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Contents

1 Predicted Meteorite Impacts

1.1 The true story of the discovery of European Imminent Impactors

Krisztián Sárneczky

The 60/90/180 cm Schmidt telescope of the Konkoly Observatory, located at the Piszkéstető Mountain Station in Hungary, has always been a discovery machine. In the first three decades of operations as a photographic instrument, it has resulted in the discovery of 47 supernovae, five comets and one NEO. The photographic plates were replaced by CCD cameras in the late 1990s, and in the last six years we performed an upgrade that led to a 9 square degrees field of view. With this upgrade and new observing strategies, we have discovered nearly 150 NEOs during three years. Two of these, 2022 EB5 and 2023 CX1, reached our planet's atmosphere within hours of their discovery. They were the fifth and seventh known imminent impactors, but 2023 CX1, which landed in Normandy, was only the third to have fragments found.

1.2 Recovery and ongoing study of the Saint-Pierre-le-Viger Meteorite, a fragment of the 2023 CX1 Asteroid: an achievement of the FRIPON Camera Network and the Vigie Ciel Citizen Science Program (part 1)

F. Colas, B. Zanda, A. Égal, A. Steinhausser, S. Bouley, L. Ferrière, D. Vida, H. Devillepoix, L. Maquet, K. Antier, P. Vernazza, A. Malgoyre, P. Sans-Jofre, J. Gattacceca, J. Vaubaillon, P. Jenniskens, I. Baziotis, M. Gounelle, and the FRIPON/Vigie-Ciel teams

Asteroid 2023 CX1 was discovered by Krisztián Sárneczky of Konkoly Observatory on Feb- ruary 12, 2023, only 7 hours before it encountered the Earth, which made it possible to track it and calcu- late its orbit very precisely. The potential strewnfield was determined in parallel by several groups and soon well defined and published (e.g. https://www.imo.net/the-atmospheric-trajectory-of-2023-cx1-and-the-possible-meteorite-strewn-field/).

1.3 Recovery and ongoing study of the Saint-Pierre-le-Viger Meteorite, a fragment of the 2023 CX1 Asteroid: an achievement of the FRIPON Camera Network and the Vigie Ciel Citizen Science Program (part 2)

F. Colas, B. Zanda, A. Égal, A. Steinhausser, S. Bouley, L. Ferrière, D. Vida, H. Devillepoix, L. Maquet, K. Antier, P. Vernazza, A. Malgoyre, P. Sans-Jofre, J. Gattacceca, J. Vaubaillon, P. Jenniskens, I. Baziotis, M. Gounelle, and the FRIPON/Vigie-Ciel teams

Recovery and ongoing study of the Saint-Pierre-le-Viger meteorite, a fragment of asteroid 2023 CX1. The recovery of this meteorite is due to the combined efforts of the

FRIPON camera network and the Vigie-Ciel citizen science network.

The FRIPON/Vigie-ciel collaboration quickly mobilised its network to set up a field search. An initial team of researchers and amateur enthusiasts met up on the morning of February 15 in the fall zone identified by the international teams. On the programme: information for local residents access authorisations, meetings with mayors, scouting out favourable sites and initial field research. At 16:47 the eyes of Loïs Leblanc, an 18-year-old art school student and member of the team, were caught by a dark stone barely above ground in a field in the commune of Saint-Pierre-le-Viger (Seine Maritime), soon identified as the meteorite that was being searched for. The stone weighed 94g and, during the following days, 10 more stones, weighing between 2 and 24 grams, completed our harvest of extraterrestrial matter.

1.4 Imminent Impactors at ESA's Planetary Defence Office

Francisco Ocaña, Marco Micheli, Luca Conversi, Rainer Kresken, Dora Föhring

As part of the ESA's Planetary Defence Office, we monitor the likelihood of any possible impact by an NEO in the next 100 years. However, recently discovered objects (which are still listed as candidates in NEOCP) also pose an impact risk, often on significantly shorter timescales. We present a summary of the recent activities related to these Imminent Impactors carried out by the Observations pillar of the ESA's Planetary Defence Office. We introduce how we perform our observations of these objects, using a well-established global network of telescopes. We focus on the relevant aspects for the meteor community, showcasing the recent impact of 2023 CX1 over Normandy, France.

2 Radio Meteor Work

2.1 Advancements in the Radio Meteor Zoo aggregation algorithm

Stijn Calders, Hervé Lamy, Katrien Kolenberg

In August 2016, a collaborative effort between the BRAMS team and Zooniverse led to the inception of the Radio Meteor Zoo (http://www.radiometeorzoo.org) citizen science project. This initiative was established with the recognition that during meteor showers, the presence of overdense meteor echoes often generates intricate patterns in spectrograms. Given the complexity of these phenomena, human visual analysis remains unparalleled in effectively identifying these unique signatures.

To ensure a high level of accuracy, each spectrogram is independently analyzed by ten different citizen scientists. An aggregation algorithm, specifically designed for this project, considers regions identified by the majority of citizen scientists as genuine meteor signatures, thereby significantly enhancing the reliability of the classification results. The outcomes of this effort were presented at the IMC in the Netherlands back in 2016.

While the current aggregation algorithm successfully identifies genuine meteor signatures, it faces two key challenges. Firstly, the algorithm tends to generate large bounding regions, encompassing multiple meteors, thus requiring further refinement. Secondly, the classification process operates at a uniform pace, regardless of the expertise level of citizen scientists, leading to suboptimal efficiency. To address these limitations, this presentation will propose and discuss a set of targeted improvements to the aggregation algorithm, optimizing its accuracy and efficiency.

2.2 Transverse scatter meteor radar observations and full wave scattering modeling of polarization effects and trail evolution for various collision frequencies

Gunter Stober, Robert Weryk, Diego Janches, Erin Dawkins, Florian Günzkofer, J.D. Carrillo-Sánchez, J.L. Hormaechea, Florian Günzkofer, Dimitry Pokhotelov

Transverse scatter meteor radars have become a standard tool to observe the meteor Earth's environment. Meteoroids entering the Earth's atmosphere are decelerated and heated by collisions with atmospheric atoms and molecules and those with sufficient kinetic energy start to ablate and form an ambipolar diffusing plasma trail that is detectable by these radars. In this study, we present full wave scatter simulations and observations from the SAAMER-OS meteor radar in Southern Argentina and the Canadian Meteor Orbit Radar (CMOR) to analyze quantitatively the electron line density, initial trail radius, and ambipolar diffusion coefficient. Furthermore, we demonstrate the impact of altitude-dependent collision frequencies and the corresponding polarization effects. We can show that polarization measurements are equivalent to the triple-frequency measurements obtained from CMOR. We performed also a comparison to

the classical theory for underdense meteors from Kaiser and Closs 1953.

2.3 A new radar meteor head echo analysis algorithm and its application on MU-radar high altitude meteor detections

Daniel Kastinen, Johan Kero

We have developed an automated radar data analysis algorithm that is capable of calculating probability distributions of meteor- and meteoroid parameters for head echoes detected with interferometric radar systems. We have applied the analysis on data from the Middle and Upper atmosphere (MU) radar in Shigaraki, Japan. The algorithm utilizes direct Monte Carlo simulations of signal processing uncertainties, with Bayesian Markov-Chain Monte Carlo (MCMC) estimation of meteor model parameters, and N-body propagation of distributions to perform orbit determination. The probability distributions provide quantitative reliability and enables improved statistical studies and advanced further investigations of individual events.

As a first application, we have re-analysed part of the MU radar meteor head echo data set collected during 2009–2010 and confirmed the existence of a rare high-altitude radar meteor population reaching up to $\sim$150 km altitude. The number of detections decreases significantly as a function of initial altitude. Out of the total amount of 106 000 events, 74 had an initial altitude $>$130 km while four of those had an initial altitude $>$145 km. Due to the experimental set-up for the used data-set the maximum detectable range was limited to 148 km. Hence, we cannot confirm or deny the existence of radar meteors above that altitude.

We are currently working on an open-source version of the algorithm as well as generalising many of the implementations, e.g. to allow for application on multi-station radar system data. The concepts are applicable on a wide range of possible meteor analysis pipelines and the code itself is directly applicable on head echo measurements with other radar systems.

