor conference that I have described above can be perceived at any—on-site—edition of the International Meteor Conference. After three-year interruption, however, one no longer takes them for granted and, therefore, they stand out much more. And this is what brought about these emotions that I told you about in my opening paragraph. The feelings that raged through me were mainly feelings of gratitude and pride. I felt grateful for being part of this community and proud for having been able—and still being able—to contribute, however modest, to the process I described above. I also felt grateful towards the local organizers of the IMC 2022 who were prepared and able to reschedule so often to finally pull off the small miracle that an on-site International Meteor Conference is to me.

In that respect, the IMC 2022 was truly a defining milestone in the history of the International Meteor Organization!

Figure 1 – Relaxing in the lobby bar on Thursday evening at the IMC 2022. We see, from left to right, Peter Stewart and Bill Ward (obscured by Peter), Gabi Koschny, the author, Marc Gyssens, enjoying his Coke, Detlef Koschny (standing) and Antonio Martínez (sitting). Credit: IMC 2022 photo page.

Of course, the hybrid aspect that the corona crisis brought about is a new asset that I expect to stay with us. It allows meteor workers who, for whichever reason, cannot physically come to an International Meteor Conference, to participate online. That does not invalidate, however, the observation that all of us on-site could make—as well as many of you who were watching us online, namely that a physical event is ever so important for the future of the international meteor community, for which so many scientific challenges are still in store, and, yes, Galina, for which many more data are needed! So, if you can, attend the IMC 2023 from August 31 to September 3, 2023, in Redu, Belgium. A first announcement by principal organizer Hervé Lamy can be found elsewhere in this issue. Also, contribute to the international meteor community by writing an article for this journal WGN—this is always much appreciated!

To conclude these reminiscenses, I need to mention, as many of you may (still) know, that I have been editor-in-chief of WGN, roughly speaking during the first decade of the IMO's existence. From this unique position, I could see from the submissions that I received how the field was evolving, and, each time I noticed something that I thought was worth sharing with the readership, I wrote an editorial about it. For the first time in so many years, I felt the urge of doing something similar because I definitely wanted to share with you the feelings that I had during the IMC 2022. Therefore, I was thrilled that the current editor-in-chief, my good friend Javor, reacted enthousiastically to my request to write a guest editorial for this issue. So, I am sure he will allow me to close with the words with which I have ended so many editorials in the past:

Happy reading!

IMO bibcode WGN-505-gyssens-editorial NASA-ADS bibcode 2022JIMO...50..109G

From the Treasurer — IMO Membership/WGN Subscription Renewal for 2023

Marc Gyssens

Renewal rates

Most members/subscribers whose membership/subscription has expired should have received a reminder email by the time you receive this issue of WGN. Via this way, we invite them again to renew for 2023.

The fees are as tabulated below. Notice that we have reduced the dollar rates to reflect the evolution of the exchange rate of the dollar versus the euro. We also continue to offer an electronic-only subscription at a reduced rate.

IMO Membership/WGN Subscription 2023				
Electronic + paper with surface mail delivery:		€26		US$ 30
Electronic + paper with airmail delivery (outside Europe only):		€49		US$ 56
Electronic only:		€21		US$ 24
Supporting membership:	add	€26	add	US$ 30

It is also possible to renew for two or more years in a row.

When you renew, give a few minutes of thought to becoming a **supporting member** by paying at least 26 EUR/30 USD extra. Smaller gifts are of course also appreciated. As you may know, there is an IMO Support Fund. With this Support Fund, we offer support to meteor-related projects. Our ability to provide this service to the meteor community depends primarily on the gifts we receive from supporting members!

Another way to help meteor workers with limited funds is to offer them a gift subscription.

We already thank all our members that will renew for their continued trust in our Organization!

Payment instructions

You first must log in into your account at the IMO website if you want to renew. For this purpose, click the log-in button in the upper right-hand corner. As login, use the email address on which you received my reminder email. In case you forgot your password, you can use the "forgot password" link to reset it. Once logged in, you will see your profile picture (or the space provided for it). If you read on the green button below it that your membership is about to expire, click it, and the rest will be self-explanatory.[1]

The outcome of this process is that you will see the total amount due and your payment options. If you choose to pay using PayPal (or using a credit card via PayPal), you can complete the payment on our website.

If you experience any difficulties, do not hesitate to contact me at `treasurer@imo.net`.

One final request: every year, a lot of members renew late. As a consequence, back issues that already appeared have to be sent out to these members. Please support our volunteers in their bimonthly effort to have WGN shipped to you by renewing promptly! Thank you for your understanding and cooperation!

IMO bibcode WGN-505-gyssens-renewal NASA-ADS bibcode 2022JIMO...50..111G

[1] Alternatively, you can also click on "Extend your membership" in the pull-down menu to the right of your name in the upper right-hand corner, with the same result.

Conferences

41st International Meteor Conference
Poroszló, Hungary, September 29–October 2, 2022
What happened and how on-site participants perceived it

Felix Bettonvil, with testimonies from Joachim Balis, Justina Nováková, Tuğça Şener, Olivér Norton Szabó, and Maximilian Vovk

After two successive years in which the COVID-19 pandemic held us in a tight grip, fortunately this year we were able to resume our traditional annual International Meteor Conference (IMC) in the way we were used to. Our host was the Research Center for Astronomy and Earth Sciences (CSFK) and Konkoly Thege Astronomical Institute in Hungary, who chose as a venue the village of Poroszló in the beautiful Hortobágy area on the Great Hungarian Plain. Despite the fact that the Hungarian organizers had to wait for two years, the conference was organized in a fantastic way, very much like the IMCs have always been. One novelty, however, an inheritance of two successive online editions, is that we offered the present conference in a hybrid format.

Introduction

The IMC 2022 was the first ever International Meteor Conference that was organized as a hybrid meeting, with both participants on-site (52 in total) and participants online (104). They came from everywhere: we counted 34 countries, including the United States and Japan (both of these being represented in Hungary!). It was encouraging to see that, apart from many well-known faces, there were also many new ones, among whom several master and PhD students. In a cozy atmosphere, with a super-friendly hotel staff, great food, excellent facilities even including hot pools, an own bar and bowling area (!), and beautiful surroundings next to a lake, it was the perfect setting for a great three-day conference.

This report has been written by a long-time participant of International Meteor Conferences for whom traveling to this IMC was an emotional experience after two years without on-site conference. To balance his perspective, we also gave five young, first-time and therefore unprejudiced participants the opportunity to express the impression the IMC made on them. The framed items troughout this report are their testimonies.

Figure 1 – Group photo of the on-site participants of the IMC 2022 in front of the hotel, on which the official IMC 2022 has been pasted. *Credit:* IMC 2022 photo page.

One of our new faces is H. Tuğça Şener. She is from Turkey, but lives in Krakow, Poland. Tuğça is a freelance astrophysicist, working as data analyst for Google at TTec. Shortly after the IMC 2022, she wrote down the following reflection:

My first acquaintance with the IMO was in the early 2000s, when I was an undergraduate student at the Astronomy and Space Sciences Department in Ankara University. We were a group of students interested in meteor observations and IMO resources were our main light in the darkness. We learnt a lot from the manuals, we had lots of observing nights, and we even used the sky maps to draw the meteors we observed, and tried to calculate the radiant through those drawings. I still remember how excited I was when I got a reply to an email I had sent to Rainer Arlt. As Jérémie has told me at the first dinner of the conference, it is normal to get a reply to your emails, but in those years it was a huge thing for a student, especially in Turkey. In my PhD application to Armagh Observatory in 2010, I indicated two preferences to focus my studies on: meteors and stellar astrophysics. Aswin Sekhar, who then became my office mate for 4 years, was quicker to pick the spot to study meteor-related topics with David Asher, and that is why I turned kind of permanently to stellar astrophysics. Still, I was lucky to be close to the more scientific aspect of meteors thanks to Aswin, David, and Apostolos Christou. Although I did not study in this field, I was able—and privileged—to follow their work during our weekly discussion meetings at the Observatory.

This year, when Ferhat Fikri Özeren told me, “this time, I will meet you in Hungary, and we will attend the IMC together”, all the emotions I had buried deeply for so long came up to the surface again. If I had to, I could have run from Krakow to Poroszló! That is the level of excitement and happiness I felt, even from the mere thought of it. My answer to Ferhat was an immediate “yes”, without any hesitation! Now, looking back to those four days at the IMC, I can comfortably say that it was my best decision of 2022!

Organization

The venue selection and local organization were indeed very well done. All who have been active in international organization committees for scientific events know how much dedication it requires to pull off such an event. The way how the organizers handled the travels from/to airport and train stations to the venue, despite all the delays caused by commercial travel operators, was truly flawless. Gluten and other sensitivities, as well as vegan options, were considered at all meals and coffee breaks.

Meetings were arranged according to topics and separated according to on-site and online presentations, which allowed the participants to select and focus according to their priorities and interests. As usual, the program was full, and covering many areas. Without any doubt, one of the highlights were the tau-Herculids, which were

Figure 2 – H. Tuğça Şener in the garden of the hotel in which the IMC 2022 took place. *Credit:* IMC 2022 photo page.

predicted to have a possible outburst on May 30-31, and for which many observer groups traveled to Arizona and Texas. Even an airborne campaign was set up!

After the official opening, on Thursday evening, the conference was kicked off with an invited talk on the Hungarian tau-Herculid expedition to Texas by László Kiss. And spread over the various days there were several other reports on the tau-Herculids: Javor Kac and Francisco Ocaña González (Arizona), Olivér Norton Szabó (Texas), Pavel Koten (history of the tau-Herculids), and Jérémie Vaubaillon, replacing Juraj Tóth (airborne campaign over Texas and Arizona). From this last talk, we learnt that airborne ZHRs are normally 3–5 times higher than ground-based ZHRs, due to the larger atmosphere coverage.

Nagatoshi Nogami had an interesting presentation studying ancient Chinese records on aurorae. At the end we were even able to distinguish between Chinese characters, like, e.g., white, red, and vapor!

Olivér Norton Szabó is a student at Eötvös Loránd University Institute of Physics in Budapest. He has just started researching meteors at Konkoly Observatory after the May outburst of the tau-Herculids. He also works as a science communicator in the field of astronomy. An IMC often yields a boost for local meteor enthusiasts, and, therefore, it is important to also get this local perspective. These are Norton's impressions:

I was privileged to be the youngest local participant of the IMC 2022 in Poroszló, Hungary. This was not only my first IMC, but also my first scientific conference.

On the first night, I was still too shy to venture away from my fellow Hungarians. After the welcoming speech and the first three talks, I felt already more comfortable, however. On Day 2, I tried to absorb as much of each presentation as possible. Thankfully, Mike Hankey's talk was easy to follow, and I did not drop out of the flow as newer speakers came forth. The first and second sessions went by so fast that I could not get my head around it. After the lunch break came the session I was presenting in, so we had a last-minute consultation within the Hungarian team. Although I am a public speaker, I was incredibly nervous, but as soon as I started talking all nervousness went away. It was a wonderful feeling: a room full of meteor enthusiastics paying full attention to what I was going to say. To my surprise, I even received questions, what I think was a good sign. My session had three tau-Herculid-related talks, and during the coffee break the speakers quickly found each other to exchange thoughts. Once again, this was a wonderful experience!

Then came an online section. To be honest, this technology needs way more testing, but still, we heard great talks. In the evening, the organizers had booked us a ballroom to network and drink. Marko Šegon quickly grabbed his guitar and filled the space with music, followed by singing. I believe I stayed up until 2 am, and only then went to bed. On the way to my room, I saw a meteor shooting across Orion. What a way to end the day!

For me, Day 3 was fully about networking. After the morning sessions (in which I got some ideas on using radio detection) we had a group photo (which I almost missed) and went to the local eco-center. While we were there, I tried to spend time with as many people I could. I had several small chats with participants form many countries and a few longer conversations with Simon Anghel from Romania and Francisco Ocaña from Spain.

After dinner, we had the bowling alley for ourselves. We swiftly formed international teams and started a light-hearted competition in which I ended fifth out of twelve. This was also the time I found the other university students who participated in the IMC 2022, mostly from Slovakia and Italy. We played pool and bowling. By the time we finished, Marko's guitar was already in use again. It is a tradition to rewind the conference in singing. It is a lovely way to thank the organizers and wrap up the IMC. By this point, I really felt being part of the IMO family, so this was an eye-watering experience. After listening to the tales of more experienced IMC participants and enduring the ominous "Amsterdam pizza blues", I said good night to all.

The last day was a bitter-sweet experience. On the one hand, we heard some fascinating talks from the online Russian, and on-site international, participants. On the other hand, this was our last day and the time to say a final goodbye. Marc's final words and seeing all the online and on-site members were touching indeed.

I had an amazing four days in Poroszló, at the 2022 IMC. Maybe the best illustration of how great it was is that, while we had two 24/7 swimming pools at our disposal, I did not even think about them until after the conference. See you in Redu in 2023!

Friday is traditionally the fullest day, packed with presentations. There were many exciting topics. Two presentations focused on the computation of (live) meteor flux from video data, a difficult exercise involving many parameters (Sirko Molau, Denis Vida). Roman Piffl spoke about photometry based on video data.

Status reports on camera networks was another topic. Nowadays, there are many of those (e.g., Allsky7, FRIPON, GMN) and they keep growing. With each consisting of over 100 cameras each, no fireball seems to go unnoticed anymore. Coordination aspects and automation of the data pipeline become important aspects. An Allsky7 report was given by Mike Hankey. The number of meteorite falls (as opposed to meteorite finds) worldwide is growing, and is now at about 50. Andrea Cozzumbo presented a report on the Italian PRISMA network (using FRIPON cameras). A highlight was the fireball on New Year's day, which led to the recovery of a meteorite. Detlef Koschny reported on work done on how to get to flux densities from Allsky7 data.

Figure 3 – Olivér Norton Szabó during his presentation on Friday afternoon about the Hungarian tau-Herculid campaign from McDonald Observatory in Texas. *Credit:* IMC 2022 photo page.

Also covered at this IMC was (automatic) astrometry, aiming towards ever higher accuracies. Martin Baláž proposed to use Zernike coefficients.

Another core topic for all of us are shower analyses and/or forecasts. We enjoyed presentations on the Geminids (fireballs and mass sorting—Jiří Borovička, as well as mathematical modeling—Galina Ryabova), shower identification (Silvia Ďurišová), review of the year 2022 (Jürgen Rendtel), a possible meteor stream from Comet 45P/Honda-Mrkos-Pajdušáková (Ireneusz Włodarczyk, but unfortunately not presented due to audio issues), and on whether Daytime Arietids fall into the Sun? (Aswin Sekhar). Regina Rudawska presented new nomenclature rules for meteor showers.

