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"Meteor streams" do not exist

Three years of Southern delta Aquariid observations by UNIVAP stations

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- The 2020 August 25 daylight fireball over the Netherlands
- Connecting ionospheric, optical, infrasound, and seismic data from meteors over Hungary
- Does a meteor's "color" reflect its spectral classification?
- Lyrids 2020 observations by AMOS, spectral, visual and photographic methods
- Low-cost night vision device for video recording of faint meteors

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Bright fireball on 2020 November 19, at $02^{h}46^{m}$ UT, from Kepler Remote Observatory, Austria. Photo courtesy: Kepler Remote Observatory.

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The same bright fireball as on the front cover, recorded on 2020 November 19, at $02^{h}46^{m}$ UT, from Fornach, Austria. Canon EOS 450D camera equipped with Sigma 10 mm lens was used with a 60 s exposure at ISO 1600. Photo courtesy: Hermann Koberger.

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In memoriam: Hugo van Woerden (1926 – 2020)

Felix Bettonvil[1]

On September 4, 2020, Prof. Dr. Hugo van Woerden passed away at the age of 94 after a short illness. Hugo was both an amateur and famous professional astronomer. In 1946, he was one of the founders of the Meteor Section of the Royal Netherlands Association for Meteorology and Astronomy (KNVWS Werkgroep Meteoren), and invented the use of star fields to determine the observer's limiting magnitude. Van Woerden was professor in radio astronomy, made famous by his work at the Kapteyn Institute in Groningen and among the first practicing radio astronomy in the Netherlands, and carried out important research with the Dwingeloo and Westerbork radio telescopes.

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A true amateur astronomer

Hugo van Woerden was born in 1926 and grew up in Arnhem. Like many of us, he got interested in astronomy at a young age,awakened by his father who was a chemistry teacher. Only 8 years old, his father taught him about the constellations and the planets their wandering on the sky, scintillation. He liked these evening walks very much.

His grandmother took him to the Sijthoff planetarium in The Hague in the summer of 1936, where he was fascinated by the show that used one of the two very first Zeiss planetarium projectors. With the Dutch astronomical almanac *Sterrengids*, written by the director Dr. J.J. Raimond Jr of the Sijthoff planetarium, he observed all the celestial phenomena he could. By then he was already a motivated observer and analyst. He preferred the naked eye over an instrument, because it felt being closer to the stars. Two phenomena had his special interest: the zodiacal light and Mercury, both being difficult to observe from the Netherlands, but keeping his attention his entire live (I do remember at least two occasions being outside with him and where he looked at the evening sky and then pointing at the barely visible planet).

Hugo wrote letters to Raimond about his observations, including brightness, colour and timings, and also visited him in 1942. Raimond was in contact with a dozen active amateurs, with among them Sidney van den Bergh, also very young, who was looking for companions to set up a network of meteor observers. Together with Lammert Huizing they started a small society, the 'Astro Club'. Hugo became observing director and treasurer, the other two became chair and secretary. They communicated mainly by letters these days and wrote each other each week. It was WWII, but circumstances were ideal within the Netherlands due to the curfew and mandatory black out that prevented artificial light. These dark hours were memorable times for amateur astronomy and one of the few activities considered kind of harmless by the German occupation forces (although you better did not do it in public. There is a report that the used red flash lights were interpreted as signalling to the enemy).

In 1943 Hugo obtained his gymnasium diploma. Due to the war, continued study at a university was only possible when declaring loyalty to the German occupation forces, which for Hugo was out of the question. Fortunately, Raimond had introduced him already to the Leiden Observatory, and it was Hugo's physics teacher who brought him in contact, at the age of 17, to Jan Hendrik Oort (who later discovered the after him named *Oort cloud*, source of many of our comets). Oort invited him to volunteer as an assistant at Leiden Observatory. He could freely use the 6" refractor, library and other services. He followed some (illegal) lectures by Oort and was also present at the historic seminar (April 1944) where astronomer Henk van de Hulst predicted the observability of the 21 cm line of interstellar hydrogen.

The Astro Club grew steadily: in 1943–44 the club had 35 members, consisting of school friends, family, some members of a local astronomy division in Arnhem as well as some amateurs elsewhere in the Netherlands.

Hugo liked the hunt for meteors. It appealed to him that they appeared by surprise and while on the outlook for meteors he could also study the constellations, and think about his girlfriend. He was himself one of the most active observers in these days.