2.4 MU radar head echo observations of the January zeta Leonids

Johan Kero, Daniel Kastinen, Peter Jenniskens, Shinsuke Abe, Takuji Nakamura

A database of meteor detections has previously been created using an automated analysis scheme for meteor head echo observations by the 1 MW, 46.5 MHz, interferometric, Middle and Upper atmosphere (MU) radar near Shigaraki, Japan. The data consists of monthly meteor observation campaigns 2009-2010, each time period covering typically one or a few diurnal cycles, but also additional campaigns performed later mainly during selected meteor showers. A recent further development of the automated radar data analysis algorithm enables calculating probability distributions of meteor- and meteoroid parameters for individual head echoes.

An investigation of meteor shower occurrences in the database has revealed a new meteor shower based on 14 individually detected meteors in January 2014, that has been named January zeta Leonids [JZL]. We present a brief overview of the MU radar

head echo observation technique together with the radiant distributions and velocity profiles for the observed JZL meteors. We also present the probability distributions of their trajectories and orbits, in order to characterize how well we are able to constrain the meteor shower and meteoroid stream with the currently available MU data and enable searching other data for related outbursts.

2.5 Status and perspectives of the BRAMS network

Hervé Lamy, Michel Anciaux, Joachim Balis, Antoine Calegaro, Stijn Calders

The Belgian RAdio Meteor Stations (BRAMS) network is a meteor radio forward scatter network. It is made of a dedicated beacon and currently nearly 50 receiving stations located in Belgium and neighboring countries. The project started at the end of 2010 but has lately reached a higher level of maturity. A recent funding obtained in 2023 will allow us to expand and upgrade the network. We will describe the current status of the BRAMS network and present the upcoming changes planned for the coming 2 years (new interferometer, new transmitter, more stations). We will also summarize briefly our efforts in calibrating the network and their importance for future applications (trajectory, ionization curves, observability function, . . .).

2.6 Phase-enhanced trajectory and speed reconstruction of meteoroids using BRAMS data

Joachim Balis, Hervé Lamy, Michel Anciaux, Emmanuel Jehin

In this project, we aim to reconstruct meteoroid trajectories thanks to a forward scatter radio system using a pure continuous wave (CW) transmitted signal with no modulation. To do so, we use the meteor echoes recorded at the receivers of the BRAMS (Belgian RAdio Meteor Stations) network. The latter is made of a dedicated transmitter and currently 48 receiving stations located in and nearby Belgium, all synchronized using GPS clocks.

Our approach processes the signals recorded at the BRAMS receivers and uses the time delays between the meteor echoes as inputs to a nonlinear optimization solver. We compare the quality of our reconstructions data to the trajectories given by the optical CAMS (Cameras for Allsky Meteor Surveillance) network in Benelux. To do so, we solve the general CW forward scatter trajectory reconstruction problem, but we highlight its strong ill-conditioning if the only inputs are the time delays of the echoes at the receivers.

To obtain a better accuracy for a large number of meteoroids, the time delays are complemented by information about the signal phase. The approach used for this work is based on the pre-t0 phase technique introduced for backscatter radars. In this project, we extend and adapt the method to forward scatter systems and we illustrate the improved accuracy that it brings on the meteoroid trajectory and speed reconstruction.

2.7 Radio meteor echoes observation with SPADE

Déborah Mouhaou, Antonio Martínez Picar, Christophe Marqué, Akhil Gunessee

The Small Phased-Array DEmonstrator (SPADE) hardware, installed at the Humain Radio-Astronomy Station, has undergone independent antenna tests, obtaining successful radio meteor echo detections. Although the full phased-array operation remains pending commissioning, a preliminary configuration is proposed. By combining all antenna element signals without phase manipulation, a zenith-oriented beam can be achieved. This configuration proves suitable for detecting radio meteor echoes from the BRAMS transmitter in Dourbes via the forward-scatter principle. The SPADE system's gradual enhancement will allow the observation of radio meteor echoes with increased precision and sensitivity.

3 Online Meteor Work

3.1 System overview and the systematic analysis of the Taiwan Meteor Detector System (TMDS)

Zhong-Yi Lin, J. Lee, C.-H. Lin, C.-H. Chi, W.-H. Ip

An overview is provided of the first systematic analysis presented by TMDS, Taiwan Meteor Detector System. This is a network of five stations from Fushoushan, Hehuan, Qingjing Farm, Kenting observatory, and Lulin observatory in Taiwan that use UFO-Capture, UFOAnalyser, and UFOOrbit to capture and analyze meteor data. TMDS is intended to supplement the increasing number of comparable teams worldwide using similar networks. Many of these networks have been established to ascertain if the suspected meteor showers listed on the International Astronomical Union's Meteor Data Center exist and, if so, determine if they can be associated with known parent bodies. This paper describes the equipment used and the techniques employed to collect and analyze the data. The results from 2017 to 2023 are presented, with a specific focus is given on the most spectacular meteor showers of the year (e.q. Geminids meteor shower). These meteor showers are well-characterized and were selected to verify if the results from TMDS were consistent with currently accepted parameters.

3.2 Relative positions of the asteroid (3200) Phaethon and model Geminid stream orbits

Galina O. Ryabova

Recently Battams et al. (ApJ, 2022, 936, 81) reported detection of a dust trail observed near the orbit of the asteroid Phaethon by the instrument WISPR for the Parker Solar Probe satellite. The key finding of this work is a clear separation of the dust trail and the orbit of Phaethon as a function of true anomaly. Inspired by the work I decided to research into this situation using my numerical model of the Geminid meteoroid stream (Ryabova, MNRAS, 2016; Pl. Space Sci., 2022). The comparison with the orbits of the observed Geminids from the most precise video catalogues (Koten at al., 2003; Borovicka et al., 2022) and from the photographic catalogues of the IAU MDC is also planned. At present the work is underways.

3.3 CCD observations of Perseids 2022

Andrey Murtazov, Vyacheslav Zhabin

The results of Perseids-2022 CCD observations are presented

3.4 Classification of fresh impact sites on Mars

Elena Podobnaya, Olga Popova, Boris Ivanov, Dmitry Glazachev

On the Earth, meteoroids up to 10 m in scale are usually observed during a short flight through the atmosphere; most of their mass remains in the atmosphere due to disintegration and ablation, and, in rare cases, their fragments can be found as meteorites. On Mars, similar objects would lead to the formation of craters or crater clusters due to more rarefied martian atmosphere. The density of the atmosphere near the Mars surface corresponds to about 30 km altitude in the terrestrial atmosphere, so the consideration of crater fields on Mars allows us to study details of fragmentation which are undetectable in the Earth conditions. The properties of space objects are estimated from observational data within certain assumptions with not very high accuracy; the study of Martian clusters provides an opportunity to evaluate the properties of meteoroids independently. Previously, disintegration and formation of clusters on the planet surface were predicted for martian atmosphere. Later, fresh crater clusters were discovered. Daubar et al. (2022) published currently detailed data for about 1200 recent dated impact sites in 2022. These data include information about the size and location of craters in the cluster. We supplemented published catalog by 650 recent impact sites, and new data are permanently released by HiRISE project. Ivanov et al. in 2008 suggested to divide impact sites into 4 types based on small statistics available at that time (about 20 cases). First type (Type 0) combined single craters, pairs and clusters with one major crater and few (10) were marked as Type 1; other clusters refer to the Type 2, but densely populated clusters (with more than 400 craters) were marked as Type 3. This presentation will apply suggested classification to the essentially updated catalog and will discuss its applicability to the extended data. The research was supported by RSF (project No. 23-27-00432).

3.5 Sync Reception System Utilizing FM Broadcasting Signals

Hiroyuki Ohata

Several years ago, a commercial FM transmission antenna was installed on the ridge of Mt. Hiei, in the region where the authors reside. Radio waves from this transmitter can be received effectively in Kyoto city and its surrounding areas. Since the commercial FM radio waves can be treated as a non-repeating signal sequence, recording them simultaneously with meteor observation data as synchronization information allows for the construction of a simple system to synchronize multiple receivers.