Several contributions were related to lab work, tests, and simulators: on the shooting of artificial meteorites in the ground to study their impact crater geometry and evolution, by Felix Bettonvil, with help of the public; wind tunnel experiments to estimate luminous efficiency, a parameter which is not well known, by Jérémie Vaubaillon; and on the creating of fireballs with an optical projection simulator setup (Project AllBert EinStein), by Michael Frühauf and Maximilian Vovk.

Maximilian Vovk is an aerospace engineer graduated from the M. Sc. ESPACE – Earth Oriented Space Science and Technology at the Technical University of Munich. Coming from a technical background, he ended up getting into meteors after nights of gazing at asteroids and meteors at the IAPG Observatory. For his master thesis, he has studied artificial meteoroids' entry trajectories and ablation mechanisms of meteors. This is what Maximilian had to say about the IMC 2022:

This is the first year I have taken part in the International Meteor Conference. The sessions and meetings with various experts answered several of my questions regarding this field. Moreover, I was very pleased to have received several questions about my talk that helped me understand what could be better explained and what might be more interesting to investigate further. Every evening, after the sessions, everyone moved to the bar to make way for a party atmosphere where everyone could socialize and really get to know each other. After these days, it is clear to me that this is not just a conference of experts, but also of friends with a common passion. And I am glad to be a part of this community as this will be my first IMC among many others to come!

Figure 4 – Maximilian Vovk (using the laptop) discussing with other participants during one of the breaks. At the left, we recognize Bill Ward (sitting) and, on the other side, from left to right, Olivér Norton Szabó, Felix Bettonvil (the principal author of this report), and Simon Anghel. *Credit:* IMC 2022 photo page.

We see every year that technology evolves rapidly as does the development of instrumentation. Peter Slansky reported on professional 4K/UHD video cameras, how they can be used for meteors, and results. He captured a dozen tau-Herculids from downtown Munich, without spotting anything visually. Other presentations were on the use of a near-UV camera with the Mini-EUSO telescope on the ISS (Dario Barghini), and the robotic observatory Remote Observatory of Campos dos Goytacazes (Marcelo De Cicco, Carlos Henrique Barreto).

Observation and analysis of spectra still is a rising topic, which it certainly deserves. With the sensitive cameras available now, it becomes easier to capture the specta, from which we can learn a lot. Aspects of the oxygen line were discussed by Vlastimil Vojáček; the analysis of digital spectra and how to process them by Marko Šegon. It is assumed that spectra consist of a 4000–5000 Kelvin thermal body radiation component and a hotter 10 000 Kelvin component originating from the shock wave. Adriana PisarÄDÃŋkovÃą presented results of experiments in a plasma wind tunnel with real meteorite samples, focusing on emission of CN. Peter Slansky also focused on colors in his second presentation this IMC: a blue halo around a bright fireball, registered by multiple cameras.

Software is a topic on its own. Actually, many contributions deal with software development, sometimes indirectly, as a tool to serve a higher goal. Worth noting was the presentation by Pete Gural on software for a project on simultaneous (faint) optical and backscatter radar observations, and the automation of meteor reduction using convolutional neural networks (Aisha Al-Owais).

During this conference, one could not help noticing that more and more software is developed and shared openly (through, e.g., GitHub). This is a very encouraging evolution, which is completely in line with the spirit of the IMO. In this way, astrometry, dark flights, ablation, and detection software, to name only a few, come within reach of many meteor workers, including non-hardcore-programmers.

Saturday morning, we focused on radio work. The radio community works on worldwide collection of radio meteor observations. Hiroshi Ogawa explained how to reduce the data. Chris Steyaert gave a status of the Radio Meteor Observing Bulletin (RMOB). The quest how to successfully detect reflections from radio spectrograms remains not easy: Antonio Martínez reported on a novel idea of digital filtering techniques. Hervé Lamy followed up on the progress on deriving the Observability Function of the BRAMS forward scatter network. The contribution by PhD student Joachim Balis on reconstructing meteoroid trajectories using forward scatter radio observations from the BRAMS network was really impressive. With the help of a radio interferometer at one station, he obtained encouraging results, comparing well to CAMS data.

Joachim Balis is a PhD student at the University of Liège, in collaboration with the Belgian Institute of Space Aeronomy, where he spends most of his time, under the supervision of Hervé Lamy. He is analyzing the radio signals coming from the forward scatter BRAMS network to obtain meteoroid trajectories. His perspective on the IMC is obviously different from that of the others who provided a testimony, as the BRAMS team will organize the IMC 2023 in Redu, Belgium. These are his thoughts about the IMC 2022:

From my point of view, the 41st edition of the International Meteor Conference was a great success. It was my first IMC (and only my second conference ever!), but I felt quite rapidly welcome and at ease. Scientifically, it was great to be able to discover what is done by other researchers in meteor astronomy (both professionals and amateurs). I learnt quite a fair bit about the techniques that are currently developed, some of them being potentially useful for my own work. As I am rather new to this field, the IMC allowed me to realize that there are many ways to do meteor science. All in all, it was very insightful to get a glimpse into these different approaches during the talks. It was also a nice opportunity for presenting my own research, answering questions about it, and getting interesting feedback and suggestions from people of various background and expertise.

I felt that the IMC was also very interesting for the social aspect, however. I would surely not have had the same experience if I had not participated on-site. Indeed, I would say that the most interesting exchanges took place outside the talks, i.e., during the breaks and the meals. The atmosphere was warm and friendly: most attendees knew each other from the previous editions, but were also keen on presenting themselves and getting to know the new participants. I am looking forward to the IMC 2023, which we will organize with the BRAMS team in Belgium!

Sunday, marking already the last day, always coming much too soon, covers only the morning. In the past, we often started an hour late to allow for some rest after the last night, but not this year; as all days, we started again at 9 am sharp. Presentations were on the estimation of mass of small meteoroids (Anna Kartashova), and the distribution of mass (Irina Brykina). Ablation modeling was discussed by Vladimir Efremov (porous versus solid bodies). Olga Popova presented a nice web-based application AsteroidHazard.pro which, using chosen input parameters, calculates the resulting phenomena in the atmosphere and on the ground. Elena Podobnaya looked into impact clusters on Mars. Because of the less dense atmosphere, less sorting occurs than on the Earth. Simon Anghel, finally, gave a presentation on mass estimation of meteoroids based on well-known impacts: how do you get the source energy from the different observing techniques (i.e., infrasound, seismic, and optical observation)?

Figure 5 – Hervé Lamy (left) and Joachim Balis (right) in front of the aquarium at the Lake Tisza Ökocentrum in Poroszló, which was visited during the Saturday afternoon excursion.

Figure 6 – Six students of Juraj Tóth at Comenius University in Bratislava sharing dinner in the evening. From left to right, we see Filip Hlobik, Daniela Bartková, Adriana Pisarčíková, Silvia Ďurišová, Martin Baláž and Justína Nováková.

Next to oral ("in person" and online) presentations, there were of course also contributions in poster format. These were nicely located at the back of the lecture room, next to the coffee stand and the IMO table. Actually, the poster sessions were made to coincide with the coffee breaks. In this way, the posters were a nice starting point for meteor-related discussions between participants in between the sessions.

Poster topics covered included the dropping of an artificial meteorite from a balloon to obtain insights in strewnfields (Tibor Hegedüs), infrasound detection of bolides (Peter Dolinsky, František Takács), radio captures of tau-Herculids (Peter Dolinsky), a flexibile text format for meteor measurements (Jiří Borovička), the tau-Herculids from Arizona (Stanislav Kaniansky), Capricornids 2022 by CAMS (Peter Jenniskens), the search for interstellar meteors (Dario Barghini), dynamical pathways of meteoroids and meteorites (Filip Hlobik) and the CZ-3B R/B re-entry as detected by AMOS (Daniela Bartková).

Justína Nováková is a student at the Faculty of Natural Sciences of Comenius University in Bratislava. She hopes to finish her PhD in physical chemistry in the months to follow. She works as operator of a mass spectrometry instrument. Among other things she and her colleagues try to establish is a spectra data base of meteoritical samples. As a hobby, Justína hunts micrometeorites in the stratosphere, using a stratospheric balloon and a self-made collection device. She tells us what the IMC 2022 did to her:

The IMC 2022 was my very first live International Meteor Conferece. I registered with huge expectations after listening to all the heartwarming stories my colleagues experienced at such gatherings in the pre-covid years. All of them were outperformed. In all aspects, the IMC is a true meeting of friends. Scientifically, the conference helps you grow, because your achievements are noticed, however minor or insignificant they may seem. The essence is that you pour your passion into them. No discrimination of age, education, and nationality turned the meeting into an encouraging experience. I had the great pleasure to observe the exchange of knowledge and skills between scientists and non-scientists; watched teachers being proud of their students; witnessed passion being inspired by passion. So after arriving home, I felt most of all thankful to this years' IMC. For me, it revived the feelings of fulfillment and drive for research I almost lost after the forced two-year seclusion.

Figure 7 – The room in which all lectures and poster presentations, as well as the IMO General Assembly Meeting, took place. We recognize at the first table, from left to right, Simon Anghel, Nagatoshi Nogami, and WGN Editor-in-Chief Javor Kac. Behind Nagatoshi and Javor, we see, also from left to right, Bill Ward, Matej Korec, and Felix Bettonvil.

Social time, and more

Apart from lectures and posters, there were numerous coffee breaks, lunches, and dinners. On Friday evening, we also had the traditional IMO General Assembly Meeting. The Meeting was open to all (also to non-IMO members), which provided a good opportunity for newcomers to learn what the IMO is and how it works. Due to the last-minute cancellations of both the President and the Vice-President because of personal circumstances, it was all up to Marc Gyssens to chair the Meeting, which he did in a splendid way. The IMO is doing well, and we were all made aware of the existence of a fund for special initiatives. We all may use this to materialize a good idea!

Marc also included in the General Assembly Meeting a short moment of reflection on the loss of our beloved Jean-Louis Rault, long-time Director of the IMO Radio Meteor Commission, Council Member, and steadfast participant of IMCs, who sadly passed away this summer. He will be greatly missed.

On Saturday afternoon, there is always time reserved for an excursion. This year, the destination of the excursion was within easy walking distance from the hotel: the Lake Tisza Ökocentrum, which functions as a visitor center of the Hortobágy Natural Reserve (which is a UNESCO World Heritage site). From the tower of the Ökocentrum, we had a stunning view on the lake area, and in the aquarium and zoo we watched the many fish, birds, mammals, and more, living in the Reserve. We were also offered a 3D-movie presenting the Natural Reserve. It was a relaxing afternoon, during which we had ample time to chat, not only on meteors but also on a lot of other topics to catch up (for those of us who already knew each other) or get to know each other better (for the first-time participants).

Then, Saturday evening marks the “last evening”, which is always celebrated in an extra-long social night. This year, the bar area also contained a bowling alley (a first for an IMC!), pool billiards, and table soccer. The combination of all of these created from the start an unforgettable atmosphere. Needless to say, many participants kept socializing until the wee hours of the morning, making it a painful experience to be in the Sunday morning session at 9 am sharp, as mentioned before!

No International Meteor Conference is complete without the IMC song, and this year’s version (the melody is always the same, but the lyrics change) was—in accordance to tradition—performed by Marko Šegon and Jérémie Vaubaillon. We refer the interested reader to the conference proceedings for the text!

Also the other evenings, there was spontaneous guitar music, singing, and percussion. How much had we missed this during the corona crisis!

Figure 8 – Participants relaxing in the bowling bar on Thursday evening over a beer or another drink. On the first table, we distinguish, in clockwise direction, Antonio Martínez, Bill Ward, François Colas, Joachim Balis, Detlef Koschny (kneeling), Hervé Lamy, and Urška Pajer. On the second table, we distinguish, also in clockwise direction, Peter C. Slansky, Nagatoshi Nogami, Peter Stewart, Mike Hankey, and Roman Piffl. Marc Gyssens, standing in the yellow t-shirt, is talking to François and Joachim.

The end always comes too soon

... And so the time did fly and it became much too soon already Sunday noon, thus approaching the end of the conference with the final closing words. Again, this was done in a splendid way by Marc, replacing the IMO President. He did not only thank the Local and Scientific Organizing Committees, but also Olivér Norton Szabó, who, while not in the Local Organizing Committee, did a great job in helping to make the hybrid aspect of the conference work as smoothly as possible, and the hotel manager, Imre Bóta, who really went out of his way to ensure that our experience at his venue was as enjoyable as possible.

Certainly, many of us have gone home full with memories, and full of new ideas and plans. The IMO community is really unique, and it was fantastic to meet in person again, with so many friends from all over world. Throughout this report, you were able to read testimonies from young, first-time participants, and they only confirm this conclusion. Obviously, science unites.

For sure, the IMC 2022 can also be seen as a first test case to bring together on-site and virtual attendees in one conference. Looking back, this hybrid form worked, despite there having been some technical issues. Also, we still have to learn how it was appreciated by everyone. Surely, things can be further improved, but it seems we have made a good start. It became immediately clear that, via the online option, we created an opportunity to attract new participants, who otherwise we presume would not have had the chance to come.

Our big thanks go to the organizers, for making this unforgettable event possible. More in particular, I wish to thank the Local and Scientific Organizing Committees for the logistic, respectively, scientific aspects of the conference, and Marc, for taking care of so many practical aspects as the IMO "official" on-site!

The venue of the next International Meteor Conference was revealed at the General Assembly Meeting: the Euro Space Center in Redu, Belgium. The IMC 2023 will take place from August 31 to September 3, 2023. It will be organized by the BRAMS team of Hervé Lamy, of the Belgian Institute of Space Aeronomy. Make sure not to miss it!

Figure 9 – Organizing a hybrid conference requires a lot more technical equipment as well as human power to manage it. Even though this is obviously a learning process, the Local Organizing Committee did a great job to ensure that everything went as smoothly as possible. From left to right, we see Ákos Kereszturi, Márton Rózsahegyi, and Eszter Borsai. Eszter was also the driving force in getting the logistics of the conference right. Not visible in the picture are Sirko Molau and Olivér Norton Szabó, who also played an important role in following up the hybrid aspect of this meeting. This picture was taken during the first session on Sunday morning, when Detlef Koschny was chair. We see him to the right of Eszter.

IMO bibcode WGN-505-bettonvil-imc2022 NASA-ADS bibcode 2022JIMO...50..112B

IMC 2023 at Euro Space Center, Redu, Belgium

Hervé Lamy [1]

The next IMC will be organized at the Euro Space Center, near Redu in Belgium, from 31 August until 3rd of September. This short article gives you some practical information and a little bit of teasing.