As observing director Hugo set up meteor observing campaigns, in which observers were given observing instructions by mail, varying per location. The observing strategy was to plot meteors and to record time, duration, brightness, light curve and colour. These first campaigns were not always considered a success, because e.g. viewing angles were parallel instead of co-pointing to the same atmospheric spot.

'De Meteoor'

Many more campaigns followed, with the ones in March and April 1944 being very successful. Some 200 Lyrids were observed and later that year a few tens of Astro-club members observed reported over 2000 Perseids. The instructions were always written by Hugo in the Astro Club's own periodical, *'De Meteoor'*. De first issue appeared in November 1943 and was distributed per mail. It was reproduced in small quantities with stencil

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machines at the University observatories at Leiden and Utrecht, operated by Hugo. The contribution was 1 Dutch Guilder, about €6.56 by today's standards. 'De Meteoor' had soon also English content, with the Astro Club becoming in contact with observers in Belgium, France, Spain and Czechoslovakia.

From September 1944 coordination of observations started to hamper, with the war in it's final phase. Hugo moved back from Leiden to his hometown Arnhem. Communication was difficult due to the mail being unreliable, while the absence of radio meant that no time-signals were available to calibrate the clocks during observations. In essence, until the liberation in May 1945, meteor work grounded to a halt.

As soon WWII had ended the Astro club resumed their activities, with five campaigns focused on Quadrantids, Lyrids, Aquariids, Perseids and Draconids. Results were always published in 'De Meteoor' but analyses often lagged behind due to lack of experience, mentorship and leadership. It was a conclusion drawn by Hugo himself much later, but this was not strange given the young age of the founding members.

Hugo continued creating instructions for the meteor observers and since the beginning he had already emphasized the importance of accuracy and quality and the need for calibration. He was critical when results failed to materialize, but also had an ambitious outlook. He reported also that analyses of the results required much time and in practice this started to conflict with Hugo's study at the university.

'Werkgroep Meteoren'

Raimond in meantime was elected as president of the Netherlands Association for Meteorology and Astronomy, NVWS, and thanks to the high level of amateur activity, decided to start specialized sections, called working groups ('werkgroepen'), in addition to the local divisions in each major town. He proposed to form a *'Werkgroep Meteoren'* out of the Astro Club. By Hugo, Sidney and Lammert, this was considered as a good idea, bringing likely bringing in new momentum, despite their reports on the frustrating bureaucratic process of the proposed transition. In August 1946, the Astro Club became part of the NVWS and became named 'Werkgroep Meteoren van de NVWS'. Hugo was again appointed observing director and treasurer. 'De Meteoor' became its periodical. Hugo may be considered as the architect of the new section; he wrote an observing manual which was accepted as program of the Werkgroep.

The first observing activity of the newly formed Werkgroep Meteoren focussed on the return of the Draconids on the night October 9/10 1946. A training session was organized at the planetarium in The Hague. Unfortunately, it was a full moon and weather conditions were unfavourable. Some reports were received, but mainly from non-trained witnesses. Nevertheless, astronomers of the Kapteyn Institute in Groningen reported impressive rates up to 60 per minutes.

At that time Hugo was also accepted as astronomy student at Leiden University. The following years 1947 and 1948 the momentum in the Werkgroep decreased. Sidney moved to Princeton and Hugo had to devote all his

Figure 1 – Hugo van Woerden, during the annual 'Meteorendag der Lage Landen', in Heesch, Netherlands, 2009.

time to obtain his BSc degree, which created pressure. Hugo was also drafted for the obligatory military service. Consequently the 'De Meteoor' did not appear for two years.

Meanwhile, Kees de Jager (Sonnenborgh Observatory, Utrecht) became president of the Werkgroep in 1948, allowing Hugo to focus on his studies. Kees contributed the energy that the Werkgroep needed to uphold its level of activities. Kees, together with Hubenet observed already the Perseids during the years before while hiding during WWII (and therefore under pseudonyms, and Hugo discovered that only later). From 1949 'De Meteoor' started to appear again.

While the end of the forties neared, the first photographic surveys started to take shape, with help of sensitive Schmidt cameras. The Werkgroep Meteoren also made plans to build their own (1949), and some $\sim$ 15 cm prototypes were actually constructed, which used Schmidt plates obtained by Dutch industry.