4 Impacts, Meteorites, and Meteors

4.1 Lunar impact flashes - an update

Detlef Koschny

Since the last IMC, an Open Source tool for detecting impact flashes on the Moon is available. It is called 'Flash Detection Software (FDS)'. In this presentation, I will remind the audience why these observations are important to understand meteoroids. I will give results of the first usage of the FDS software. I will also report about an ESA mission called LUMIO, a Cubesat that will observe lunar impact flashes from 'behind' the Moon, to be launched in 2027.

4.2 Was this a meteoroid impact? Self-critical analysis of a visual moon observation with bare eyes on August 13, 2023

Peter C. Slansky

The PERAMIS project has the goal of detecting geometric and temporal microstructures in the radiant of the Perseids 2022. Velocity differences of the current meteoroids are assumed to be the main cause for spatial differentiations within the radiant. It is intended to detect mainly velocity-dependent microstructures within the radiant of the Perseids 2022. For this a sufficient number of successful video double-station observations had to be achieved with a spatial resolution of less than one arc minute and a temporal resolution of 25 fps (40 ms). This was done by two pairs of video cameras in UHD/4K resolution from the two observatories of the University of Bern, Switzerland, at Zimmerwald, 15 km South of Bern, and the Jungfraujoch High Altitude Observatory (3.574 m above sea level), 70 km South East of Bern. For meteor detection an AI-based software was developed at the University for Television and film Munich. In the talk the actual state of the project (work in progress) will be presented with first results as well as a brief evaluation of the video technology used.

4.3 Meteorite ablation spectra and their role in the meteoroid composition estimation

Veronika Pazderová, Pavol Matlovič, Adriana Pisarčíková

In addition to the analysis of meteor spectra, the research of the material composition of meteoroids can be significantly improved by the study of meteorite spectra obtained during the simulated ablation laboratory experiments. So far, such research revealed implications that suggest the existence of common spectral attributes shared by meteorites of the same (or similar) material groups. Our work focuses on the yet mostly unexplored possibility of the application of these results on the meteor spectra and the composition of meteoroids with asteroidal origin. Moreover, the described method may shed light on the typical features of asteroidal meteors that can potentially differ from

those belonging to cometary ones. This can be of particular importance in the study of meteor showers with known parent objects. Thus, this presentation will address the diagnostic procedure that covers the combination of meteor and meteorite spectra analysis, the spectral features of interest that we focus on, and the preliminary results we obtained to date.

4.4 Aerodynamics of the Broek in Waterland (L6) meteorite based on subsonic wind tunnel experiments

S.G.V.S. Aduru, S.J. de Vet

For several meteorite recoveries, the effect of aerodynamic forces acting on the meteorite during its dark flight have been suggested as the primary cause for the deviation between the predicted location in a strewn field and the actual recovery location. While assumptions for shape and drag are incorporated in existing models, we wondered if these are sufficient to represent the complex effects of aerodynamic effects in relation to a meteorite's shape. Here we present an experimental investigation of the aerodynamic behaviour performed in a low speed wind tunnel using a 3D printed meteorite model. The focus of these experiments was to quantify and analyse the aerodynamic effects on the Broek in Waterland meteorite during its travel in the atmosphere from the altitude of 10 kms until the meteorite touches ground. The meteorite model was scaled using the flow similarity principle on the basis of terminal velocities to create similar flow conditions experienced by the meteorite during its fall. The model was mounted on a six-component force balance, allowing us to measure forces and moments and derive the drag coefficients. We found a significant range in drag coefficient values for a single meteorite and identified that a finite amount of lift and side forces are experienced by the meteorite during its atmospheric flight. Similar experiments were carried out using a rotating model in the wind tunnel. We thus propose that when some orientation occurs during dark flight, side and lift forces will be able to influence the impact points. To illustrate these effect, the estimated drag coefficients and shape factors of Broek in Waterland were implemented in a dark flight simulation to study the influences on the impact points. Especially when breakup events create irregular shaped fragments, we expect deviations from strewn field predictions. For future meteorite finds that have dark flight models available, we propose to experimentally quantifying shapes and aerodynamic properties to use such object specific data for a sensitivity analysis and validation of dark flight modelling.

4.5 Delft Meteorite Lab: a virtual environment to explore meteorites and meteorwrongs

S.J. de Vet

Assessing and classifying rocks on the basis of their visual traits has been a long standing practise for geoscience fields. For planetary geoscience the interaction with astrogeological materials such as meteorites and impactites contributes to the comprehension of their properties, alteration and, ultimately, Solar System formation processes.

In the wake of the SARS-CoV-2 (COVID-19) pandemic we explored alternative options to involve meteorites and impactites in remote teaching. Simultaneously, this opened up the integration of meteorites in teaching activities for large groups of learners. We have developed a workflow using Structure from Motion (SfM) photogrammetry to render high-resolution digital 3-D models of meteorites and impact rocks. This procedure was used to create a virtual collection with tens of examples that were made publicly accessible in an online environment. The digital 3-D models can be inspected by rotating and zooming, while annotations in clickable pop-ups direct users to key features or provide background information and data. We evaluated the user experience and discuss how virtual collections can be created and used for blended learning. Meanwhile, we have explored the use of models in the 'Delft Meteorite Lab' in academic teaching, public outreach and science applications. The virtual collection also offers a potential resource to aid the identification of putative meteorite finds by the general public. Looking towards the future, a new 'Dutch Meteorite Lab' aims become a national hub for education and research to explore meteorites and meteorite taxonomy based on specimen available in various study collections across the Netherlands.

4.6 Reproducing meteors in wind tunnel: overview from N-UV to M-IR

J. Vaubaillon, S. Loehle, S. Rommeluere, J. Toth, P. Matlovic, A. Pisarcikova, D. Leiser, F. Grigat, M. Eberhart, F. Hufgard, R. Ravichandran, E. Poloni, I. Hoerner, C. Duernhofer, S. Delahaie, L. Ferriere, N.Rambaux

Three artificial meteor from real meteorites in wind tunnel campaigns were organized between 2020 and 2022. We will present some general results dealing with: meteoroid behaviour (and analogy with natural meteor fragmentation), meteoroid surface temperature, N-UV and M-IR emission.

5 Online Meteor Work

5.1 Showers with both northern and southern solutions

R. Rudawska, L. Neslušan, T. J. Jopek, M. Hajduková, G. Kokhirova

In the interplanetary space, there can be a meteoroid stream, which collides with the Earth in such a way that the radiant area is located near the ecliptic. It can be then often divided into two parts (one situated northward and the other southward of the ecliptic), and thus, two showers are caused by such a stream. The Northern and Southern Taurids or Northern and Southern δ-Aquariids are examples of such streams. While the meteoroids of the northern shower collide with the Earth in the descending node, those of the southern shower collide with our planet in the ascending node of their orbits. Because of this circumstance and tradition, the northern and southern showers must be distinguished. In our talk, we will present that unfortunately this is not always the case with meteor showers listed in the IAU Meteor Data Center (MDC). In our talk, we will present the list of the problematic showers for which we found the mixed northern and southern branched (solutions) and the proposed corrections of these misidentifications.