1 The location

The Euro Space Center (ESC) is a thematic center whose goal is to raise awareness about space science via a number of activities: Space Hub, Mars Village, Space Flight Unit, Space Rotor, Planetarium, Moonwalk, Free fall slide, ... It is mostly intended for young visitors fascinated by space but is also adapted to families or VIP / team building events from various companies. It is located near Redu in the beautiful Ardennes in Belgium. A picture taken in front of the building is shown in Figure 1.

Figure 1 – The Euro Space Center under a typical Belgian sky.

The ESC is most easily accessed by car as it is located next to exit 24 on the E411 highway. It also has a huge free parking. This is an option mainly for nearby countries or people who are willing to rent a car when arriving in Belgium. However, the ESC can also be accessed via public transportation. If you fly, you will most likely end up either in Zaventem airport (the national one near Brussels) or in Charleroi airport (also sometimes misleadingly called Brussels South). From both train stations, you need to take 2 trains for a journey lasting more or less 2 hours to reach a city called Libramont where we will organize shuttles from the train station to drive people to the ESC. A third possibility could be to fly to Luxemburg City. From there, a direct train goes to Libramont in about one hour. More details will be posted shortly on the official website.

2 The facilities at ESC

The conference room (see Figure 2) at ESC has all the modern facilities as it was completely refurbished in 2020. It is an auditorium with 150 seats and the possibility to add 20–25 seats in addition on a space on top. All the technical facilities needed for a good conference are available. This includes also 220 V plug at each seat and our own private secure Wifi. An hybrid format is also possible for those who will not be able to travel to Belgium.

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Figure 2 – The new conference room at the Euro Space Center

There will be the possibility for the participants to stay at the ESC. It has 24 bedrooms (see Figure 3). Each one has 4 beds, 2 showers and 2 sinks. We will provide options for people gathering in rooms of 4 and 2 (and maybe 3). For the additional participants who wants some more privacy, there will be the possibility to stay at 2 or 3 nice hotels nearby. The closest one is at 2.3 km and can therefore be reached by foot. For the others (distance of 4–6 km) a car will be needed. In the morning we will maybe organize shuttles to pick up people in front of the hotels, depending on how many people staying there and how many cars will be available.

Figure 3 – The bedrooms at the Euro Space Center

The meals (breakfast, lunches and dinners) will be served in the ISS room (see Figure 4) where coffee breaks will also be organized. There will be a variety of meals, some very classic (e.g. meatballs) and some very typical of Belgian food (e.g. "Carbonnades flamandes" which is beef stew cooked for hours in a beer sauce). Options for vegetarians and vegans will also be possible. On the Saturday evening, a special buffet will be organized with local products from the Ardennes. We will also have our own bar in order to keep the infamous relaxed atmosphere during the evenings and even nights. Of course you will have the possibilities to taste several typical Belgian beers, in particular the Trappist from the Rochefort city nearby will be available. In summary the ISS room will be ours for 3 days and a half. Note that if the weather is nice, the ISS room is next to a nice terrace from where you will be able to enjoy the last Sun-rays and to spot a mini Solar-System in the background. Let us cross fingers for a great weather at the end of summer!

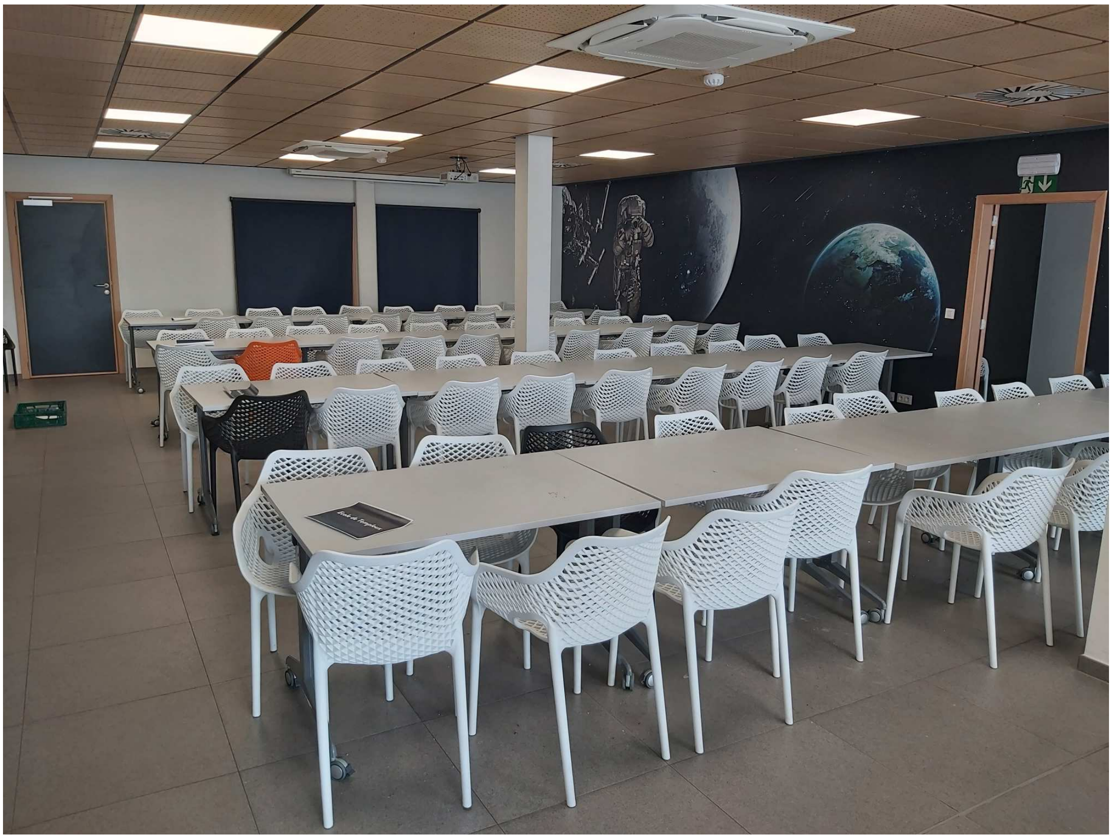

Figure 4 – The ISS room at the Euro Space Center will be used for meals, coffee breaks and social time in the evening.

3 Excursion

On Saturday afternoon, we plan to organize a nice excursion in 3 places close to each other (a few kms apart). First, we will visit the radioastronomical site of Humain which belongs to the Royal Observatory of Belgium (ROB). This place was built a long time ago with an impressive solar radio interferometer with 48 parabolic antennas installed along the North-South and East-West axes. Although the antennas have not been used for more than 20 years now, they are still there to provide nice display and pictures if the Sun shows up. Nowadays the place is hosting many radio experiments including the BRAMS radio interferometer, several experiments from the ROB, two astronomical domes and a VLF antenna for whistler detections. We will briefly visit and describe these instruments and their scientific goals.
Right after, we will visit the beautiful Caves of Han (`https://grotte-de-han.be/`) during approximately one hour and a half. You will also get the possibility to do some shopping there. Finally we have plans to visit a local brewery, discovers all secrets on how the beers are locally produced and end with a little beer tasting. Just enough to work up an appetite for the buffet at the ESC.

4 An extra-VIP event

For those interested, the ESC is offering to possibility to participate to a 2-hour VIP event, where you will be able to test the following activities :

- The Space Hub: An area dedicated to testing Astronauts' skills. Play to find if you have the skills to join our team of Astronauts.
- Space Tour: Our multimedia exhibition invites you to follow the footsteps of those who helped mankind discover our fascinating universe.

- Mars Village: Be the first to tread the Martian soil. Habitat, exploration, daily life, rover driving, etc. How will you survive on Mars?
- Mars walk and Moonwalk XP: Experience of sensation of Martian and Lunar gravity by trying out our seat equipped with a virtual reality mask.
- Free Fall Slide: Experience the sensation of weightlessness with a free fall from 8 meter high.
- Space Flight Unit: Fly over the red planet aboard your spacecraft. It's up to you to navigate the Martian canyons to complete your mission.
- Space Rotor: Test you ability to resist centrifugal force in our Space Rotor. You'll be subjected to the g-forces like real astronauts.

This will be a complementary activity, not included in the registration fee and only open to those interested. This will be organized in principle on Friday evening, in between the last session and the dinner. Depending on how many people arrive early enough on Thursday, we may organize it that day or maybe 2 sessions on 2 consecutive days. More details coming soon on the website.

5 The organizers

The BRAMS (`https://brams.aeronomie.be/`) team will be in charge of the local organization. The team belongs to the Space Physics group of the Royal Belgian Institute for Space Aeronomy (`https://www.aeronomie.be/`, BISA) located in Uccle, Brussels. We will get some support from additional persons from BISA, from ROB, from the ESC itself and of course with the support of the IMO. We will do our best to provide you a really great experience at this IMC, both on a scientific and a social level.

6 Conclusions

2023 will mark the return of the IMC in Belgium. The last one was organized in Oostmalle in 2005 and was apparently epic (I was not involved in meteor studies yet at the time). A radio meteor school was organized before and we have plans to organize a similar event but on a much shorter scale.
We will do our best to make this IMC an epic one too. After all, it will be the 42nd edition and therefore we may end up with finding all the solutions to meteor physics, chemistry and dynamics and even understand the whole purpose of the Universe. We hope to welcome many of you at the Euro Space Center or online next year for a very exciting scientific program and many interesting discussions. See you in Redu!

IMO bibcode WGN-505-lamy-imc2023 NASA-ADS bibcode 2022JIMO...50..122L

Ongoing meteor work

Flux Density Determination in MetRec and MeteorFlux

Sirko Molau[1]

This paper gives a detailed description of algorithms that are used by MetRec and MeteorFlux to calculate flux densities and population indices of meteor showers. These algorithms have been used for over a decade now and the individual aspects have been discussed in different publications before, but the full procedure is described here for the first time.

Received 2022 September 18

1 Introduction

The flux density is one of the basic properties of meteor showers. It describes the number of meteoroids of a defined minimum size that pass a defined atmospheric collection area under standardized conditions per unit time. The flux density is directly proportional to the number density of a meteoroid stream with the stream velocity as scaling factor. In the past, flux densities have mainly been derived from visual meteor observations by transformation of zenithal hourly rates. Even though the parameters of video cameras are known much more precisely than for human observers, video observations have not been used for flux density determination for very long because the limiting magnitude is difficult to calculate. Analyses have been conducted for selected showers and time intervals (e.g. Koschny et al., 2014; Blaauw, 2017), but there has been no permanent monitoring of meteor shower activity. An algorithm for limiting magnitude calculation has been implemented in the MetRec meteor detection and analysis package since 2010 (Molau, 2010), and cameras of the IMO Video Meteor Network have been continuously determining flux densities since April 2011. In the same year, the MeteorFlux web tool (`https://meteorflux.org`) was introduced (Barentsen & Molau, 2013; Molau, 2020). All flux data obtained by IMO network cameras have been uploading to that tool ever since, which allows for interactive creation of meteor shower activity graphs. The tool has undergone major extensions recently to handle the large amount of data collected over a decade more efficiently and to offer new analysis functions.

In this paper we want to describe in detail the underlaying algorithms in use to determine flux densities of meteor showers in MetRec, and to obtain flux density and population index profiles in MeteorFlux. Individual parts of the algorithm have been presented before, but never the whole story at once.

2 Algorithms

In order to determine the flux density (FD) of a meteor shower, you need to know the following:

1. the effective collection area of your video camera (ECA),
2. the effective observing time (ET), and
3. the number of shower meteors (NM).

The flux density is calculated as follows:

$$FD = NM/(ECA \times ET) \tag{1}$$

The first quantity is most difficult to determine, because here you need to apply all corrections to transform the actual field of view of your camera into a normalized collection area. Hence, we will describe the determination of these three parameters in reverse order.

2.1 Number of shower meteors

Meteor detection is a core task of software like MetRec, so the number of meteors is an immediate output. However, flux densities are meteor shower dependent, so the software also needs to determine the shower membership. Most precisely that can be done by multistation observations, which will give the trajectory and orbit of individual meteoroids. However, even in dense meteor networks not every meteor is detected by two or more stations. Omitting single-station meteors from the analysis would have an immediate impact on the calculated flux density. Since MetRec is focusing on single-station observations, it calculates the shower membership for every meteor in the same fashion as we do in visual meteor observation. Each recorded meteor is backward-prolongated to determine at which distance it passes the radiant, and the measured angular meteor velocity is compared to the expected velocity. The values required in order to calculate the expected angular velocity are the meteor shower velocity, the typical height at which meteors of this shower occur (height of meteoric layer), the radiant distance, and the altitude of the meteor. There are thresholds for both the radiant miss distance and the velocity deviation. These thresholds can be adjusted by the observer, but the default is a radiant miss distance of 5 degrees (10 degrees for the more diffuse Anthelion and sporadic sources), and a velocity deviation of 20% of the angular velocity plus 2 degrees/s. If neither of these thresholds is passed, a meteor is assumed to belong to the radiant of the respective meteor shower. If more that one radiant fulfills the criteria, the one with smaller deviations is selected.

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IMO bibcode WGN-505-molau-flux
NASA-ADS bibcode 2022JIMO...50..126M

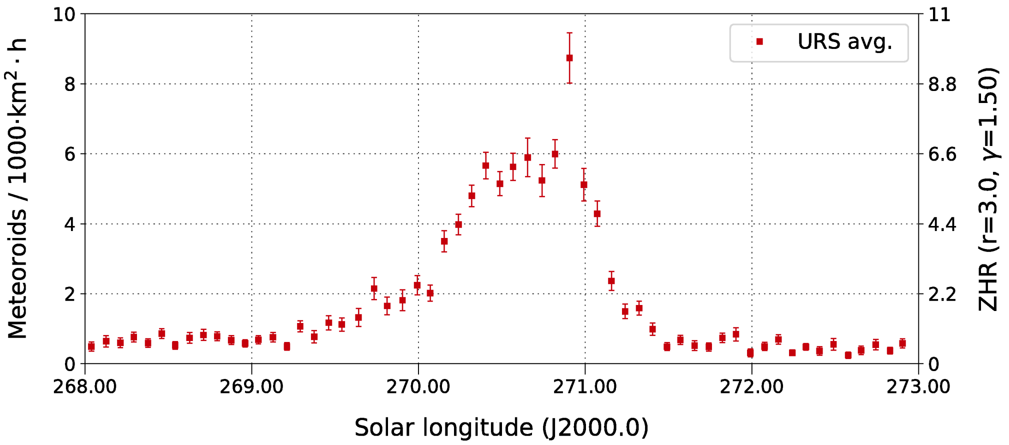

Figure 1 – Average flux density profile of the Ursids from 2011 to 2018. Between 269.0 and 271.5 deg solar longitude, the shower emerges from the sporadic background.