In 1950 Hugo returned to the Werkgroep and would never leave again, eventually becoming an honorary member in 2002. He continued in his role as observing director, organising campaigns and writing observing instructions, he made observations and performed analyses. These activities took place at a somewhat larger distance while new members took over. On April 7, 1953 a bright fireball appears while Hugo made photo-electric observations on variable stars. From the indirect flash he was able to derive the brightness of the fireball.

Determining the limiting magnitude

From the very beginning of the Astro Club Hugo underlined the importance of accuracy and calibration, and he kept doing so, as well as stressing the importance of the link between observation and theory. In 1949 Hugo instructed the observers, triggered by Whipple's interest in meteor brightnesses, to use specific stars as a reference for their brightness estimations. To us as meteor observers, this is arguably his most important achievement and contribution to the field of meteor astrometry. He refined and tested his method in 1956 (in Sweden), and in 1957 introduced the use of star fields to determine the observer's limiting magnitude (Roggemans, 2010). He pointed out that it was not straightforward to find suitable star fields that are practical in use and have the required range of brightnesses. He starts with a few which he later expands to 12 (1958). Today, these fields are as still the standard and worldwide used.

The diversity of topics in Dutch meteor astronomy broadened, and apart from visual observing, also meteorites, photography (the first Dutch meteor photograph was taken in 1953), comets, fireballs, physics of streams, and statistics are discussed. Analysis of observations goes into deeper detail, and focused often on orbit determination. Strangely, analysis of annual shower activity, and discussion of ZHR profiles, is largely missing.

By the end of the fifties, the scope of 'De Meteoor' broadened: it is not only used to report on meteor work anymore, as other NVWS sections started making use of the magazine to report on their activities. Hugo's time to spend on meteor work diminished and soon after he gave up his function as observing director, followed in 1961 by his stepping back as editor of 'De Meteoor'. At that time photography was widely used albeit difficult (in 1964 Ten Haaf – Degewij – Naber start operating modified high resolution military cameras), and meteor spectroscopy, radar observation (Jodrell Bank; Sheffield) and space research starts. Members of the Werkgroep became routinely involved in satellite observation. There is close collaboration with Belgian observers regarding meteor work.

In these years, we learned for the first time of the uprising of the powerful Super Schmidt cameras (Harvard, Ondrejov), which were so sensitive that they almost reached the sensitivity of the human eye. The belief started to grow that the role of the visual observer would lose in importance soon, although visual reporting remained an 'official' research goal of the Werkgroep. In later years, Hugo still contributed his observations every now and then, but it is clear that his focus changed.

Radio astronomy

The reason for Hugo's shift in focus is evident, as in 1955 he started his PhD research on the structure of the interstellar clouds in the Orion region. He became an expert user of the then brand-new 25-m Dwingeloo radio telescope which was just completed (1956) and provided him with observations in the 21-cm line, one of the first major studies in the new exciting field. Soon, in 1957, an opportunity arose that would change his career. Adriaan Blaauw, the director of the Kapteyn Laboratory in Groningen was looking for excellent people who could support him in expanding radio astronomy in Groningen and offered Hugo a position as scientific research assistant. This could help Hugo to support for his PhD work, allowing him to participate in the creation of the first radio map of the Milky way.

Hugo played an important role in the development of radio astronomy in the Netherlands, which started shortly after WWII and culminated in the realization of the Westerbork Radio Synthese Telescope (WSRT) in 1966.

Hugo started to focus on radio astronomy, but was and remained interested in optical astronomy as well. After obtaining his PhD, he left for two years to Mount Wilson and Palomar Observatories in Pasadena (now the Observatories of the Carnegie Institution of Washington), supplementing the radio data with optical data.

In 1965 he returned to Groningen and was appointed associate professor. After Adriaan Blaauw left Groningen, much of the managerial work at the Kapteyn Laboratory was left to him, and later he became director. The institute flourished like all Dutch universities in the late 1960s and 1970s as they underwent an enormous expansion. New staff positions became available almost every year, and Hugo made excellent use of these positions, attracting many international guests and staff. Hugo laid the Groningen foundation for radio astronomy and extragalactic research and he was a key person behind the huge success of the WRST in the 1970s and 1980s.