5.2 How a grazing meteor study can help advance LEO satellites' orbit evaluation?

Marcelo De Cicco, Iharka Szücs-Csillik

Grazing meteors are meteoroids debris that enters the planetary atmosphere in a near-horizontal orbit, perigee very high to the ground, having only part of their material being ablated during air interaction, which remains return to space at a different orbit after that short encounter. Such close approaches are better analyzed using numerical integration with regularization methods, as the distance between two bodies, regarded as a point mass, tends to zero (close encounters). Several advantages for avoiding singularities are provided over classical Newtonian equations. We discuss the grazing fireball EN13190 case that occurred on October 13th, 1990, observed above Czechoslovakia and Poland and registered by two Czech stations of the European Fireball Network, which conclusions as physical properties, trajectory dynamics and orbital parameters after and before close approach are published in the article of Borovicka and Ceplecha (1992). Using the Rebound python package we implemented calculations for the grazing orbits back and forth in time. The same steps were done using the equations of motion of perturbed two-body problem under 4th-order symplectic integrators (De Cicco and Szücs-Csillik, 2022). Moreover, we proposed a regularized spatial elliptic restricted three-body problem with a symplectic integrator with 9 steps to investigate the singularity region (De Cicco and Szücs-Csillik, 2023). Similarly, the latter can be applied to study the satellite motion, as the precise orbit prediction of the artificial satellite's motion depends on the correct initial condition and from an adequate numerical inte-

grator (a concrete application has been done for LEO satellites using the regularized two-body problem in the paper Szücs-Csillik, Turcu (2023)). The numerical integration technique presented herein introduces convenient coordinate and time transformations to magnify the motion's area around the close encounter providing an efficient method for evaluating Earth's satellite orbits. The findings of this study contribute insights into the field of meteor dynamics and hold the potential for enhancing the assessment of LEO satellite orbits, which are crucial for various scientific, communication, and navigation applications.

5.3 Regarding the parent bodies in the Meteor Data Center

Silvia Ďurišová, Mária Hajduková, Regina Rudawska, Tadeusz J. Jopek, Luboš Neslušan

Currently, the only known database containing both meteor shower parameters and the parent bodies associated with them is the IAU Meteor Data Center Shower database. Although, out of all the listed showers, only about 16% have a parent body linked to them. The database also does not offer any other information regarding the method used for associating the parent body with the corresponding stream apart from a flag "?" to mark some dubious relationships. The aim of our work is to search as many sources suggesting shower parent bodies as feasible and create a list of possible meteor shower parent bodies, taking into account the method of investigation and looking into the random associations.

5.4 Remarks on searches for interstellar meteors – quick database assessment

Silvia Ďurišová, Mária Hajduková

Hyperbolic meteoroid orbits are generally present in every freely accessible meteor database, sometimes making up to 10 % of all orbits. Some of the hyperbolic orbits might be real and of interstellar origin, but some of them might be created due to the mechanisms inside the solar system. Generally, most of the hyperbolic orbits are presumed to originate in the solar system and be predominantly the results of errors. Naturally, investigation of a single meteoric event is insufficient for confirmation of its interstellar origin, an assessment of the whole database is also very much needed. The hyperbolic orbits among the stream meteoroids are the most obvious indicator of erroneous measurements and might be used for quick assessment of the database. The aim of this talk is to offer a look at such a population and a few remarks on the relation between the meteor geocentric velocity and the angular elongation of the radiant from the Earth apex visualized in the Kresak diagram and its uses for database assessment.

5.5 An optimized design for camera boxes of meteor surveillance systems

Hayder Almamoori, Ozan Ünsalan

This presentation unveils a sophisticated strategy for optimizing meteor tracking through engineering innovation:

Our system, underpinned by precision load, heat, and motion sensors, synergizes with powerful ARM microcontrollers (STM32) to dynamically adapt to environmental complexities. Key technical aspects encompass:

1. Sensor Integration: Utilizing load sensors for enclosures, heat sensors for climate monitoring, and motion sensors for wildlife detection, our setup precisely gauges conditions. This data fuels nuanced adaptations, including targeted heating for ice prevention and real-time wildlife tracking.
2. Rapid ARM Processing: STM32 microcontrollers swiftly process intricate sensor data, empowering immediate responses. Rain-triggered glass cleaning, bird deterrence, and real-time wildlife tracking are seamlessly executed for uninterrupted tracking performance.
3. Elevated Engineering Efficiency: By integrating sensor-driven intelligence, our approach revolutionizes meteor tracking efficiency. Addressing ice accumulation, rain disturbances, avian interferences, and wildlife presence, our system ensures steadfast accuracy.

In essence, this presentation introduces a new engineering era where sensor-driven adaptation and ARM microcontroller finesse intersect to elevate meteor tracking, fostering precision, adaptability, and global cohesion.

6 Meteoroid Streams, Modeling and Physics, Ongoing Meteor Work

6.1 Planetary Meteor Ablation

Maximilian Vovk, Peter Brown

The research aims to develop a statistical meteor ablation and fragmentation model using optical data from meteor events captured by the Canadian Automated Meteor Observatory (CAMO) and Electron Multiplying CCD Cameras (EMCCD) at Elginfield and Tavistock. The goal is to statistically define Earth's faint meteor environment and apply this knowledge to other planetary atmospheres.

The study focuses on sporadic meteoroids with velocities under 20 km/s and sizes between 1 mm and 1 cm. Using this data, we'll employ a Monte Carlo approach to create a synthetic meteor fragmentation model from CAMO data. This will involve adapting the existing MetSim model to include statistical fragmentation and verifying results using height and brightness metrics from Western University's EMCCD database. The new model will be then applied to other celestial bodies like Venus, Mars, and Titan, offering a comprehensive tool for simulating meteors on different planetary atmospheres.

This study endeavors to offer an enriched understanding of meteoroids' physical characteristics, their behavior, and their broader implications, both for Earth and other planets. These findings will not only further academic knowledge but also have tangible applications, particularly in satellite safety and future interplanetary mission designs.

6.2 Chaos in meteoroid streams: the example of Draconids, Leonids, and Taurids

Ariane Courtot, Melaine Saillenfest, Jérémie Vaubaillon, Marc Fouchard

Today more than 900 meteor showers are listed by the IAU, meaning a similarly large number of parent bodies existed in the Earth vicinity in the near past (1-100kyrs). This raises the question of the authenticity of these showers. To tackle this, we aim to better understand the dynamical evolution of meteoroids, which can be done by drawing chaos maps.

We studied the Draconids and Leonids meteor showers, whose orbits are close to respectively Jupiter-family comet and Halley-type comet. The effect of mean motion resonances with Jupiter will be shown in both cases, as well as the effect of close encounters, mainly with Jupiter, Saturne and the Earth. We also investigated the effect of non-gravitational forces, in relation to mean motion resonances.

Finally, we worked on the Taurids, whose legitimity as meteor shower has been questioned before. Chaos maps for the Taurids are widely different from those drawn from the Draconids and Leonids, and explain the difficulty with Taurids modelisation. We

also started to work on projected radiants from our computations, in conjunction with data from camera networks.

6.3 The dust size distribution in comet 67P/Churyumov-Gerasimenko and comparison with meteor information

Julia Marin Yaseli de la Parra

This study focuses on investigating the dust size distribution in comet 67P/Churyumov-Gerasimenko and comparing it with meteor information. Comets serve as invaluable remnants of the early solar system, providing insights into the composition and formation processes of celestial bodies. By analyzing the dust particles emitted by comet 67P, we aim to unravel the underlying mechanisms governing its size distribution and examine how it compares to meteor data.

To achieve this, we utilized data collected by the Rosetta mission, which successfully rendezvoused with and orbited comet 67P. The measurements were primarily obtained from the Rosetta Plasma Consortium's instruments, which allowed for the characterization of the dust environment surrounding the comet. The data included size distribution information, specifically focusing on dust particle sizes ranging from submicron to millimeter scales.

By examining the size distribution of the comet's dust particles, we discovered a broad range of sizes, suggesting a diverse population of grains within the comet. Furthermore, the presence of distinct peaks in the size distribution hinted at the existence of various particle sources or formation mechanisms. Comparing these findings with meteor data collected on Earth, we observed several similarities and differences.

The comparison with meteor information provided valuable insights into the potential origins and evolutionary processes of the dust particles in comet 67P. The variations in size distribution patterns between cometary dust and meteoroids could be attributed to differences in formation environments, transport mechanisms, and post-formation dynamics. These findings contribute to our understanding of the broader context of cometary activity and meteoroid populations in the solar system.

In conclusion, our analysis of the dust size distribution in comet 67P/Churyumov-Gerasimenko sheds light on the composition and dynamics of cometary particles. By comparing these findings with meteor data, we gain a better understanding of the underlying processes shaping celestial bodies in our solar system. This study underscores the importance of interdisciplinary research in unraveling the mysteries of our cosmic neighborhood.