It is clear that there will be cases where shower meteors are not recognized as such because of measurement errors, and where sporadic meteors align by chance with meteor shower radiants (sporadic dilution). The probability for these false positive and negatives varies. As the velocity and radiant distribution of sporadic meteors is not uniform, some meteor shower radiants have higher probability of sporadic dilution than others. The net effect is, that a flux density graph of a meteor shower does not start and end at zero, but it emerges at some time from the sporadic background and later it disappears there (see Figure 1 for illustration). In the IMO network experience has shown that the sporadic background can be well-defined and shower activity can be separated even if the corresponding zenithal hourly rate is well below one.

2.2 Effective observing time

The effective observing time is the time interval between start and end of observation, reduced by observation breaks (e.g. due to clouds or hardware downtime) and the dead time introduced by meteor shower detection.

The decision as to whether skies are clear or not is addressed by the limiting magnitude calculation described in the next paragraph. Whenever stars are visible, the corresponding minute is counted as observing time. If cloudiness varies in the course of a night, the effective observing time is only reduced by the time when it was fully overcast.

In order to calculate the effective observing time, MetRec counts every second in which meteor detection is active and accumulates these. There are typically 59 or 60 observing seconds per minute, and the loss by dead time accumulates at most to a minute per night.

2.3 Effective collection area

To determine the raw collection area (RCA) of a video camera is straightforward, but to transform it with the actual observing conditions into a normalized collection area is not. The following parameters typically lead to a reduction of the effective collection area (ECA):

- Radiant altitude (RA)
- Stellar limiting magnitude (SLM)
- Distance to meteoric layer (DML)
- Meteor motion (MM)

In short, the effective collection area can be calculated as follows:

$$ECA = RCA \times \sin(RA) \times PPI^{(SLM - LLM_{DML} - LLM_{MM} + 6.5)} \quad (2)$$

whereby PPI is the population index of the meteor shower, and LLM_{DML} and LLM_{MM} are the loss in limiting magnitude due to the distance to the meteoric layer and due to meteor motion, respectively.

2.4 Calculation of raw collection area

For the calculation of the raw collection area, the camera's field of view is decomposed into its pixels. Since each pixel covers a small area of much less than a square degree, there is no need to apply spherical trigonometry at pixel level. With the plate constants respectively lens model, we calculate the angular width and height of the pixel. The product of these values gives the collection area in square degrees which the pixel covers. The sum over the collection area of all active pixels, i.e. those which are covered by the detection mask, gives the raw collection area of the camera. The detection mask is a binary image which defines the region of unobstructed skies in the field of view, that is used for meteor detection. The lens model is obtained in MetRec from up to 100 000 reference star positions, so it is very precise with sub-pixel accuracy down to the edges.

In order to convert the raw collection area from square degrees to square kilometers, we project the pixel onto the meteoric layer, determine the spatial width and height of the pixel at this layer, and multiply these values. The altitude of the meteoric layer (MLA) in km is determined from a formula obtained earlier (Molau & SonotaCo, 2008):

$$MLA = 79 + 0.48 \times V_{inf} - RA/10 \qquad (3)$$

whereby V_{inf} is the meteor shower velocity in km/s, and RA the radiant altitude in degrees.

Again, the raw collection area of the camera is the sum of the collection areas of all pixels that that are marked active by the detection mask. By applying further corrections, the raw collection area is transformed into the effective collection area.

2.5 Radiant altitude correction

If the radiant is located at zenith, meteoroids are passing the raw collection area of the camera perpendicularly. Usually the collection area is tilted, so that fewer meteoroids can pass it. The correction factor is the sine of the radiant altitude, corrected by zenith attraction.

Practice has shown that in addition to zenith attraction the zenith exponent γ also plays a relevant role in the flux density calculation. Analysis of flux density profiles of major meteor showers has revealed a zenith exponent between 1.5 and 2.0 (Molau & Barentsen, 2013). MetRec is still using the default value of $\gamma = 1.0$. After observations are uploaded to the MeteorFlux tool, individual flux measures can be transformed to other zenith exponent and population index values in order to study the impact of these parameters.

2.6 Stellar limiting magnitude correction

The flux density is calculated for meteors of at least 6.5 mag brightness. Typically, our video cameras are less sensitive. MetRec computes the stellar limiting magnitude within the active field of view. The difference to 6.5 mag is transformed into a correction factor for the visible number of meteors, involving the population index of the meteor shower. Since a reduction of the meteor count by a factor of x is identical to a camera having a collection area that is reduced by the same factor, MetRec is applying the limiting magnitude correction to the collection area.

The determination of the limiting magnitude is not simple, but it is the most important parameter in the flux density calculation. Whereas most other factors are known or can be derived by geometric considerations, the limiting magnitude is highly variable for different cameras and over time.

MetRec is calculating every minute an average limiting magnitude for the whole field of view as follows:

- Based on the inverse lens model and the Tycho star catalog, the expected spatial x/y position of all catalog stars in the active field of view (i.e. within the detection mask) is determined.
- A number of video frames are averaged in a sliding window, high-pass filtered and binarized with a defined threshold.
- Adjacent pixels in the binarized image are combined to stars, and the mean spatial x/y position of each is star is calculated. The stars are matched against the expected positions of catalog stars in the active field of view. If the catalog star is no farther away than a certain limiting distance, the star is counted as identified, independent of its size respectively brightness.
- The identified catalog stars are counted.
- The list of catalog stars that should be visible in the active field of view is sorted by brightness. If n catalog stars are identified, the limiting magnitude is given by the brightness of the n^{th} star in the sorted list

This algorithm gives an accuracy of typically about 0.1 magnitude if enough stars are visible, and it is quite robust. The detection of a few more or a few less stars affects the limiting magnitude only marginally. However, some heuristics have to be applied to retain robustness under the large variety of real-world observing conditions and camera types.

- The stars selected from the star catalog must be brighter than the last measured lm value plus 1 mag, with a minimum of ten catalog stars.
  If catalog stars that are too faint are used, there will always be a matching star for every spot in the binarized image. If their number is too small, on the other hand, some faint stars in the binarized image cannot be identified.
- The limiting distance for star identification is calculated from the catalog stars in the active field of view. It is set within some boundaries such that less than 5% of the catalog stars have another star within the limiting distance.
- The threshold for binarizing the video image is dynamically adjusted such that there is on average one unidentified star per 2500 pixel in the active field of view. This threshold is actually the most critical parameter in the lm calculation routine. The lower the threshold, the more "stars" (real stars and noise) are detected, the more matches with catalog stars are found, and the higher is the calculated limiting magnitude.
  If all stars in the binarized image are identified, then the threshold was too high and some faint stars have been missed, so the limiting magnitude is underestimated. If the number of stars not identified in the binarized image is too high, then the probability of chance alignments with faint catalog stars rises and the limiting magnitude is overestimated.
  It is important that the threshold converges to the same stable value over time even when coming from different start values. It turned out that over an extended range of the threshold, the number of identified and non-identified star increases nearly proportionally. In order to ensure stable

and fast convergence of the threshold, an asymmetric parameter update was implemented which increases the threshold in the next iteration by a large amount when the number of unidentified stars is too small, but only by a small amount when it is too big (Molau, 2016).

- Even when skies are totally overcast, some stars (noise) will be detected in the binarized image, and sometimes they will match by chance to catalog stars. To avoid this, there is an additional condition: If n stars are identified from the binarized image, one of the n brightest catalog stars in the active field of view must be among them. Otherwise the identification is not counted. E.g. if three stars from the binarized image are matching to the position of catalog stars, one of the three brightest catalog stars in the active field of view must be among them. This reduces the probability of chance alignments to near zero.

- We typically observe some drift of the field of view due to thermal effects of the camera mount. If the drift is getting too large, the stars from the binarized image will no longer match with the expected catalog star positions. For this reason, the average position deviation of all identified and nearly identified stars (those within ten times the limiting distance) is calculated and tracked over time. The deviation is smoothed and applied as correction to the position of the catalog stars. The camera operator can choose if the correction is applied in x/y space (e.g. if thermal drift of the camera is expected) or in Ra/Dec space (e.g. is a clock drift is expected).
  In this way, MetRec measures and tracks the motion of the camera over time with an accuracy of a few hundredths of a pixel. In addition, it determines the x/y position of a few tens to a hundred catalog stars every minute. This results in up to over 100 000 catalog star positions for a camera per night, or on average of one reference position per pixel, which is the basis for highly accurate lens models.

- If two stars in the catalog are closer than two pixels in each axis, the camera cannot resolve this double star, and it will be reduced to one catalog star.

- MetRec is keeping track of hot pixels, i.e. pixels which are constantly brighter than their surroundings and therefore frequently detected in the binarized image. They are harmful, because MetRec adjusts one threshold to fix the number of unidentified stars in the binarized image. If more and more of these stars are hot pixels, the calculated limiting magnitude is affected. If the number of hot pixels is getting too high, the observer is alerted to create a new darkfield, which will remove these pixels from the detection process.

2.7 Distance to meteor layer correction

The closer a pixel is to the horizon, the farther away is the meteoric layer from the camera. The intensity of the meteor light is reducing with the square of the distance. In order to normalize for a constant meteoric layer distance of 100 km, the distance of each pixel is transformed into an additional loss of limiting magnitude. A pixel pointing at the meteor layer at 200 km distance is receiving only 1/4 of the intensity, for example, which makes up for an additional loss by 1.5 magnitudes for that pixel.

2.8 Meteor motion correction

Within the integration time of a video frame, stars are not moving and all of their photons are collected by the same pixel(s). Meteors, on the other hand, are moving significantly, and the photons are distributed over more pixels. This leads to an additional loss of limiting magnitude, which is not only dependent from the meteor shower velocity, but also from the radiant distance and the altitude. These values depend on the observing direction, so MetRec is calculating the expected angular velocity of a shower meteor for each pixel in the active field of view. This value is converted into a spatial x/y distance the meteor moves at this pixel position during the integration time of the video frame, and this value is transformed into a limiting magnitude loss. The integration time depends on the video signal type (PAL, NTSC), the recording type (interlaced, non-interlaced) and the frame integration that might have been configured at the video camera.

The loss in limiting magnitude is solely determined by the brightest pixel of the meteor, i.e. the one that receives most photons. The limiting magnitude loss function has been derived analytically in the past (Molau et al., 2016). However, in order to stay compatible with older flux density measurements, MetRec is currently using an old loss function that is proportional to the spatial meteor motion.

Thanks to meteor motion correction, MetRec excludes regions near the radiant from flux density calculation, where meteors are moving so slow ($< 2°$/s) that they are filtered out as satellites in the detection process.

2.9 Flux density calculation and presentation

With the described parameters and algorithms, MetRec is calculating the flux density of meteor showers. Note that some parameters are variable over time (e.g., limiting magnitude and meteor motion correction) whereas others are almost constant (e.g., raw collection area and meteor layer distance). The constant parameters are pre-calculated for every pixel, and the variable parts are determined every minute. This is computationally demanding and leads to the loss of a few video frames at the end of each minute. In order to minimize the loss, the procedure has been heavily optimized. The binarized image is not calculated immediately, for example, but line by line during a number of video frames. In addition, the variable parameters are not calculated for every pixel, but for each cluster of 4×4 pixels. This introduces only negligible approximation errors.

Note that only the stellar limiting magnitude is calculated in real-time and cannot be corrected later on. All other parameters can be adjusted when the flux density is re-calculated (e.g., with new meteor shower parameters), but the calculation is time consuming. It currently takes about one day on a single computer to re-calculate the flux densities from all IMO network cameras for one month.

The limiting magnitude and the flux density data are stored every minute in text files, which are uploaded to the MeteorFlux server once the observer has processed the observation and delete false detections. In addition, flux density measures can be sent by MetRec in real-time to the MeteorFlux server if the computer is online, which allows to create real-time flux profiles for meteor showers with a delay of only a few minutes.

Raw flux measures from single cameras with a temporal resolution of one minute do not yield a proper flux density profile yet. They need to be combined and accumulated in a sensible manner, which is what MeteorFlux was written for. This web application gives numerous options to combine individual flux measures and adjust the binning parameters and other values to get meaningful profiles. MeteorFlux allows to select

- the start and end date or solar longitude of the observing interval,
- the meteor shower,
- the observing years, whereby either an own profile is generated for every year, or all years are combined into an average profile,
- the bin size based on a combination of the number of meteors, the effective collection area, and the minimum and maximum duration,
- the camera set that contributes to the profile,
- the minimum stellar limiting magnitude, as well as minimum and maximum values for the radiant altitude, solar altitude, and lunar altitude, phase and distance from the field of view, and
- the population index and zenith exponent.

MeteorFlux can plot two data sets in a single graph to compare the flux density profiles of different showers, or of the same shower with different parameter settings.

Over the course of more than ten years of IMO network flux data collection, several hundred million individual flux density measures have so far been accumulated in the MeteorFlux database. Some optimization of the underlying PostgreSQL database has been necessary to ensure that activity profiles can still be generated with acceptable waiting times.

3 Shortcomings of the algorithm

3.1 Limiting magnitude calculation

The calculation of the stellar limiting magnitude is clearly the Achilles heel of the flux density calculation. That comes as no surprise: if only a few stars are visible in the field of view, for example, there is no way to determine the limiting magnitude precisely. The more stars are visible, the better the conditions.

MetRec can only determine an average limiting magnitude for the whole field of view, but there are cases where the limiting magnitude is highly variable, e.g., if clouds are drifting through or the Moon is in the field of view. Let us estimate the error from a borderline case where 50% of the field of view is perfectly clear with a limiting magnitude of 6.5 mag, and 50% is totally overcast. The stars will be on average equally distributed, so MetRec will identify half of the number of stars up to 6.5 mag in the full field of view. Stars have an average "population index" of about 3, that is, the number of stars increases by a factor of three with each magnitude. So, 50% of the stars will lead to a reduction of about $\log_3(0,5) \approxeq -0.6$ mag, and MetRec will determine an average limiting magnitude of 5.9 mag. This stellar magnitude correction is applied to every pixel in the field of view. If the population index of the shower is 2.0, the effective collection area will be reduced by about 35%, whereas in reality the collection area was cut in half. The calculated flux density will be about 30% too low.

To overcome this problem, we could try to calculate the limiting magnitude for different areas in the field of view. However, only few cameras record so many stars that we can cut the field of view into pieces.

Another approach would be to omit all observations where skies are partly clouded or the limiting magnitude is otherwise highly inhomogeneous. However, it is in fact not easy to determine such conditions, and it would reduce the available data set significantly.

A completely different approach would be to determine the faintest visible star in individual areas. However, this algorithm would be much less robust against effects like double stars, different colors indices of stars and spectral responses of cameras. It would also not solve the issue of variable limiting magnitudes within the field of view.