With the WRST he worked on neutral hydrogen in Spiral Galaxies and later produced important work on neutral hydrogen in lenticular galaxies and in galaxies in the Virgo cluster in the 1980s and 1990s and on mapping and understanding and finding distances to high-velocity hydrogen clouds.

Hugo eventually became full professor in 1980 and was chair of the Astronomy Department from 1985 until his retirement. In that function he played significant roles in many national and international committees and boards.

Netherlands Association for Meteorology and Astronomy

In 1991 Hugo retired. As expected, he remained very active. He kept visiting his office at the Kapteyn Institute in Groningen, first on a daily basis, later once per week. He was one of the main organisers of the XXIInd General Assembly of the International Astronomical Union held in 1994 in The Hague.

Soon after his retirement, he was asked to take over the role as president of the NVWS and joined the board before taking office from 1992 until 2002 as president. He returned to his roots as amateur astronomer, back to popularising astronomy and as leader of the amateur community, on the basis of what he started 50 years earlier.

It turned out to be a very good choice. Under his guidance the NVWS celebrated its 100th anniversary, and its centenary celebration was attended by the Her Majesty Queen Beatrix. Hugo was instrumental in obtaining the reputable predicate 'Koninklijk' (Royal), which was bestowed by the Queen in 2002, allowing the NVWS to change its name into the Royal Netherlands Association for Meteorology and Astronomy: KNVWS.

This period is the time which gave many of us our fondest and lasting memories of Hugo. He was interested in everything and everyone. He maintained close contact with all sections of the NVWS, including his beloved Werkgroep Meteoren. He participated in almost all annual meetings, and if he not contributed himself, he came with a reaction after almost every talk, stimulating and participating in debate and discussion. He valued your work, showed enthusiasm, gratitude and courage, hinted to next steps. If you made a mistake in your presentation, he would let you know, though, but always in a kind way. For many of us he was as a mentor or coach. With his enormous drive, being extremely precise, and his fantastic memory, he was a strong supporter of amateur work to assist in our scientific understanding of the universe. This made him stand out.

International Meteor Conference

Hugo gave *acte de présence* during the International Meteor Conferences in 1996 and 2006, both organized in The Netherlands. At both conferences he gave oral presentations, the first on his experience with meteors in three different periods of his life: as amateur meteor hunter, professional astronomer and as president of the KNVWS, for which he wore three different hats during his presentation. At the International Meteor Conference of 2006, he put the meteor observing in broader perspective, from comets to planetary systems and exoplanets. Even today, some 17 years later, many of us look at meteor astronomy that way. Again, he stressed the importance of calibration once more, identical to what he did in his early years in meteor astronomy.

Figure 2 – Hugo van Woerden giving his presentation at the IMC in 1996.

During his period as KNVWS president, Hugo on three occasions handed out the Dr. J. van der Bilt prize to meteor observers (Ten Haaf, Koning, Van Leverink), a prestigious national award for extraordinary achievements by amateur astronomers in their respective fields. In 2011, the KNVWS council installed a similar prize for extraordinary achievements by youngsters (below 25 years), the *Hugo van Woerden prize*. The prize aims to motivate and enthuse youngsters, like Hugo was when he was young, to pursue the wonders of meteorology and astronomy. In November 2019

Hugo attended the prize giving ceremony at the yearly Astro Day, with hindsight his last, when the prize was awarded, fittingly, to a teenager who had built his own back-yard radio telescope to observe the 21 cm line of the Milky Way.

In 1992, Hugo was decorated as 'Ridder in de Orde van de Nederlandse Leeuw', and also asteroid 10429 van Woerden was named after him. At the age of 90, in 2016 a symposium was organized to honour is 90th birthday.

Dutch astronomy is proud to have had Hugo van Woerden among them, being a passionate scientist and true ambassador for astronomy, both for amateur and professionals. He has inspired many of us.

Huug, as many of us know him, will always have a special place in the hearts of many, and he will be missed.