6.4 A new book on meteor astronomy: Atlas of Earth's Meteor Showers

Peter Jenniskens

When writing the 2006 book "Meteor Showers and their Parent Comets", the task of creating a list of known meteor showers proved to be the most challenging. At the time, there was a short list of about 10 meteor showers that everyone could agree existed, but going past that was nearly impossible. The existence of meteor showers was based on finding groupings of similar orbits among photographed or radar-detected meteors. The number of photographed orbits was only a few thousand, a handful of meteors each night. There were more radar-derived orbits, but even that data was sparce. The agreement between the two datasets was poor. A list of 286 possible showers with IAU numbers 1 to 318 was published in the form of two Working Lists based on photographic and radar orbits and a Table of possible southern hemisphere showers only recognized by visual observers.

6.5 A simplified meteor spectrum classification scheme

Bill Ward

After 12 years of regular video meteor spectroscopy at the Kilwinning Spectroscopic Survey for Meteors, some trends have emerged. This talk will review the main types of meteor spectra that have been captured using WATEC and ZWO video cameras. A classification scheme is proposed.

7 Meteor-Related Software and Hardware, Miscellaneous

7.1 VASCO virtual all-sky corrector plate

Martin Baláž, Leonard Kornoš, Filip Hlobik, Tomáš Vörös, Daniela Bartková

One of the necessary steps in astrometric reduction of meteor observations is finding the mapping of the sky onto the imaging sensor. In simple cases the projection can be described analytically through the geometry of the optical path. However, actual cameras often have multiple optical elements and imperfections that introduce complex distortions. On the sensor, these manifest as systematic errors in positions or reference stars and the meteor frames, even with an optimal parametric fit. We present an open-source software package vasco, a virtual all-sky corrector plate, which minimizes the global systematic errors of the projection and attempts to correct the local residual errors.

7.2 Fireball Analysis using the Auroral Optical System ALIS_4D

Gabriel Borderes-Motta, Daniel Kastinen, Tima Sergienko, Urban Brändström, Lars-Henrik Snow, Johan Kero

The optical system ALIS_4D operates in the northern region of Sweden to investigate low-light luminous phenomena like airglow and aurora. This optical system has a wide field of view and detectors that operate in the visible and near-infrared regions. Each ALIS_4D station is equipped with a highly-light-sensitive and high-resolution scientific EMCCD detector and 3” narrow-passband interference filters in six-position filter wheels. Besides these phenomena in the upper atmosphere, the optical system sometimes capture other events, such as meteors, illuminated satellites and space debris. The ALIS_4D AUTO-SSA project aims to investigate if the ALIS_4D can significantly contribute to Space Surveillance by tracking space objects. In the work frame of this project, we developed a pipeline for identifying a space object traces and determining their orbits. In this work, we intend to evaluate the feasibility of using this pipeline to analyze a meteor event. For this purpose, we used images from ALIS_4D of a fireball captured on February 27, 2023, at about 18:15 local time. These images have a time exposure of about 0.1 seconds and an observed center wavelength of 4278 Å (N+2 1Neg). We extract from the images the trajectory of the meteoroid. Finally, we discuss what role ALIS_4D can play in the meteor monitoring framework.

7.3 Meteor detection on radio spectrograms by means of computer vision

Christian Steyaert

A computer vision model (the oldest form of machine learning - ML) using open source tools was developed and trained on the author’s Speclab spectrograms for detecting

meteor reflections. Precision of over 90% is reached. Source and data sets are available.

ML yields meteor reflection properties that allow (re)analysis of large amount of data in a consistent way.

7.4 Revolutionizing meteor work: converging innovations in Generative AI, Website DevOps, and AllSky7

Mike Hankey

In this talk, Mike Hankey from the American Meteor Society and AllSky7 Global Network takes us on a journey into the cutting-edge world of Generative AI and Website DevOps, where transformative tools like Chat GPT are reshaping the information industry. Discover how these innovations have propelled productivity to unprecedented levels, revolutionizing the way we approach meteor-related tasks and other spheres of work.

Join us as Hankey unravels real-world AI success stories, showcasing how AI has effectively addressed current challenges faced by the AMS and IMO websites. The discussion delves into the remarkable impact of Generative AI trends and its seamless integration with Website DevOps, outlining how they have synergistically contributed to the advancement of the AMS/IMO/AllSky7 websites and fireball reporting tools.

From envisioning the future possibilities of these converging technologies to unveiling the roadmap for AMS/IMO/AllSky7's upcoming initiatives, this talk offers invaluable insights for meteor enthusiasts, AI enthusiasts, and technology aficionados alike. Prepare to be inspired by the potential that lies at the intersection of AI and meteor work, propelling us toward a new era of innovation and discovery.

7.5 Complementary applications to meteor cameras: Cloud cover estimation via deep learning

Simon Anghel, Dan-Alin Nedelcu, Mirel Birlan

Advancements in sensors enable automated atmospheric data acquisition from satellites and ground stations. Within this context, the night sky monitoring becomes important for estimating the number of clear and photometric nights. In this study we present a method of estimating the level of cloud cover (CC) using Deep Learning (DL) applied to all-sky images of Meteorites Orbits Reconstruction by Optical Imaging (MOROI) network. We obtained accuracy scores ranging from 84-91 % accuracy for CC classification. The methods are independent of sensor specifications, hence, the process can be scaled and applied to multiple camera configurations. Moreover, the novelty of our method is given by their ability to classify monochrome images, which are more abundant due to the large number of fireball networks. The results entail future studies on other stations of MOROI network, and ultimately, to assess the efficiency of optical meteor detections.

7.6 Influence of weather parameters on the dark flight computation of fireballs

Felix Bettonvil, Dušan Bettonvil, Tammo Jan Dijkema, Kees Habraken, Gert-Jan Netjes, Sebastiaan de Vet

The computation of the dark flight trajectory of fireballs requires knowledge of the metereological properties of the atmosphere. Among them are the wind speed and -direction. Often weather balloon sounding data is used, but that is still not perfect: generally, the trajectory of the radio sonde and its time of flight do not match well with that of the fireball. Moreover, it is not always clear which data to pick best. In this paper we compare different sources of data and analyze what the impact is on the dark flight computation.

8 Visual Meteor Work, Meteor Showers, and Ongoing Meteor Work

8.1 The behavior of the beginning height in Quadrantids, Perseids, and Geminids

I-Ching Yang, Chih-Ming Lin

According to SonotaCo Network Members data sets during 2008 to 2019, the probability distributions of beginning height of Quadrantids, Perseids and Geminids per year are obtained. These probability distributions of beginning height are fitted with the Gaussian distribution function and approach the Gaussian distribution. The fitting parameters $x\_$"c", the mean of the Gaussian distribution, of Quadrantids and Geminids are lower than 100 km, and of Perseids are higher than 105 km, and all of fitting parameter are close to the arithmetic mean $\bar{x}$ of the raw data.

8.2 Current status of the Extension of the FRIPON network in Chile

Felipe Gutierrez, Sébastien Bouquillon, Rene A. Mendez, Hernan Pulgar, Marcelo Tala Pinto, Katherine Vieira, Millarca Valenzuela Picón, Andrés Jordán, Christian H.R. Nitschelm, Massinissa Hadjara, José Luis Nilo Castellón, Maja Vuckovic, Hebe Cremades, Bin Yang, Adrien Malgoyre, Colas Francois, Pierre Vernazza, Pierre Bourget, Emmanuel Jehin, Alain Klotz, Carlos Araya Fernández

FRIPON is an efficient ground-based network for the detection and characterization of fireballs, which was initiated in France in 2016 with over one hundred cameras and which has been very successfully extended to Europe and Canada with one hundred more stations. After seven successful years of operation in the northern hemisphere, it seems necessary to extend this network towards the southern hemisphere - where the lack of detection is evident - to obtain an exhaustive view of fireball activity. The task of extending the network to any region outside the northern hemisphere presents the challenge of a new installation process, where the recommended and tested version of the several sub-systems that compose a station had to be replaced due to regional availability and compatibility considerations, as well as due to constant software and hardware obsolescence and updates. In Chile, we have a unique geography, with a vast extension in latitude, as well as desert regions, which has generated the need to evaluate the scientific and technical performance of the network under special conditions, prioritizing the optimization of a set of factors related to the deployment process, as well as the feasible and achievable versions of the required components, the geographical location of the stations, and their respective operational, maintenance, safety, and communication conditions. In this talk, we will present the current status of this effort, including a brief report on the obstacles and difficulties encountered, how we have solved them, as well as present the current operational status of the network in Northern Chile, as well as the challenges and prospects for densification of the network over South America.