3.2 Atmospheric extinction

The atmospheric extinction leads to lower limiting magnitudes near the horizon. Given a standard model for atmospheric extinction (Flanders & Creed, 2008), MetRec can subtract the expected limiting magnitude loss per pixel, and add the average loss over the whole field of view. This differential correction reduces the limiting magnitude for pixels near the horizon, increases it for pixel higher up in the sky, and leaves the average limiting magnitude over all pixels at the value that was determined from the detected stars. This correction is currently not used in order to remain compatible with older flux measurement value. Experiments have shown, that the correction changes the effective collection area by typically a few percent with slightly larger values for lower radiant altitudes.

3.3 Population index

Another important ingredient is the population index of the meteor shower, which is per se unknown but has a large effect in particular for insensitive cameras. To solve this problem, MetRec calculates a coefficient that allows the conversion of effective collection areas from one population index to another. In the MeteorFlux tool you can manually select a new population index, and the flux densities will be adjusted accordingly on the fly. Details are given in the next chapter.

3.4 Meteor detection probability

A big shortcoming is the assumption of a step function in meteor detection probability, i.e., that all meteors up to the limiting magnitude have a detection probability of 100%, and beyond that of zero. The meteor detection algorithm is more deterministic than a visual meteor observer (it is time independent and has the same sensitivity in the full field of view, for example), but the detection is also probabilistic in the end. When the meteor brightness is approaching the limiting magnitude, more and more of them will be missed by the detector. Ignoring this effect leads to significant underestimation of flux densities.

On the other hand, meteor detection and limiting magnitude calculation are two completely different and unrelated procedures. Meteors are identified in consecutive single video frames, which have a lower signal-to-noise ratio than the averaged image from which the stellar limiting magnitude is calculated. However, due to the requirements that meteors must be visible in at least three consecutive video frames at the right distance and speed, we can lower the detection threshold and find meteors below the noise level of single frames.

In the end, these effects will lead to a fixed and hitherto unknown scaling factor of all calculated flux densities, which may be smaller or larger than unity. MetRec can precisely calculate flux density profiles and relative activity changes, but the absolute flux density value may be significantly off. Consequently, error bars that are given in flux density graphs like Figure 1 are too optimistic as they only represent the relative error (proportional to the square root of the number of meteors), not the absolute error of measurement.

3.5 Unknown meteor showers and sporadic meteors

The described procedures for flux density calculation works only for known meteor showers, because you need to know the radiant position, velocity and population index of the shower. This is a minor limitation, since only the stellar limiting magnitude is calculated on the fly and cannot be corrected later on. All shower dependent parameters can be re-calculated. So, when a new meteor shower is assumed or detected, the shower assignment and the flux density can be re-calculated, which is just time-consuming as explained earlier.

The algorithm does not work for sporadic meteors because they have no defined radiant, velocity or population index. MetRec is solving the problem by modelling sporadic meteors as a mixture of the well-known Apex, Antapex, Helion, and N/S Toroidal sources, each of them weighted with a value that reflects their activity, and with "shower" parameters taken from literature. Note that the Antihelion source is not modelled, because it overlaps with the Anthelion meteor shower from the IMO working list, which is detected independently.

4 From flux densities to population indices

One of the short-comings of IMO network data is the large variety of cameras and lenses used. The stellar limiting magnitude ranges roughly from magnitude three to magnitude nine, the field of view diameter from below twenty to over a hundred degrees. The cameras are of different types with different spectral responses.

However, when it comes to population index calculation, this becomes an advantage over homogeneous camera networks where every camera has similar characteristics. The reason is that each camera is sampling the flux density at a different magnitude range, and the difference in meteor detection capability between the cameras is governed primarily by the population index.

Right from the start MeteorFlux had the capability to calculate flux density graphs for different predefined population indices. Recently a function was added to calculate the population index profile in the same manner as flux density profiles. Here we will give details about the underlying algorithms and implementation.

Two tasks have to be solved:

- to convert the flux density between different population indices,
- to determine the best population index from a set of observations.

4.1 Flux density conversion

It was shown in Equation 2 , that the population index PPI is a major factor in the transformation from the raw to the effective collection area. The larger the limiting magnitude deviates from the reference value of 6.5 mag, the bigger is the impact of the population index. To illustrate that with some numbers: We have many cameras in the IMO network with meteor limiting magnitudes of 2 to 3 mag. In case of 2.5 mag, the correction factor is $2^4 = 16$ for a population index of 2.0, and $3^4 = 81$ for a population index of 3.0. That is, the calculated flux density will differ by a factor of five!

In earlier work (Molau et al., 2014) we found, that the dependency of the effective collection area on the population index can be approximated by a power function of type $a \times PPI^b$ with free parameters a and b. Therefore, the conversion factor (CF) to transform the effective collection area from a value PPI_{old} to PPI_{new} can be written as

$$CF = PPI_{old}^b / PPI_{new}^b \quad (4)$$

Hence, we have to estimate one additional parameter b during the observation. The analysis has also shown that the approximation error from the power function is smallest (typically $< 1\%$) if the parameter is not estimated for the full effective collection area, but for every pixel.

This leads to the following algorithm. When all terms for the calculation of the effective collection area of pixel are determined, this collection area is calculated for different population indices in the range 1.5 to 3.5 with step size 0.1. For each population index, the effective collection area is accumulated over all pixels, and a power function $a \times PPI^b$ is fitted by least squares estimate to the sums. Only the exponent b of this fit is stored in a text file together with the limiting magnitude and other relevant parameters of that minute.

If flux density profiles are calculated in MeteorFlux with a new population index, the effective collection area ECA of each minute is corrected by the factor CF according to Equation 4.

4.2 Population index calculation

This procedure is a little more complex. Here we look for the population index that yields the smallest deviation for the flux densities of different cameras. The procedure, which was described in (Molau et al., 2014), is as follows.

Cameras have variable limiting magnitudes. Hence, it is not wise to bin the observations by camera. MeteorFlux is taking all flux density measures of all active cameras for the time interval in question, and is sorting them by limiting magnitude. Next, the sorted data set in split into bins, such that each bin has the same total effective collection area with the population index that was used during the observation. Observations with low limiting magnitude have only a small effective collection area, so the first bin will contain a lot of flux density measures. Intervals with good limiting magnitude have a large collection area, so the last bin contains only a few measures. Typically, we split the set of observations into four bins, but the user can select also other values in MeteorFlux.

The assignment of observations to the bins remains fixed. Hence, we can calculate for each bin, how many meteors k we observed. On the other hand we know, that each bin has the same effective collection area and should contain the same number of meteors. Thus, by dividing the overall number of meteors by the number of bins, we get the expectation value λ for the number of meteors in each bin. The Poisson distribution $P_\lambda(k)$ gives us the probability that k meteors are observed, when the expectation value is λ. All we need to do is to calculate the product of the Poisson probabilities (or sum of log probabilities) from all bins to find, how well the current population index fits to the observations.

MeteorFlux is repeating the calculation for every population index in the expected range, and selecting the one where the sum of log probability from all bins is highest. Here is the overall procedure:

- Distribute the observations by their limiting magnitude into n bins. The number of meteors that belong to each bin is the observed value k_n . Note that MeteorFlux gives you the option to fix the minimum and maximum limiting magnitude of each bin for all data points in the population index profile, or to re-calculate the bins for each data point.

- For each population index, calculate the effective collection area of each bin applying the transformation (Equation 4 to every observation that belongs to the bin.

- Calculate the fraction f_n of collection area of each bin from the total collection area over all bins. The fraction will be near $1/n$ for the population index which was used during observation, but it will deviate for all other values. The same fraction f_n of meteors from the overall number of meteors is the expectation value λ_n.

- Calculate the Poisson probability P_n for each bin. The sum of log probability over all bins is the log probability of the population index.

- Select the population index PPI_{max} with the highest probability.

- Take the log probabilities from five population indices in the interval $[PPI_{max} - 0.2, PPI_{max} + 0.2]$ and fit a quadratic function $ax^2 + bx + c$ to these values. Calculate the best population index PPI_{best} where the quadratic function has its global maximum using the derivate $PPI_{best} = -b/2a$.

In the first part of the procedure, we can calculate only a discrete population index PPI_{max} with a granularity of 0.1. By fitting the quadratic function in the last step, we get a continuous measure for the population index PPI_{best}.

Using the Poisson distribution to calculate the probability for each bin and population index has certain advantages. It gives us a theoretically profound solution to estimate the probability of observed vs. expected number of meteors assuming random fluctuations of independent events with a constant average rate. Even more, it gives the individual bins a different weight. When we change the population index, the percentage of the inner bin(s) with average limiting magnitude from the overall effective collection area changes only little. In other words, these bins contain only little information about the population index and their impact is lowest, because they have almost the same log probability over a wide range of population indices. Most relevant are the bin at the edges with the smallest and biggest limiting magnitude. Their percentage from the overall collection area changes significantly with the population index. So, their log probability changes most, and they have the biggest impact on the population index estimation. Last but not least we can take the steepness of the quadratic function as a quality measure of the population index. If the function is shallow, many population indices have about the same probability, so the accuracy is small. If the function is steep, the best population index is well-defined and the accuracy is high.

The algorithm, which has been developed in 2014 and used ever since for meteor shower analyses, has now been ported to the MeteorFlux tool. The tool offers the same flexible parameters to define the bin size for population index calculation as for flux densities. Note, however, that typically much more meteors are required to get a proper population index measure than to get a flux density measure. The calculation takes also much more time, because effectively an own flux density profile has to be calculated for every population index.

The algorithm has the advantage of being completely independent of video meteor brightness measurements (which are notoriously unreliable) and the disadvantage that only one fixed population index is calculated over the full magnitude range of meteors. If the meteoroid population is discontinuous, we would need to refine the algorithm e.g., by calculating population indices pairwise from adjacent limiting magnitude bins.

Not yet implemented is a function to correct the flux density profiles in MeteorFlux directly with the calculated population index profile. This function will be provided soon.

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Handling Editor: Javor Kac

Possible meteor shower with the comet 45P/Honda-Mrkos-Pajdusakova

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We present computations of orbital elements together with the non-gravitational parameters of the comet 45P/Honda-Mrkos-Pajdusakova based on all 3039 published observations over intervals: 1949 Jan. 09.54284 – 2022 May 18.44905: (`https://minorplanetcenter.net/iau/mpc.html`). We also computed a possible meteor showers connected with this comet.

Received 2022 June 28

1 Computation method and results

To compute the orbital evolution of the comet 45P/Honda-Mrkos-Pajdusakova, we used the publicly available Orb-Fit 5.0.6 software. We used the error model 'vftc17' according to Veres et al. (2017). We used the JPL DE431 Solar System model with an additional 17 massive asteroids as described in del Vigna et al. (2018) and in Farnocchia et al. (2013). Also, we computed non-gravitational parameters $A1$ and $A2$.

Table 1 – Starting nominal cometary orbital elements for the non-gravitational orbital model and for pure gravitational model.

Epoch: 2017 February 24 TDT		
orbital parameter	model	value
q (au)	NG	0.532470360 ± 1.012E-06
	GRAV	0.532512475 ± 4.604E-07
e	NG	0.823857193 ± 1.852E-06
	GRAV	0.823926031 ± 1.581E-07
i (deg)	NG	4.24742661 ± 2.105E-05
	GRAV	4.24748923 ± 3.463E-05
Ω (deg)	NG	88.9684000 ± 3.679E-04
	GRAV	88.9702696 ± 6.813E-04
ω (deg)	NG	326.2891496 ± 4.027E-04
	GRAV	326.2921427 ± 6.803E-04
TP (TDT)	NG	$2457753.76619126 \pm 4.113$E-05
	GRAV	$2457753.26500587 \pm 8.571$E-05
Earth MOID (au)	NG	0.06030
	GRAV	0.06031
Asc. node-Earth separation (au)	NG	-0.40799
	GRAV	-0.40795
Desc. node-Earth separation (au)	NG	2.07295
	GRAV	2.07411
RMS (arcsec)	NG	0.7908
	GRAV	3.2759
$A1$ (au/day^2)		$1.21879499173 72$E-8 ± 3.536E-10
$A2$ (au/day^2)		-3.6032151289734E-10 ± 6.263E-13

Table 1 shows starting computed nominal orbital elements of the comet 45P/Honda-Mrkos-Pajdusakova for the non-gravitational orbital model and for pure gravitational model using the error model 'vftc17', where q is a perihelion distance, e – eccentricity, i – orbital inclination, Ω – longitude of ascending node, ω – argument of perihelion, TP – perihelion time, $A1$ denotes the non-gravitational radial acceleration parameter, $A2$ – the non-gravitational transverse acceleration parameter. NG denotes orbital elements computed with the non gravitational parameters $A1$ and $A2$, GRAV – with the pure gravitational model only. We can see that computed orbital parameters depend on using the propagation model, with the non-gravitational forces or using only gravitational perturbations in the motion of the comet. Next, we searched for possible meteor showers for three moments of the comet's close approaches (CA) to the Earth.

The CA of the comet is taken from the `https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=45P&view=OPC` and is presented in Table 2.

Table 2 – The CA of the comet 45P with the Earth.

Date/Time (TDB)	Nominal distance (au)
2017-Feb-11.34722	0.08319
2032-Nov-11.29167	0.17091
2043-Nov-15.01944	0.39694

We used the program described in Neslusan et al. (1998). The program computes a theoretical radiant of meteor showers for both propagation models and is presented in Table 3.

Table 3 presents possible meteor showers connected with the comet 45P/Honda-Mrkos-Pajdusakova for Equinox 2000.0, where
METH. denotes a method of computation,
Q – adjustment (Svoren et al., 1993),
ALPHA and DELTA – right ascension and declination of the predicted radiant (deg),
VG – predicted geocentric velocity of meteors (km/s),
VH – predicted heliocentric velocity of meteors (km/s),
L – solar longitude of the maximum of the potential shower (deg),
DATE-MAX – predicted time of the shower maximum,
D-DISC – D-criterion characterizes the difference between the orbit of the parent body (input orbit) and modified orbit crossing the Earth's orbit (output orbit).
It is visible that the predicted meteor shower connected with the comet 45P/Honda-Mrkos-Pajdusakova is almost the same for different years.

In Table 3, the D-disc seems relatively high. The Radiant software also provides the minimum distance

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IMO bibcode WGN-505-wlodarczyk-45p
NASA-ADS bibcode 2022JIMO...50..134W

Table 3 – Possible meteor showers connected with the comet 45P/Honda-Mrkos-Pajdusakova computed for different epochs and the propagation model.