Acknowledgements

I want to express my gratitude to Urijan Poerink, Sebastiaan de Vet, Kees de Jager, Herman ten Haaf, and Niek de Kort, who helped in giving additional insight in Hugo's life and career, providing answers to questions, and/or helped in studying and checking reference material, which included: De Meteoor, periodic of the Astro-Club (1943–1946) and NVWS Werkgroep Meteoren (from 1946), in Dutch; Hemel and Dampkring, periodical of the Netherlands Association for Astronomy and Meteorology (NVWS), in Dutch (1943–1973); De Meteoor, special issue Werkgroep Meteoren NVWS 50 Years (1996); Proceedings International Meteor Conferences, IMO, (1996, 2006); Terugblik, Kees de Jager, Stip Media, Alkmaar (2014, in Dutch); and websites KNVWS Werkgroep Meteoren (`https://werkgroepmeteoren.nl`), KNVWS (`https://knvws.nl`), and Kapteyn Institute (`https://www.rug.nl/research/kapteyn/?lang=en`). This article, in a slightly different version also appeared in eMeteorNews (vol. 5, no. 6, p. 362–365, 2020).

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IMO bibcode WGN-486-bettonvil-vanwoerden NASA-ADS bibcode 2020JIMO...48..163B

Figure 3 – Hugo van Woerden (photo: Kapteyn Instituut, RUG).

On the new design of the IAU MDC portal

L. Neslušan[1], *V. Porubčan*[2], *J. Svoreň*[1], *M. Jakubík*[2]

We report the launch of new IAU MDC web portal: `https://www.astro.sk/iaumdcDB/`. The portal is an access to the database of a large number of meteor orbits and further parameters.

Received 2020 November 26

The Meteor Data Center (MDC) of the International Astronomical Union (IAU) is a depository of data on a large number of meteors (Lindblad et al., 2003; Neslušan et al., 2013). The IAU MDC database has been created in purpose to provide the researchers interested in meteor astronomy with the precise, reliable, and complete-in-compulsory-parameters data obtained by various detection techniques.

In more detail, the IAU MDC database is the collection of 41 catalogs of the photographically detected meteors and 2 video catalogs. Recently, a sample of radio-meteor data was added. There are currently 4 873 photographic, 110 521 video, and 8 916 radio-meteor records, in total.

Each meteor in the database is characterized by its geocentric parameters and orbital elements. The IAU MDC established the set of "compulsory parameters", which are provided for each meteor. These parameters are listed in Table 1. Each catalog contains also some additional parameters, which may not, however, occur in other catalog. The full list of the parameters in the 2020-version of the database was given by Narziev et al. (2020; Table 1 in their paper).

Recently, the new design of the IAU MDC portal was created (see the title page in Figure 1). The portal is located at the URL:

`https://www.astro.sk/iaumdcDB/`

The pages contain the data and documentation to the individual catalogs. The user can choose his or her own set of the catalogs and own set of parameters by which each meteor is characterized. The chosen data can be printed or downloaded in the PDF, Excel-table, or CSV format.

A development of further functionality of the IAU MDC portal is still in progress. Potential visitors will be informed about a current status.