8.3 An expected new shower caused by Comet 46P/Wirtanen in 2023

J. Vaubaillon, Q. Ye, A. Egal, M. Sato

Although Jupiter family comet 46P/Wirtanen is a near Earth object, no shower has ever been detected from this potential parent body. Here we report a possible birth of a new shower from this comet on Dec. 12th 2023 around 10:15 UT. The level of the shower is hardly predictable since the shower is new. The visibility zone covers North and Western Australia, Papua New Guinea, New Zealand and Indonesia.

8.4 Tau Herculids in Texas

Bernd Gährken

In 1995, comet Schwassmann-Wachmann-3 surprised astronomers with a sharp, unexpected increase in its brightness from about 13 mag to about 7 mag in just a few days.

In 2005, some scientists predicted a possible increase in activity for the years 2022 and 2049, with the dust cloud produced during the 1995 eruption being cut off in 2022. The earth was moving at the outer edge of the cloud in 2022 and as a result only light particles should have drifted in the direction of our planet.

The maximum should still be short, falling on 5/31/22 at 5am UT. At this time the sky is too bright on the European continent and even on the Canary Islands the radiant is only about 10 degrees above the horizon just before dawn. The Midwest of the USA or the Caribbean proved to be ideal.

Our journey took us to brady in texas. The forecast for the maximum time was well met. The sniffles were all remarkably slow. However, because of the zenith of the radiant, the apparent angular velocity was still higher than expected. Contrary to the forecast, there were also brighter meteors with -2 mag. Subjectively, the fall rates corresponded to a Perseid maximum. My co-observers counted 150 meteors in 3 hours. Already during the visual observation there was the impression that the snouts appear rather reddish. The otherwise so often visible green and blue tones were completely missing. The impression was confirmed photographically. Obviously, at the low speed, the friction is not sufficient to reach high temperatures.

With a Sony7s, 273 meters were recorded at 25fps and 320.00ASA. Further information is available at: http://astrode.de/reisen/reisen22/texas22a.htm

8.5 Tau-Herculids meteor shower observed by AMOS cameras

Filip Hlobik, Juraj Tóth, Tomáš Paulech, Peter Vereš

Comet 73P/Schwassmann-Wachmann experienced a break-up in 1995 and numerous authors predicted an increase in tau-Herculids meteor shower activity. The outburst occurred at the end of May 2022. Reports of expeditions and observations were one

of the main themes of IMC 2022. Now, we present some results of our analysis of the shower captured by two all-sky AMOS cameras located in Arizona. We captured more than one hundred double-station tau-Herculids meteors on the night of 31 May 2022. We found that the radiant and orbital parameters of the shower agree well with the predictions and observations which have already been published.

9 Video Meteor Work

9.1 Video observation of fireballs by the European Fireball Network

Lukáš Shrbený, Pavel Spurný, Jiří Borovička

Video recordings of fireballs have been added in recent years as a full complement to the photographic data. For most fireballs where video recordings are used, these data are important for refining the initial velocity and thus the heliocentric orbit. Video data also provide information about the meteoroid fragmentation process and is the only source of data on daylight fireballs. The flawless use of these recordings depends on the correct settings of the cameras, both software and hardware. We will present settings of our video cameras and also discuss the inappropriate settings we have encountered.

9.2 Periodic short-term variations in meteor shower fluxes

Sirko Molau

During the 1999 Leonid meteor storm, we have detected perodic variations in activity with a wavelength of about 7 minutes. We will report on a re-validation of the results obtained more than 20 years ago, and if similar variations have been found for other meteor showers as well.

9.3 A new approach to analyze single-site video meteor observations

Norton O. Szabó, Krisztián Sárneczky, Antal Igaz, Márton Rózsahegyi, József Vinkó, Livia Deme, László L. Kiss

We present our new pipeline utilizing the wide-field Sony a7 videocamera for the analysis of meteor outbursts, astrometric measurements, and a novel approach for radiant determination. The methodology was successfully applied to the Tau Herculids 2022 outburst, confirming results through literature comparison. Astrometric measurements and photovisual magnitudes were obtained, revealing valuable insights into the properties of the outburst. Additionally, we present promising preliminary findings for the 2023 Perseids.

9.4 Compensation for the effect of moon on meteor shower flux densities

Sirko Molau

We have observed for long, that the moon has a clear impact on meteor shower flux densities obtained from video meteor observations at meteorflux.org. A new method to compensate for this effect will be presented and discussed.

10 Use of Meteor Spectroscopy and Seismology, Meteor Physics and Dynamics

10.1 Fitting your spectral observations to models

J. Zender, D. Koschny, R. Rudawska, A. Kariapis

Since several years, a growing number of ground-based stations provide spectral data of meteor events. The analysis of these spectral data requires the comparison with reflectance models of atoms, molecules, and ions. In the talk the background to the model we use for the CILBO (Canary Island Long-Baseline Observatory) station is given and some main considerations of applying such a model are discussed. A special emphasis will be given to the problem of fitting a number of parameters in a model to a given, observed spectral event, as these parameter space can be large: different temperature regimes at the meteor and its surroundings (shock front), different chemical elements and their different number densities.

10.2 Updates in digital meteor spectroscopy

Marko Šegon

Meteor spectroscopy has been an active field of research in the Czech Republic since 1960 when the first single-station system of analogue cameras was set up at the Ondrejov Observatory. That system, operational until 2018, is now replaced by 12 stations of the European Fireball Network - each equipped with two digital Canon EOS 6D cameras. The switch to digital cameras has allowed the acquisition of a significantly larger volume of data spanning a wider spectral range, extending to the near-infrared region. However, it has also been accompanied by a substantial drop in spectral resolution, necessitating an improved method of data analysis. Several aspects of the analysis process were already discussed in a presentation given at last year's IMC. Since then, additional steps have been implemented in the software used for the analysis, and new discoveries have been made, shedding light on some of the previously posed questions. These advancements will be the central topic of the talk.

10.3 Preliminary analysis of CN emission in meteor spectra

Adriana Pisarčíková, Pavol Matlovič

The cyano radical (CN) as a tracer of organic matter in meteoroids has not been confirmed in meteor spectra thus far. Our previous work, which focused on the analysis of CN emission from a wide range of ablated meteorites from laboratory experiments using the high-resolution HEFDiG Echelle spectrograph, pointed out the presence of the investigated emission in carbon-rich meteorites and best resolved in the early stages of the ablation. Our proposed method for identifying the CN band in lower-resolution meteor spectra from the AMOS network is now put into practice. In this talk, we will

present the preliminary results from this analysis with a focus on monochromatic light curves of meteors and measuring relative intensity ratio of the main CN band peak to the nearby Fe I peak to differentiate the content of the organic compounds in asteroidal and cometary meteoroids.

10.4 The high temperature component in fireball spectra

Vojáček V., Borovička J., Spurný P.

Two temperature components are observed in meteor head spectra (Borovička, 1994). The low temperature (3500K 5500K) component consists of lines from excited neutral atoms like for example Na I, Mg I, Fe I, or Ca I. The high temperature (10000K) component is connected with ionized atoms of Ca II, Si Ii, or Fe II, some spectra can show neutral hydrogen H I. We studied well-resolved lines of Si II and H I together with other spectral lines in fireball spectra and we compared them with various fireball parameters that were obtained by fireball cameras of the European Fireball Network. We will show the first and preliminary results.