METH.	ALPHA	DELTA	VG	VH	L	DATE-MAX.	D-DISC.
Data for the year 2017							
NG							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 20.3	0.357
GRAV							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 20.3	0.357
Data for the year 2032							
NG							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 20.2	0.357
GRAV							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 20.2	0.357
Data for the year 2043							
NG							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 21.0	0.357
GRAV							
$-Q$	298.3	−18.3	27.40	29.24	89.0	JUNE 21.0	0.357

Table 4 – Possible meteor showers connected with the comet 45P/Honda-Mrkos-Pajdusakova.

LP	meteor shower	RA	DE
193	Northern mu Sagittariids	271.9	−17.3
272	Daytime Capricornids-Sagittariids	299.8	−15.3
1279	June xi1 Sagittariids	283.6	−17.8

between the orbit of the Earth and that of the input orbit. In all cases in Table 3, this computed distance is probably too high, about 0.06 au. Hence the existence of the shower is doubtful. Theoretically, however, we can find it in the meteor showers list: `https://www.ta3.sk/IAUC22DB/MDC2007/`; last update: Feb 28, 10:00:00 UTC, 2022 modified by R. Rudawska, M. Hajdukova and T.J. Jopek. Table 4 lists possible meteor showers connected with the comet 45P/Honda-Mrkos-Pajdusakova, where LP denotes the running number in the `streamfulldata.txt` file, RA – the right ascension of the shower radiant (J2000, deg), and DE – declination of the shower radiant (J2000, deg).

Finally, as was noted in Vaubaillon and Christou (2006), comet 45P is known to cause a meteor shower at Venus. Additionally, we calculated that comet 45P's closest approach to Venus took place on 1825 January 24.08416 at 0.0474 au, the next will be 2135 January 4.16596 at 0.0376 au.

Acknowledgements

The author thanks Jeremie Vaubaillon for his comments. We also thank L. Neslusan for his software. We want to thank the Space Research Center of the Polish Academy of Sciences in Warsaw for the possibility of working on a computer cluster.

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Handling Editor: Javor Kac

This paper has been typeset from a LaTeX file prepared by the author.

A Short Note on Piscis Austrinids (#0183PAU)

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Piscis Austrinids (#0183PAU) have been listed in many shower compilations since McIntosh (McIntosh, 1935) published the results of visual southern hemisphere meteor observations. Photographic and recent visual observations suggest that Hoffmeister's view is correct (Hoffmeister, 1948) – in visual observations the PAU are buried in the activity area of Southern delta Aquariids (#0005SDA). We cannot trace the classical PAU but can indicate a weak separate meteor activity around $\lambda s = 135°$ which should be called by a different name.

Received 2022 July 14

1 Introduction

Jenniskens cites two of McIntosh's observations as PAU (see Table 1), although McIntosh himself listed 10 meteor showers in Piscis Austrinus in July and August (McIntosh, 1935). Hoffmeister also detected the Piscis Austrinids in his conclusive shower list as No. 11 (see also Table 1). He noted that this shower had been noticed by Denning but not by Öpik nor by Olivier (Hoffmeister, 1948, Table 29) and Jenniskens quoted McIntosh's observations only (Jenniskens 2006). We have been influenced by McIntosh and not by Denning in this case, though McIntosh wrote "The material for this paper was obtained mainly from the three reports of the New Zealand Meteor Section, covering the years 1927 to 1934, but recourse was also had to Denning's General Catalogue of Meteor Radiants".

2 Radar and video observations

Activity of the Piscis Austrinids cannot be detected by photographic observations (see Figure 4). For our study, we use the 2018 January 13 version of the IAUMDC SD (IAUMDC Shower Database) which gives six observations as PAU (Table 2) including some curious entries. (The more recent data base version has changes of many entries, and for example, #0183PAU05 is omitted.)

First, the entries in the IAUMDC SD are originally based on Jenniskens' working list (Jenniskens, 2006). Here, he listed #0183PAU00 as a former Soviet radar observation. This is not correct, but he compiled two radar observations listed in Table 3.

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IMO bibcode WGN-505-koseki-pau
NASA-ADS bibcode 2022JIMO...50..136K

Second, CMOR data have been published twice as CMOR1 (Brown et al., 2008) and CMOR2 (Brown et al., 2010). The entry #0183PAU01 originates from CMOR1 and the result of CMOR2 for PAU is not included in the list, though the number of orbits is much greater than CMOR1 (Table 4). The corresponding radiant chart is shown in Figure 1.

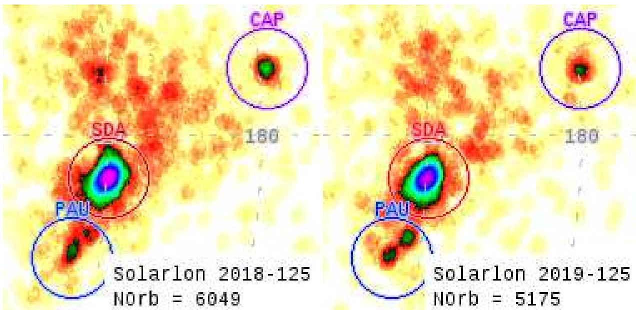

Figure 1 – Radar radiant distribution of the PAU in 2018 (left) and 2019 (right) by CMOR. Norb means the total number of radiants obtained during the day.

Third, and the most curious entry is #0183PAU03: its source is unknown. If we neglect these problematic entries, that is, PAU000, PAU01 and PAU03, the maximum would be around $\lambda_s = 135°$. However, CMOR2 suggests it occurs around $\lambda_s = 135°$, the figures of CMOR data from 2018 and 2019 show the maximum at $\lambda_s = 125°$ as CMOR1 indicated. We will discuss the plausible maximum of the PAU in the next section. It is necessary to note that the radiant point of PAU obtained from CMOR is located some 5 to 10 degrees east of the classical Piscis Austrinids.

We checked the entry #0183PAU01 using SonotaCo net observations from the period 2007–18 and found that there are several radiants in the vicinity of the position given for #0183PAU01 (Figure 2). But these are observed around $\lambda_s = 125°$ rather than near $\lambda_s = 135°$ (Figure 3). Video observations indicate that the PAU's maximum is around $\lambda_s = 135°$, as suggested by the SD entries #0183PAU04 & 05.

Table 1 – Visual observations of the PAU.

Source	No.	Period	α	δ	N	Name
Denning	262	rich at end July	338.7	−29.8	11	α Piscis Australids
McIntosh	274	July 14–22	330.5	−30	11	β PsA ii
			339	−30		
	290	July 26–August 8	337	−33	24	α PsA
			350	−30		
Hoffmeister	11	July29–August 2	337	−28		PsA

Table 2 – Piscis Austrinids in the IAUMDC SD. "O" denotes the observing technique, with C – CCD, R – radar, T – TV.

Code	α	δ	V_g	λs	$\lambda - \lambda s$	β	$\Delta\alpha$	$\Delta\delta$	N	O	Reference
0183PAU00	340.7	−25.7	40.5	123.7	208.6	−16.2	0.90	0.40	32	R	Kashcheev et al., 1967
0183PAU01	347.9	−23.7	44.1	126.5	212.9	−17.0	0.89	0.16	91	R	Brown et al., 2008
0183PAU02	352.8	−20.4	42.8	133.2	212.0	−15.8	0.27	−0.03	10	T	SonotaCo, 2009
0183PAU03	347.9	−23.7	44.1	123.7	215.7	−17.0					?
0183PAU04	352.5	−20.5	43.8	136.0	208.8	−15.8	0.94	0.40	23	T	Jenniskens et al., 2016
0183PAU05	353.9	−20.9	42.4	135.1	210.8	−16.7			173	C	Jenniskens et al., 2017

Table 3 – The original data for #0183PAU00 which is mixed data from two observations.

Code	α	δ	V_g	λs	$\lambda - \lambda s$	β	e	q	i	ω	Ω	N
K1-99	340.7	−25.7	42	125.7	206.6	−16.3	0.96	0.17	45.0	134.0	305.7	32
K1-100	337.7	−35.7	42	123.7	201.9	−24.4	0.98	0.30	47.0	114.0	303.7	7

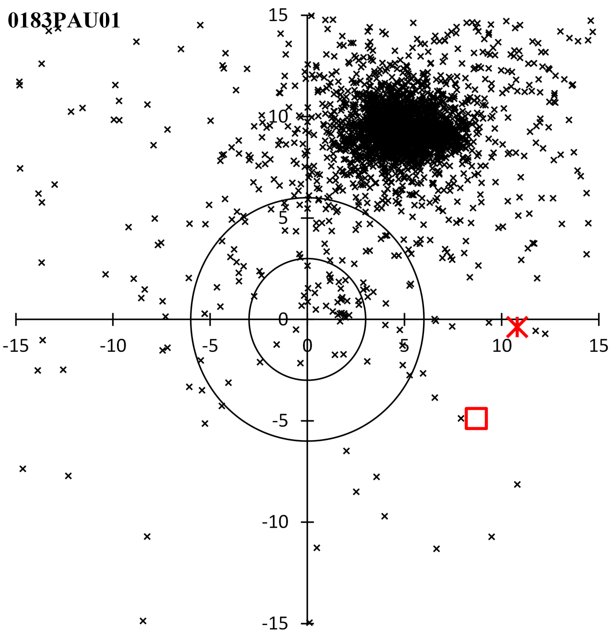

Figure 2 – The radiant distribution centred at #0183PAU01 did not perceive PAU activity because the data of SonotaCo net does not show respective activity between $116^\circ.5 \le \lambda_s < 136^\circ.5$.

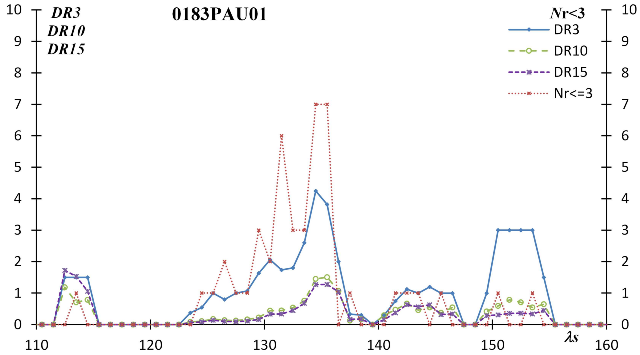

Figure 3 – Activity profile of the #0183PAU01. Nr $<$ 3 represent the video meteors per day, DR3, DR10 and DR15 are the radiant density ratios giving the shower activity level to the sporadic background.

We cannot find a trace of the former historic Piscis Austrinids which were given by McIntosh and by Hoffmeister (shown as a box and an asterisk in Figure 2, respectively).

3 Shigenos' image intensifier video observations in Australia

Yoshiko and Tomoko Shigeno published the results of their two Australian expeditions of II (image intensifier) video meteor observations (Shigeno Y. and Shigeno T., 2004). Note that image intensified and video data differ as shown by Koseki et al. (2010). The Australian II observations did not detect the PAU activity because they could not find any concentration of the radiants around the position given by McIntosh (Figure 4). We plotted the II radiants in the same area and the same period as Figure 2. A similar concentration as seen in video observations lies near the center instead near McIntosh's radiant (Figure 4).

15 II meteors found within 6 degrees from the center of Figure 4 are listed in Table 5. The observations consisted of two periods: 7 meteors above MSSIgx are from 1998 and 8 below this are from 2002. If we reject farther and upper two meteors (MSSif5 and MSSIgx) as these may be contaminated from SDA, there are 5 meteors before $\lambda_s < 130$ and 8 after this. The II observations suggest that the activity profile is rather flat and the maximum would be later than $\lambda_s > 130°$. The II observations can detect fainter meteors than video can. The majority of the meteors listed in Table 5 are fainter than +4 mag (Ma – absolute magnitude). Not

Table 4 – Canadian Meteor Orbit Radar (CMOR) give two different PAU data: CMOR 1 is listed in the IAUMDC as PAU01 but CMOR2 is not, though the latter has much more data (see the number of orbits $N_{\rm orb}$).

	$\lambda_{\rm max}$	$\lambda_{\rm begin}$	$\lambda_{\rm end}$	α	δ	$\Delta\alpha$	$\Delta\delta$	V_g	a	e	q	i	ω	Ω	$N_{\rm orb}$
CMOR1	126.5	125	131	347.9	−23.7	0.89	0.16	44.1	3.12	0.9611	0.122	64.1	142.8	306.2	91
CMOR2	135	124	142	357.1	−21.5	0.52	0.39	44	3.1	0.955	0.1395	65.6	139.96	315.0	1637

Table 5 – 15 II meteors within 6 degrees from the center of Figure 4.

Code	λs	$\lambda - \lambda s$	β	V_g	Dist.	Angle	x	y	Ma
MSSIfN	128.2	211.7	−16.3	41.6	1.31	300	1.1	0.7	4.6
MSSIfY	128.2	209.4	−18.8	20.9	3.77	241	3.3	−1.8	3.7
MSSIfm	128.2	213.8	−14.9	34.0	2.26	23	−0.9	2.1	1.1
MSSif5	128.3	213.4	−11.7	38.1	5.34	5	−0.4	5.3	4.3
MSSIg9	129.2	213.4	−16.8	43.9	0.48	62	−0.4	0.2	1.3
MSSIgi	129.2	215.7	−16.7	31.9	2.65	83	−2.6	0.3	3.8
MSSIgx	129.2	208.0	−13.7	34.7	5.81	304	4.8	3.2	−0.6
MSSJJt	132.1	211.4	−15.5	43.1	2.07	316	1.4	1.5	5.2
MSSJKO	133.9	217.8	−19.0	37.8	5.08	114	−4.6	−2.1	5.4
MSSJKT	133.9	210.6	−18.8	39.6	2.86	231	2.2	−1.8	4.8
MSSJLN	134.0	209.6	−16.1	16.9	3.34	285	3.2	0.8	5.3
MSSJLQ	134.0	210.9	−17.2	42.5	1.99	264	2.0	−0.2	4.3
MSSJLc	134.0	211.0	−18.8	40.8	2.61	225	1.9	−1.8	4.2
MSSJMW	134.9	209.7	−18.5	41.6	3.45	244	3.1	−1.5	4.8
MSSJMp	134.9	216.1	−18.3	16.9	3.24	114	−3.0	−1.3	5.6

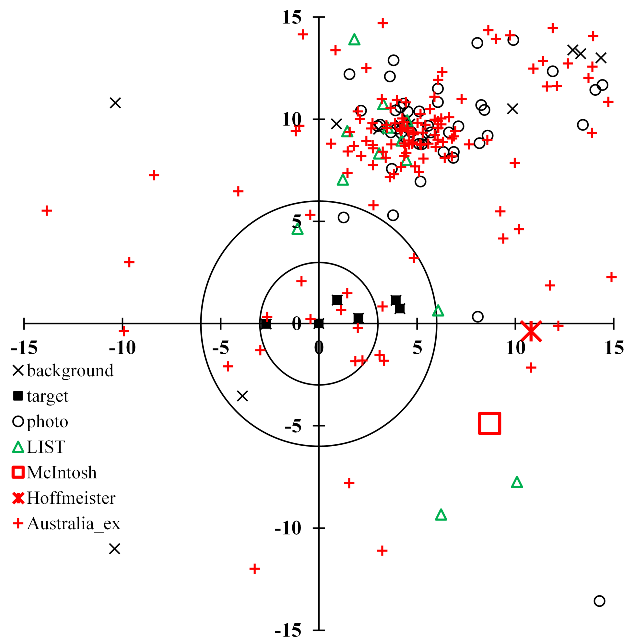

Figure 4 – Radiant distribution centred at #0183PAU01 showing II observations obtained in Australia (pluses as Australia_ex) with comparison data. Black boxes (target) are PAUs and crosses (background) are other entries in the SD. Triangles (LIST) show the meteor showers not included in the SD.

only the brighter meteors but also the fainter meteors which are detected by radar suggest that this shower is active from $\lambda_s > 125°$ and reaches its maximum around $\lambda_s > 135°$.

Circles in Figure 4 show photographic radiants and they scatter around the δ-Aquariid (SDA) radiant. The nearest photographic radiant to the center $(x, y) = (1.3, 5.2)$ is determined by a graphical reduction and it should be classified as SDA.

Triangles (LIST) in Figure 4 represent other sources excluded in the SD, though $(x, y) = (6.1, 0.7)$ is K1-99 (Table 2) and $(x, y) = (10.1, -7.7)$ is K1-100 (Table 2). The triangle $(x, y) = (-1.1, 4.6)$ seems to be a candidate for a member of PAU and this is Nilsson's radar observation 61.7.3 which he noted as Southern ι-Aquarids (Nilsson, 1964). It may be suggested that his observations are a mixture of SDA and PAU meteors because $\lambda_s = 125\overset{\circ}{.}5$ (B1950.0).

4 Discussion

We cannot find the trace of the classical Piscis Austrinids in photo and video data. Hoffmeister (1948) himself wrote on p. 89–90: Nr. 11 ($\lambda s = 127°$, $\alpha = 337°$, $\delta = -28°$). "After a careful check of the charts, I could not decide to postulate the 'Piscis-Austrinids' as an independent shower. I rather concluded that the meteors from this region should be associated with the extended strewn field of the July Aquarids which are active at the same time." (translation by courtesy of Jürgen Rendtel).

Hoffmeister added in his summary of the chapter, on p. 93: "The Piscis Austrinids of July and August, being regarded here as a branch of the δ Aquarids."

5 Conclusions

In our data, we find weak activity from a radiant some 10 degrees east of the "classical Piscis Austrinids" and about 10 degrees later in solar longitude than usually given (corresponding to August 8 rather than July 28), indicating that the PAU as listed e.g. in the Meteor Shower Calendar is not presently active. Video observations show that the radiant point moves northeastwards and locates in Aquarius at the maximum $\lambda s = 135°$. It seems natural this activity should be designated by a nearby star, such as b^1 (or 98)-Aquarii, for example.

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Handling Editor: Jürgen Rendtel

Hyperbolic meteors: is CNEOS 2014-01-08 interstellar?

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In 2019 a claim was made that the CNEOS 2014-01-08 meteor is interstellar. However, apparent interstellar meteors have been detected for decades. Moreover, they are expected from any meteor observation survey, as a natural consequence of measurement error propagation. Here we examine if enough scientific data were published to identify the orbital and physical nature of CNEOS 2014-01-08. Given the lack of proof regarding the accuracy of the observation, the derivation of the trajectory, velocity and tensile strength, and given the current state of meteor observations and reduction tools, we find no scientific ground to conclude about the interstellar orbit nor the physical properties of CNEOS 2014-01-08. Moreover, given the current data release of this object, to find any piece at the bottom of the ocean seems extremely unlikely.

Received 2022 October 4

1 Introduction

At the time this article is written (late 2022), several announcements claiming that the meteor CNEOS 2014-01-08 observed by "US sensors" (likely those described in Brownet al., 1996) is of interstellar origin (Siraj & Loeb, 2019; Siraj & Loeb, 2022). However, the scientific community has not validated this claim, mainly for lack of scientific evidence. Only an analyst at the US Department of Defense declared that the accuracy of the data is good enough to confirm the interstellar origin. However, the data acquisition and reduction process are not described, preventing anyone from building on such a claim.

The goal of this article is first to provide the reader with the basics of meteor science, and to examine if enough scientific proof are available to derive a hyperbolic nature of the CNEOS 2014-01-08 object. This work is based on a web page published in late Aug. 2022[a], and is intended to be accessible to non-meteor specialists as well as the general public. We do not exclude that future scientific proof regarding CNEOS 2014-01-08 may change the conclusions presented here.

2 Introduction to meteor science and optical observations

2.1 Basics of meteor phenomena

When a meteoroid (small rock in the interplanetary space) enters the Earth atmosphere, it hits the air molecules (Ceplecha et al., 1998). The energy involved in this process is so high that atoms are excited. The disexcitement process involves the emission of light, (often) detectable by the naked eye as a meteor (a.k.a. a "shooting star"). Usual meteoroid top of the atmosphere velocity is comprised between 11 km/s (caused by Earth gravity) and ~ 72 km/s (the heliocentric hyperbolic limit). Meteors usually start at an altitude of $\sim 100(\pm 20)$ km. The end point depends on the size and velocity of the initial meteoroid. Meteorite falls are associated with bright meteors (fireballs). As a rule of thumb, if the initial meteoroid is large and slow enough, and is still visible at "low" altitude (typically < 30 km), the possibility of a meteorite fall is real. However, a fireball does not necessarily lead to meteorite fall. Any "fast" meteoroid (typically > 40 km/s) has nearly zero chance to survive the atmosphere entry, simply because the shock with the atmosphere is too violent, making the ablation and fragmentation process extremely efficient. In short: the fastest the meteoroid is, the less likely it is to survive.

2.2 Optical meteor Observations

Current and widely spread method to observe the meteors is to set up at least 2 cameras, pointing towards a similar portion of the atmosphere, able to detect the same meteor from two different sites which are at least 30 km away from each other (Koten et al., 2019). This allows, after thorough and careful calculations, the 3D-trajectory to be computed. From this trajectory, provided the data are time-resolved, the velocity can be derived.

2.3 Velocity

Deriving a meteor velocity and quantifying the velocity accuracy is difficult. The reasons are numerous. First, any position measurement has errors. If one computes the velocity from 2 consecutive positions, the spread in the velocity will necessarily be extremely high. The reason is simply because $v = d/t$, with d being the distance between 2 positions: any position measurement error will induce a high velocity error. Another reason is that the geometry is different from one camera to the other. Suppose the meteor appear above camera 1: this camera will detect the meteor before camera 2 because camera 2 is farther away from the meteor. Suppose now that the meteor is travelling towards camera 2: instead of detecting a moving object, the camera will see a single point which increases and decreases in brightness, making deriving a 3D trajectory impossible, as well as the velocity. Regarding software data analysis, recent studies (see Section 2.4) have shown that the velocity accuracy directly depends on the method used to compute it (Egal et al., 2017; Vida et al., 2018). Finally, remember that the meteoroid velocity decreases along its path, because of the friction with the atmosphere molecules.

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IMO bibcode WGN-505-vaubaillon-interstellar
NASA-ADS bibcode 2022JIMO...50..140V

[a]`https://www.imcce.fr/recherche/equipes/pegase/hypermeteor`

Long story short: the derivation of a meteor velocity is an extremely complicated process that required 2 PhDs in the recent years to tackle (see Egal et al. 2017; Vida et al. 2018). Most accurate instruments, dedicated to meteor velocity measurements provide at best, depending on the meteor and camera geometry (see previous paragraph), m.s^{-1} accuracy velocity (Borovička et al., 2007; Egal et al., 2017; Vida et al., 2021). Several tens of m.s^{-1} accuracy is expected from lower resolution instruments (time and space) (SonotaCo, 2009; Kornoš et al., 2014; Colas et al., 2020). Remember also that the meteoroid is constantly decelerating during its flight in the atmosphere (see Section 2.1).

2.4 From Velocity to Orbit

The derivation of a meteoroid orbit from its derived velocity is another complicated problem. This can be done analytically or numerically, and a comparison by (Clark & Wiegert, 2011) between the 2 methods shows that, in most cases, the analytical approach is correct.

However, when publishing an orbit (usually as Keplerian osculating elements), the epoch for which these elements are provided matters. Indeed, because of gravitational perturbations, any orbit in interplanetary space (slightly but) constantly changes. In particular, for an apparent hyperbolic meteor, its past orbit might simply have been perturbed by Jupiter (known to kick small bodies out of the Solar System): this does not mean it comes from another planetary system (see also e.g. Wiegert, 2014).

2.5 Hyperbolic Meteors

Hyperbolic meteors were detected long ago: a quick search shows that such meteors were detected several decades ago (Almond et al., 1951; Almond et al., 1952; Hajduková et al., 2019). In other words, CNEOS 2014-01-08 is not the first (apparent) interstellar meteoroid.

Even more, hyperbolic meteors are expected from any observation set: given the meteor position and velocity uncertainty (see above), any meteor orbit survey program (for a review, see Koten et al., 2019) will produce data containing apparent hyperbolic meteors. This is expected and perfectly normal, and is a natural consequence of measurement errors and error propagation given the method used to compute the velocity. The percentage of apparently hyperbolic meteors in a meteor orbit database is actually an indicator of the real accuracy a network (hardware, method + reduction pipeline) provides (Hajdukova, 1994; Hajduková et al., 2017).

Another reason is the extremely fine line between a high eccentricity orbit and a hyperbolic orbit: suppose a meteoroid comes from the end of the Solar System (let us say from a region close to Pluto). Its velocity as measured as a meteor in the Earth atmosphere will be "high" (typically > 30 km/s, depending on the orbital geometry): this is a simple consequence of the gravitation. Suppose now that an interstellar meteoroid coming from outside the Solar System at nearly zero velocity (at infinity): it will also show a "high" velocity. The difference between the two velocities might be less than 0.1 km/s. Again, given the uncertainties in deriving the velocity, it is expected that apparent hyperbolic meteors are measured from any meteor orbit survey. Remember also that the meteor samples the trajectory over a few dozen km, while the whole orbit might bring the meteoroid several hundred millions of kilometres from the Earth. In other words, we sample an extremely tiny portion of the meteoroid orbit, and the slightest error on the velocity makes it appear either bound or unbound (i.e. hyperbolic).

For a full review of the problem of apparently hyperbolic meteors, see e.g. Hajdukova et al. (2019) and Hajdukova et al. (2020).

3 Is CNEOS 2014-01-08 peculiar?

3.1 Orbit: is CNEOS 2014-01-08 interstellar?

In order to establish the hyperbolic (interstellar) character of CNEOS 2014-01-08, it would be necessary to provide at the very least:

- The accuracy of the measurement.
- The method used for the computation of the velocity.

The measurements were performed by the classified "U.S. Government sensors", about which little is known, except that there are visible wavelength detectors. Any such satellite likely orbit at an altitude higher than 200 km (otherwise, the orbit decay would make it unstable). Since meteors occur at 100 km of altitude, the physical distance between the sensor and the meteor is at least similar than any ground-based network. The space resolution has to be at least equivalent to that of the best meteor camera resolution (which is 1 arcsec, see Vida et al., 2021). Similarly, the frame rate must be at least comparable to ground meteor cameras, i.e. at least 25 fps (or combined with another sensor, see Brown et al., 1996). Given the performance of modern optics and sensors, to build a space satellite showing such performances is likely. In order to perform 3D measurement of the position and velocity, at least 2 satellites were used. The overall geometry matters in this case (as seen in sec. 2.3). Last but not least, the very method used to derive the velocity matters when one wants to compute an accurate meteor velocity.

Unfortunately, none of the space and time resolution, number and geometry of the detection, nor the very method used to compute the trajectory, velocity and orbit of CNEOS 2014-01-08 are provided. As a consequence, there is no proof that the data are sufficiently accurate to indicate an interstellar trajectory. There is no proof that CNEOS 2014-01-08 is interstellar: its apparently hyperbolic orbit might simply reflect the influence of measurement uncertainty, as expected from any meteor observation, and as reported for the past few decades. The real velocity error can easily be of several km.s^{-1}. This would challenge the results of a study based on a ~ 1 km.s^{-1} accuracy.

3.2 Nature: is CNEOS 2014-01-08 of high density?

The light curve of a meteoroid allows one to derive its mass (see Section 2.1). Spikes in the light curve allow the meteor scientists to derive its tensile strength, thanks to the $\rho\ V^2$ equation. However, the velocity considered here is not the initial velocity: this is the velocity at the time of the light curve spike. Usually, for "large" (dm scale) object, such spike occurs when the meteoroid is "low" in the atmosphere (typically below 50 km of altitude). By then, it has lost quite an amount of velocity, because it is now entering the densest part of the atmosphere. In order to derive a tensile strength, it is therefore necessary to consider the velocity change along the 3D-trajectory.

In order to derive the tensile strength of CNEOS 2014-01-08, it would be necessary to consider the velocity change along its trajectory, and consider its velocity at the time of the light curve spike. Unfortunately, no velocity change curve is provided by CNEOS. In all cases, the velocity of CNEOS 2014-01-08 below 30 km of altitude is necessary smaller than the initial velocity at the top of the atmosphere. As a consequence, there is no proof that CNEOS 2014-01-08 is of high density (or tensile strength).

Regarding the mass: in absence of velocity curve, the dynamic mass (or size) of CNEOS 2014-01-08 cannot be derived. The photometric mass assumes a luminous efficiency τ. Given the latest estimates, a value of τ greater than 5% is unlikely (but more works are needed to constrain this parameter). Usually, comparing the dynamic and photometric mass allows scientists to put boundaries on possible mass and size of the meteoroids. An accuracy of a factor of 2 or 3 in mass estimate is perceived as a good estimate. As a consequence, given the data publicly available for CNEOS 2014-01-08, an accuracy of a factor of 10 or more in the mass estimate is plausible.

3.3 Is it possible to recover pieces of CNEOS 2014-01-08?

According to CNEOS, CNEOS 2014-01-08 fell near the northeast coast of Papua New Guinea, i.e. in the ocean. If the initial velocity derived by CNEOS is correct (44.8 km/s), then the chances of atmospheric survival is small, since the faster the meteoroid is, the less likely it is to survive the atmosphere entry (see Section 2.1). If the initial meteoroid experienced 3 fragmentation events above 20 km of altitude (which is likely given the measured light curve) then a significant fraction of mass was lost during each event.