10.5 Estimating a meteor's trajectory using seismic data: A case study of the November 2017 meteor over Germany

Dario Eickhoff, Jan-Phillip Föst, Runa Ostermeier, Mohsen Koushesh, Joachim Ritter

A meteor's trajectory in the Earth's atmosphere carries information about its origin within or beyond the solar system. Knowledge about meteoroid origins helps to achieve a better estimation of the meteoroid flux which the Earth is subjected to. The traditional visual methods work best at nighttime hours, leaving daytime hours poorly monitored. Closing this temporal observational gap is a challenge in meteor monitoring, but it can be partially achieved by using seismological observations to verify nighttime meteors and to record new meteor occurrences in the daytime hours. The increasing number of seismic stations also helps closing spatial observational gaps of the traditional meteor monitoring methods. To estimate the feasibility of using seismological data to study meteor trajectories a visually well detected meteor over Germany was used.

On November 14th 2017 around 16:47:00 UTC a meteor flew over Germany and the Czech Republic. The meteor's shock wave was measured by in total 112 seismometer stations in Germany and surrounding countries. Additionally, the DEEP-TEE seismic network of KIT, located in the Eifel in Germany, also recorded the shock wave of the meteor. Using the recorded seismic data we estimate the meteor's trajectory and velocity. The meteor's trajectory was found to be ca. 140 km long and had a velocity of 37 km/s. The meteor's incident and azimuth angle were calculated as 75.8 ° and 93.2 °, respectively. Calculating and constraining these parameters can highlight deficits of the used methods, which should be eliminated in future seismological meteor studies.

10.6 Towards improved seismological meteor localization: finite difference modelling of meteor-induced acoustic and seismic signals

Jan-Phillip Föst,Dario Eickhoff, Runa Ostermeier, Mohsen Koushesh, Joachim Ritter

Meteor trajectory determination plays a pivotal role in modern astronomical research, enabling scientists to gain valuable insights into the composition of meteors, their parent bodies, and their impact potential on Earth. As meteors enter Earth's atmosphere, they generate acoustic waves, which then induce seismic waves by coupling into the Earth's surface. This research aims to understand the behaviour and characteristics of meteor-induced seismic signals by simulating their propagation through the atmosphere and Earth's subsurface using finite difference numerical methods (WAVEtoolbox). The simulations consider various meteor properties such as velocity, and entry angle to understand the resulting seismic signatures. The acquired knowledge can aid in discriminating meteors from other seismic events and distinguishing between different signal sources like the super-sonic shock or surface waves and contribute to the detection and monitoring. The ability to differentiate between the arriving wave types has practical applications by improving meteor trajectory determination with the assistance of seismic monitoring networks. The usage of dense seismic networks to estimate the meteor trajectory provides a good spatial coverage and is also feasible during daylight hours in contrast to other observation techniques.

10.7 Long-duration artificial meteors created during the CZ-3B R/B re-entry observed by AMOS

D. Bartková, J. Šilha, J. Tóth, L. Kornoš

Space debris objects, such as upper stages left after rocket missions, orbit the Earth in an environment that affects their dynamic properties. The perigee gradually decreases and after reaching critical altitude, re-entry begins. A re-entering object does a few more revolutions during which it can break up into smaller fragments and start to ablate, creating artificial meteors. These meteors enter the denser atmosphere at shallow angles and speeds typical for objects on low-Earth orbits (up to 10 km/s according to altitude and mass), thus they are rather slow and long-lasting with ballistic trajectories, unlike most natural meteors. Nevertheless, analysis of a re-entry event makes use of the knowledge and methods from meteor astronomy. Studying re-entry events is key to understanding the physics behind their mechanism and properly estimating the damage such events can cause to the human population, property, and the environment. Two AMOS all-sky cameras simultaneously observed the re-entry of CZ-3B R/B (upper stage of Chinese Long March 3B rocket) over the Hawaiian Islands on October 25th, 2020. The re-entry produced tens of fragments forming a cluster, from which seventeen could be manually identified on both recordings and measured to reconstruct their trajectories using triangulation for each measured position. The focus was on possible approaches to properly extract dynamics from the obtained trajectories, especially the

velocity needed for dynamic modeling to estimate the mass of individual fragments. In the talk, obtained trajectories and dynamic properties will be presented and discussed.

10.8 Meteor pairs and groups simulation

Pavel Koten, David Čapek

A number of observers reported that meteors appear in pairs or even bigger groups. Such conclusions are rather subjective as these originate mainly from visual observers. The instrumental detections of such events are rather rare.

Recently, we analysed arrival times of Geminid meteors recorded by the video cameras. Despite the relatively higher number of close in time meteors no firm evidence for real pairs was found. All the detected cases can be explained as random coincidence. Results of the recent Perseid observational campaign are more promising.

To answer the question of longevity of meteoroid pairs and groups on the heliocentric orbits a simple model was prepared which follows motion of the fragments under the solar radiation pressure. It seems that such pairs dissipate relatively quickly, mainly if the fragments mass ratio is higher.

Posters

The spatial distribution of meteoroids in the ecliptic coordinate system

Kun-Ning Yang, I-Ching Yang, Chih-Ming Lin

According to SonotaCo Network Members data sets during 2008 to 2019, the probability distributions of beginning height of Quadrantids, Perseids and Geminids per year are obtained. These probability distributions of beginning height are fitted with the Gaussian distribution function and approach the Gaussian distribution. The fitting parameters $x\_$"c", the mean of the Gaussian distribution, of Quadrantids and Geminids are lower than 100 km, and of Perseids are higher than 105 km, and all of fitting parameter are close to the arithmetic mean $\bar{x}$ of the raw data.

Analysis of the frequency of superbolides on the last 2000 years

Maria Elisa Rocha Bouzo, Alejandro Sánchez de Miguel, Francisco Ocaña

The detection and documentation of astronomical events, particularly superbolides, have witnessed significant advancements over the course of history. While the historical records might indicate a scarcity of such events in the past, it does not necessarily imply their absence. Therefore, a comprehensive analysis of the frequency of superbolide occurrences can offer valuable insights into the potential of meteor impacts, and in the future, those that present a real risk could be deviated as recently at the DART mission. This study presents a data-driven approach utilizing nonparametric and Bayesian statistical methods to analyze two distinct and non-coetaneous databases that afterwards are compared. The relationship between periods of maximum meteor flux and intense meteor showers such as the Perseids in July and the Leonids in November is also shown. However, superbolides are probably associated with additional sources, specifically Near Earth Asteroids (NEA), which could facilitate the entry of such sizable objects into Earth's atmosphere.

Linking meteorites to parent bodies: artificial space weathering on meteorite minerals

Akos Kereszturi, Ildikó Gyollai, Zoltán Juhász, Richárd Rácz, Dániel Rezes, Béla Sulik, Krisztian Sárneczky, Máté Szabó, Zoltán Szalai, Péter Szávai

To link meteors and meteorites to parent bodies is supported by spectral analysis among others. Artificial proton irradiation was done on the NWA 10580 meteorite with gradually increasing steps. The first results indicate Mg loss and distortion of the silicate tetrahedral, producing negative peak shifts of infrared mineral bands. Further analysis helps to understand the space weathering induced changes of asteroid spectra and optimize detectors onboard next missions.

Conceptual approach to community-involved, drone-assisted meteorite searching: strategy to find fusion-crusted meteorites

Nick Ezra van Gerven, Alyona Glazyrina, Zeno Hamers, Anna Mao, Iris Andreea Petre, Quinn van der Schaar, Sebastiaan J. de Vet

Meteorites offer valuable insights into the composition of asteroids and geological processes contributing to planet formation inside the solar system. Their rapid retrieval after fireball sightings allows this science potential to be used. Finding new meteorites is notoriously difficult due to various complicating factors. A promising search strategy can involve the aerial vantage point of drones (aka: UAV, RPAS). However, drone regulations by the European Union Aviation Safety Agency (EASA) and complex zonation of airspace will impact flight operations, which makes drone-assisted searching in Europe more complex than in e.g. desert environments. Here we present the results of a multidisciplinary desk study, which aimed at proposing a conceptual framework for drone-assisted meteorite searching. We propose the development of an open-source detection and coordination tool to improve aerial assistance by drones during field searches. The design provides drone enthusiasts (referred to as 'community drones') and researchers with a platform to coordinate joint drone-based search operations. Image processing is envisioned to take place via a convolutional neural network pipeline, after which high-likelihood locations are identified and manually verified to recover a potential meteorite. This approach will require development of multiple models to account for variations in soils and vegetation. Given enough meteorite samples, transfer learning makes the training of new, environmentally specialised models possible. Through API integration with the most popular drone manufacturers (e.g. DJI), a broad range of drone models can be supported, which increases community involvement and data from other sensor types (RGB, multi-spectral). Once a registered community or research drone joins the network, a pre-programmed flight path will automatically be assigned and imaged after which the data will be send to a central server. Considering EASA drone regulations, use of the DJI Mini 3 Pro is favoured as an accessible community drone. Follow-up research, implementing the proposed conceptual approach, should validate the design presented in here and highlight practical areas of improvement.

Urban Meteor Map: a map-based forecast of hourly rates for visual observers

S.J. de Vet

The visible rate of meteors is dependent on various local condition during shower peak nights. The interrelationship of the visible fraction of the night sky, radiant elevation and effects of light pollution on sky brightness confounds outreach efforts to manage realistic expectations for visual meteor observations by the public. The Urban Meteor Map offers a map-based forecast of hourly rates to help make the effects of local viewing conditions more insightful. The project generated maps based on rasterised data

for parameters in the Zenithal Hourly Rate formula. A Digital Surface Model (DSM) covering the Netherlands was used to generate maps of the visible percentage of the sky. At 5 m resolution this DSM offers insight into obstruction by buildings, vegetation and topography. To incorporate effects of light pollution, a national sky brightness map for cloudless nights was converted into Naked Eye Limiting Magnitudes (NELM). Combined with known shower parameters such as population index and radiant height, a map was generated with hourly rates forecasts at local and national scales. The Urban Meteor Map aims to helps raise awareness for the effects of light pollution, and promotes exploration of local living environment to seek the best viewing spots for meteor showers.

Morphometrics of regmaglypts based on a 3D Model of the fusion-crusted ordinary chondrite Broek in Waterland (L6)

.A.V. Veithen, S.J. de Vet

Regmaglypts are shallow depressions on meteorite surfaces formed by the ablation processes during atmospheric entry. These features can potentially offer insights in break-up events. However, quantitative methods to analyse regmaglypts have not yet been proposed, so far. Here we present the results of a study to evaluate break-up processes during the luminous flight by analysing regmaglypt morphometrics. We developed a novel approach based on a 3D shape model of the Broek in Waterland meteorite that was generated using photogrammetry. We converted sections of the 3D model into a smoothed Digital Elevation Model (DEM) that contained the fracture surfaces adorned with regmaglypts. Lending techniques from terrain analyses, we extracted Land Surface Parameters (LSP) and delineated regmaglypts based on the mean curvature inflection point. The outliers of the regmaglypt population were discarded based on mean and total curvature scatter plots. The mean, profile, tangential, total and gaussian curvatures were found to be most descriptive of regmaglypt morphologies. Various other curvature types were tested and found to be consistent across the studied regmaglypt population. Using this initial framework, we found that the two regmaglypted surfaces of the Broek in Waterland meteorite appear to be similar. This would reflect similar formative conditions, which we interpret to be most consistent with formation from the same breakup event. Future studies will aim to expand the presented method to regmaglypt populations of other L6 meteorites to understand how surface characteristics can inform us on ablation and breakup processes.

Towards improved seismological meteor localization: finite difference modelling of the November 2017 meteor over Germany

Dario Eickhoff, Jan-Phillip Föst, Runa Ostermeier, Mohsen Koushesh, Joachim Ritter

Determining meteor trajectories is a core aspect of modern astronomical research, enabling scientists to gain insights about the composition of meteors, their parent bodies,

the meteoroid flux on Earth and the impact potential of individual meteoroid bodies. As meteors traverse the Earth's atmosphere, they generate acoustic waves, which in turn induce seismic waves upon contact with the Earth's surface. These waves can be measured by seismological stations and can help supervise otherwise poorly monitored areas and time periods. The visually well detected meteor over Germany on November 14th 2017 is used to test the feasibility of using seismological data as a means of meteor trajectory estimation.

The meteor's trajectory was found to be ca. 140 km long while it's incident and azimuth angle were calculated as 75.8 ° and 93.2 °, respectively. The meteor had a velocity of ca. 37 km/s. Using the found meteor parameters, finite difference numerical methods (WAVE- toolbox) are used to simulate the propagation of seismic signals through the atmosphere and Earth's subsurface. The simulation can aid in discriminating meteor-induced seismic signals from different source signals and also in constraining the influence of atmospheric effects on the meteor's shock wave and it's arrival times. Understanding the magnitude of these effects is essential for future improved seismological meteor studies.

Generative AI Meteor Art: A Fusion of Creativity and Celestial Beauty Unveiling a Hand-Selected Collection of AI-Generated Meteor Art with Expertly Cr

Mike Hankey

Generative AI Meteor Art: A Fusion of Creativity and Celestial Beauty Unveiling a Hand-Selected Collection of AI-Generated Meteor Art with Expertly Crafted Prompts by Mike Hankey.

Infrasound Detections of Large Bolides

E.A. Silber, M. Ronac Giannone, D. Bowman

A meteoroid's passage through dense regions of the Earth's atmosphere results in a visual phenomenon (or a meteor) through the variety of processes, including heating, sputtering, and ablation. In addition to producing a spectacular display in the sky, especially during clear nights, fireballs and bolides are also capable of generating shockwaves. The shockwaves are produced during the hypersonic flight (cylindrical line source) and/or fragmentation episodes (quasi-spherical or point source). A by-product of shockwaves is a low frequency (lt; 20 Hz) acoustic wave, or infrasound, which should carry some information about the source, such as its energy deposition. Large objects have a destructive potential, as demonstrated a decade ago by the Chelyabinsk event. Thus, their characterization is of utmost importance, and helps shed the light on why some events are more destructive than others. However, even though infrasound experiences very little attenuation which in turn facilitates its propagation over vast distances, it is still poorly known which parameters related to bolides can be reliably extracted based on infrasound records alone. In this work, we embark on an

endeavor to probe this question. We leverage the JPL Center for Near Earth Object Studies (CNEOS) database of nearly 1,000 fireballs detected by the US government sensors since 1998 alongside other sources of ground truth to identify suitable bolide events to serve as our case study events. The criteria include detections by more than one infrasound station, and the existence of well- characterized source parameters obtained through other means (e.g., optical). Currently underway are detailed analysis of infrasonic signals from these events to determine which, if any, bolide parameters can be obtained through infrasound records alone, when no other quantifiable ground truth is available.

The OSIRIS-REx sample return capsule re-entry: plans for a coordinated infrasound observational campaign

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Meteoroids and asteroids are of great scientific interest. Well-documented scientific observations of asteroids are rare and generally happen by chance. Since the end of the Apollo era, only four instances of a hypersonic re-entry of an artificial body from interplanetary space with an incident speed of 11-12 km/s have been observed and studied. These were the Sample Return Capsules (SRCs) that brought physical samples of extraterrestrial material back to Earth. Arriving from interplanetary space at hypervelocity, SRCs are considered analogues for low velocity meteoroids and asteroids impacting the Earth's atmosphere, and as such provide unprecedented and unique opportunities to perform detailed studies of meteor phenomena, test and calibrate sensors, and validate and improve models. The next opportunity will present itself on 24 September 2023 with the re-entry of OSIRIS-REx SRC that will bring samples of the carbonaceous near-Earth asteroid Bennu. The OSIRIS-REx re- entry presents a unique and exceptional opportunity to observe a well-defined artificial meteor, to perform detailed studies of hypersonic entry and event characterization, to test sensors, and validate and improve models. Sandia National Labs will lead multi-instrument observations of the OSIRIS-REx SRC re-entry. The instruments will include seismic and infrasound sensors strategically positioned in the immediate and extended region around the projected re-entry trajectory to maximize the scientific output. Data collected during this observational campaign will be made freely available to the broad scientific community following publication.