Suppose a least one fragment made it to the bottom of the ocean: the probability to recover it is also very low. The search of meteorites on dry land proves to be extremely challenging: the search area is often very large, and even teams of more than 10 people may fail at finding anything, unless very accurate measurements and searches are performed or we have the best luck ever. The only case a meteorite was found at the bottom of a lake was Chelyabinsk in 2013, because the very location of the impact was perfectly known since it fell during the winter and made a hole in the ice of a frozen lake. Russian scientists did wait for the (warmer) spring to dive and recovered a 50 cm piece of meteorite.

Therefore, is seems very unlikely to recover a piece of CNEOS 2014-01-08 at the bottom of the ocean.

4 Conclusion

Given the lack of proof regarding the accuracy of the observation, the derivation of the trajectory, velocity and tensile strength, and given the current state of meteor observations and reduction tools, we find no scientific ground to conclude about the interstellar orbit nor the physical properties of CNEOS 2014-01-08. Moreover, given the current data release of this object, to find any piece at the bottom of the ocean seems extremely unlikely.

Acknowledgements

The author is thankful to IMO and WGN for promoting meteor science.

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Handling Editor: Javor Kac
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Notes on a series of meteor observations

Glenn Hughes[1]

A road trip across the Australian Outback is combined with viewings of meteors including primarily the ETA and with a bonus of the TAU outburst.

Received 2022 August 21

Following 2 years of COVID lockdowns in various states my wife and I set off from Sydney on a postponed trip to the Australian Savannah. This was to coincide with the dry season and hopefully be relatively cloudless, pleasantly warm and puncture free on the rough Outback roads. As you will read, the meteorology made for good meteor observations, gave a wide range of temps but still threw in a few curve balls.

Departing Sydney on April 13th for what turned out to be a 78 day adventure, the moon was nearing full in the evening sky but alas a dark pre-dawn window was fogged out. A morning later in the small town of Inverell 7 SPO and 1 ANT were seen in slightly light polluted skies. Dwelling in Sydney, a city of 5 million my LM is 5 to 5.5 at best so this trip was going to be a treat.

A week after departure we parked our van at the midge ridden Chinchilla Weir, our appendages would show a 2 week testament to the bites we got. The evening sky was now moon free with 5 SPO and 2 ANT seen in 40 mins. Two nights later at the melodic Angallala railway bridge a one hour session resulted in 18 of which 6 were ANT. The next morning was the LYR max but only 1 was seen with 5 SPO in an hour. Blame can be apportioned to a 3rd quarter moon being overhead and the radiant elevation being equal to the latitude at 26 degrees.

Figure 1 – Blackall.

Checking the satellite photos now revealed an unseasonal cloud mass with heavy rain forecast in Central Queensland. The heavens opened with 125 mm in 24 hours – see Blackall pic (Figure 1). All dirt roads on the black soil plains turned to mud and were closed. But such was the runoff that the tar Landsborough Hwy was flooded by several creeks and we were stuck in Blackall for 2 days. I was dressed for 36°C and it was only 16°C but the heat and humidity would soon return.

Arriving in Longreach on the 27^{th}, caravans were parked everywhere, trees were down after wind gusts of 90 km/h and there were a lot of stranded grey nomads. The road to the NW opened at 4 pm but we decided to stay just out of town, breaking the rule of never camp near a busy highway. It proved to be a noisy night. However the skies had cleared and my first ETA for 2022 was seen along with 12 SPO.

It was now 9 days until the predicted ETA max on May 6^{th} at 08^{h} UT making it 5.30 pm CST in the NT. My observing windows would be 12 hours either side i.e. the mornings of the 6^{th} and 7^{th}. So the trip continued with daytime temps back into the mid 30's but with unseasonal humidity. NW Queensland is essentially flat with little of consequence with any relief. It's hardly the Rockies nor the Alps but even a mesa 100 m above the plains will give the illusion of being a decent mountain (Figure 2).

Figure 2 – A mesa above the plains.

Approaching Cloncurry the landscape changes with genuine mountains by Australian standards, with curves and gradients on the route to Mt Isa. Why, the road elevation may have just cracked 400 m!

Changes in latitude, changes in attitude

Sydney daylight length at departure was $11^{\text{h}}17^{\text{m}}$ reducing by 15 minutes/week. By May 1^{st} it would be $10^{\text{h}}47^{\text{m}}$ but now at our lower latitude $-19°$ it was $11^{\text{h}}24^{\text{m}}$ – a gain of 7 minutes over when we left. At the Qld/NT border one is 12° west of the 150° E meridian of the EST zone, making local noon at nearly $12^{\text{h}}50^{\text{m}}$.

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IMO bibcode WGN-505-hughes-trip
NASA-ADS bibcode 2022JIMO...50..144H

Figure 3 – Approaching Cloncurry.

Sunrise is accordingly 48 minutes later. This is a bonus for the meteor observer. 80 minutes can be spent from 4 am til dawn, allowing one to then catch up on lost metabolism repair with a sleep in til 8 am. Further action to prevent compromise of the immune system was provided by an afternoon siesta.

On April 30$^{\text{th}}$ we left Mt Isa and headed W then N to Lawn Hill NP. For two and a half weeks we had been tar-huggers, avoiding the dirt. The bitumen is black gold when you get back onto it. That was ahead of us, now we began 1500 km of dirt. In Australia you can be Beyond the Black Stump in the Outback all the way to the Red Centre. Driving on dirt creates clouds of fine pink dust. The car cabin must be pressurised so the dust is not sucked in. The van has a scupper vent on the roof to accomplish the same effect. Leave a window down an inch and soon you can taste, see, smell and feel the dust which coats everything electrostatically. All par for outback travel (Figure 4).

Figure 4 – Outback driving.

As you physicists know $KE = \frac{1}{2}mv^2$ so the energy of a sharp rock on a tire is less by a factor of the square of the speed reduction. Slowing from 100 km/h on tar to 80 km/h on dirt means 2/3 the KE and down to 70 clicks will halve the energy and thereby the force from the dreaded corrugations or washboards in the US. Tire pressures were also reduced on the car from 32 psi down to 28.

Lead up to the Lorella sessions

The ETA were slowly cranking up in superb skies. Evenings had the indigenous Emu easy to see as the population density is insignificant so there's effectively zero light pollution. The ecliptic was near vertical in the mornings so the zodiacal light was impressive. Late April gave the Venus-Jupiter conjunction. We had travelled 15° north in latitude. Evenings had the Big Dipper on the meridian well clear of the horizon. Alkaid was now at 21° altitude instead of 6° at home. It was nice to record a meteor ending in Draco or Cepheus. That cannot happen in Sydney.

Morning observations were made for 17 consecutive days. I'd never done anything similar before. The 4 minute difference between the sidereal and synodic day turned into over an hour and constellations rose up out of the dawn twilight. I got that sense of Earth orbiting the sun, day by day all that 30 km/s adds up. Venus passed Jupiter and ticked along at a degree a day while Mars neared the gas giant at half that speed.

We spent 7 nights on the million acre Lorella Springs Station. Once raising cattle, it is now a tourist attraction with over 70 points of interest including warm artesian pools, 4WD tracks, bushwalks, fishing and camping (Figures 5 and 6).

Figure 5 – Campsite at Lorella Springs.

A few evenings were partly cloudy but by 4 am it was cloudless. The overly bright Venus and Jupiter could be blocked with a leafy branch. Temps were around 20°, bugs were few and the ETA delivered. 243 were seen with 40 on the 5$^{\text{th}}$, 36 hours before the max and 37 on the 8$^{\text{th}}$, 36 hours after max. The table below makes adjustment for observation duration. Mostly it was 80 minutes.

Figure 6 – Nanny's retreat swimming hole.

Figure 7 – Train.

DATE	No. ETA	ETA/hour
27/4	1	0.8
28/4	1	1.2
29/4	2	1.5
30/4	4	2.4
1/5	5	3
2/5	7	5.3
3/5	13	9.8
4/5	22	16.5
5/5	40	24
6/5	19	11.4
7/5	19	19
8/5	37	27.8
9/5	22	16.5
10/5	18	13.5
11/5	14	10.5
12/5	13	9.8
13/5	6	4

Figure 8 – Lava tube.

The ETA were over, the moon in the morning sky so observations were put on hold but resumed under a moon 5 days before new. Only a week until the TAH. And so 1500 km later after a ride on the Gulflander train – vintage 1950's suspension-arghh (Figure 7), a tour through some lava tubes at Undara (Figure 8) and a dip in the Innot Hot Springs – 71° so add cold, we arrived in Queenland's highest town, Ravenshoe – 930 m.

The TAH max was at 3 pm local on May 31st. This was 4 hours before dark at 7 pm when observations began. Almost immediately I saw a nice mag 1 TAU below Arcturus i.e. 10° north and of similar colour. This proved to be the best of six more seen over 75 minutes. It wasn't Texas but was still nice to be part of history. `https://www.imo.net/members/imo_vmdb/view?session_id=84051`

June began, the official start of winter in Australia. Attempts to observe the ARI proved fruitless with only one seen despite the North Queensland latitude being more favourable than home. SPO meteor numbers waxed and waned as usual and the final June sessions along the Queensland coast were intermittent due to the usual variables of cloud and moonlight. Next year 20th April is the TSE in Western Australia, a 5500 km drive across the continent with clear dark skies in the deserts. Well, that's the plan.

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include METEOR in the e-mail subject line

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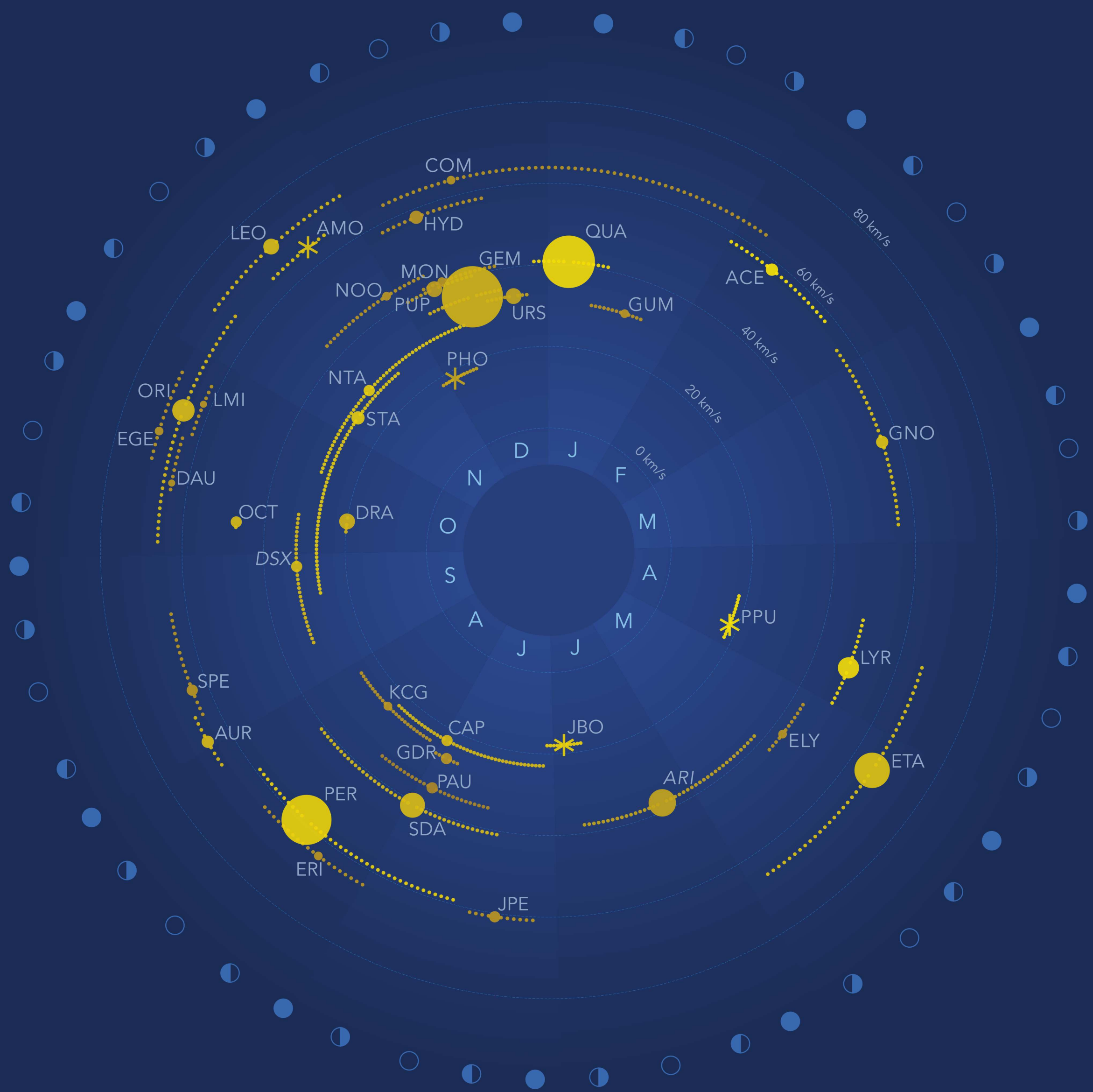
2023 METEOR SHOWER CALENDAR



Shower days

Peak day of an annual recurring event

* Peak day of a non annual recurring event

· Not a peak day of any event

Shower brightness

Fainter Brighter

Lunar phases

Meteor frequency

The zenithal hourly rate (ZHR) is the shower rate in optimum observing conditions (number of meteor per hour during peak activity).

150
50
10

Shower names (Italics is for daytime meteor showers.)

ACE	alpha-Centaurids	ELY	eta-Lyrids	KCG	kappa-Cygnids	PER	Perseids
AMO	alpha-Monocerotids	ERI	eta-Eridanids	LEO	Leonids	PHO	Pheonicids
ARI	*Daytime Arietids*	ETA	eta-Aquariids	LMI	Leonis Minorids	PPU	pi-Puppids
AUR	Aurigids	GDR	July gamma-Draconids	LYR	Lyrids	PUP	Puppid-Velids
CAP	alpha-Capricornids	GEM	Geminids	MON	Monocerotids	QUA	Quadrantids
COM	Comae Berenicids	GNO	gamma-Normids	NOO	November Orionids	SDA	Southern delta-Aquariids
DAU	delta-Aurigids	GUM	gamma-Ursae Minorids	NTA	Northern Taurids	SPE	September epsilon-Perseids
DRA	Draconids	HYD	sigma-Hydrids	OCT	October Camelopardalids	STA	Southern Taurids
DSX	*Daytime Sextantids*	JBO	June Bootids	ORI	Orionids	URS	Ursids
EGE	epsilon-Geminids	JPE	July Pegasids	PAU	Piscis Austrinids		

SOURCES: INTERNATIONAL METEOR ORGANIZATION, AMERICAN METEOR SOCIETY

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