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

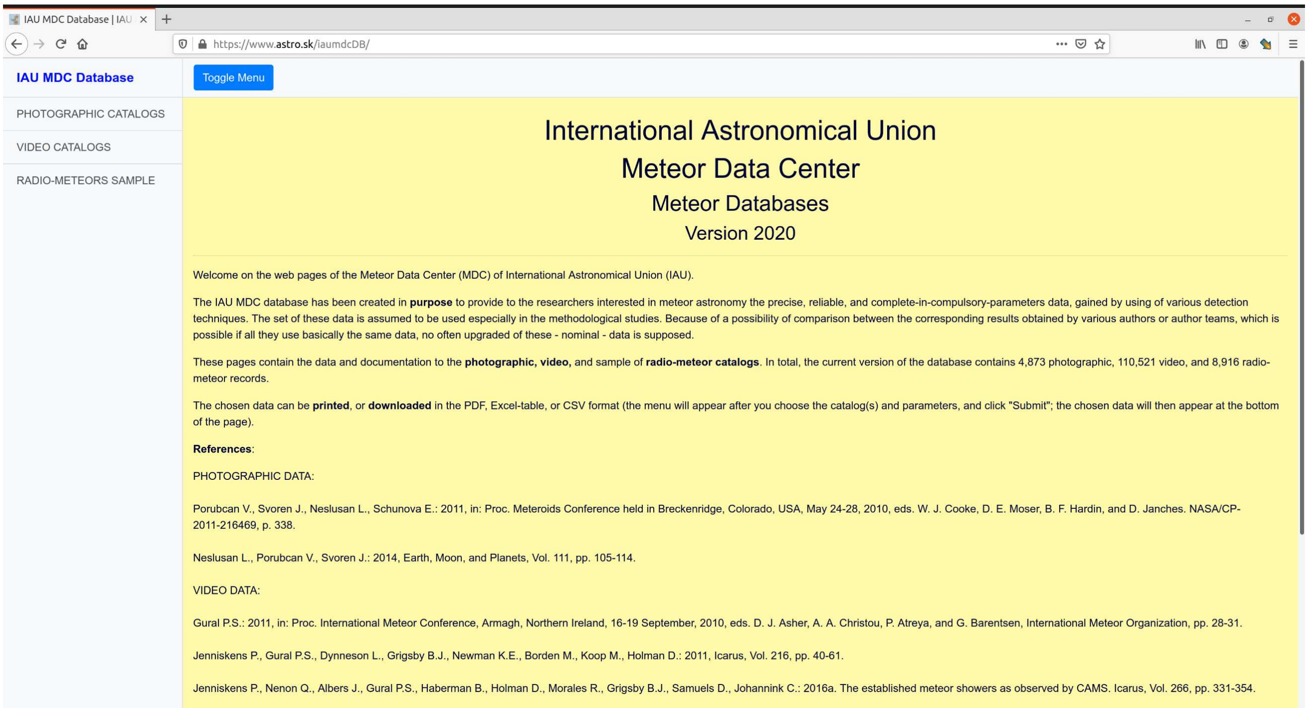

Figure 1 – The title page of the IAU MDC portal.

Table 1 – The list of compulsory parameters characterizing each meteor in the IAU MDC database.

code of parameter	description of parameter
#IC:	IAU MDC identification code
Yr :	year of the meteor detection
Mn :	month of the meteor detection
Day:	day and fraction of day of the detection in the UTC time scale
RA :	right ascension of the geocentric radiant [deg]
DEC:	declination of the geocentric radiant [deg]
Vg :	geocentric velocity [$\mathrm{km\,s^{-1}}$]
Vh :	heliocentric velocity [$\mathrm{km\,s^{-1}}$]
q :	perihelion distance [AU]
e :	numerical eccentricity of the orbit
i :	inclination of the orbit to the ecliptic [deg]
arg:	argument of perihelion [deg]
nod:	longitude of ascending node [deg]

Meteor nomenclature

"Meteor streams" do not exist.

J. Vaubaillon [1]

The difference between a meteoroid stream and a meteor shower is well understood today: meteoroid stream evolving in the interplanetary space cause meteor showers when they enter an atmosphere. For this reason, the expression "meteor stream" is a non-sense: meteors are organised as showers and do not exist outside an atmosphere. Although the usage of "meteor stream" in the literature decreases since the early 2000s, the effort to correctly use meteor-related vocabulary in order to clarify the different phenomena is to be continued.

Received 2020 November 5

1 Introduction

The expression "meteor stream" has been widely used in the past and even today. However, as recalled below, such an expression is a non-sense, since meteors cannot exist in interplanetary space (only meteoroids). The usage of correct words or expression matters both for a better understanding of a phenomenon and in the context of e.g. fake news based on truncated truth. The goal of this short paper is to recall why the expression "meteor stream" should be avoided, and to encourage the dissemination of meteor science.

A brief bibliographic survey undertaken using ADS[a] shows that the expression first appeared (in ADS tool) in a paper abstract by (Perry, 1872). The expression appears first in the title of an article by (Penrose, 1879), where the author reports that stream-like features were observed during a Solar eclipse and interprets them as meteoric material, linked to the "November meteors" (probably the Leonids). The expression appears first (in ADS tool) as linked with a meteoroid stream appears in a paper title by (de Kövesligethy, 1882).

Ever since, the expression "meteor stream" has been widely used in scientific literature. Table 1 sums up the number of occurrence of the expression in the literature (according to ADS).

Table 1 – Number of occurrence of the expressions "meteor stream" and "meteoroid stream" found in ADS database (since 1872).

expression	location	refereed	non-refereed
meteor stream	abstract	750	625
meteor stream	title	385	305
meteoroid stream	abstract	434	327
meteoroid stream	title	177	150

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[a]https://ui.adsabs.harvard.edu/, consulted on 5th Nov. 2020.

2 Meteoroid stream and meteor showers.

According to the today IAU definitions[b]

- A Meteor is the light and associated physical phenomena (heat, shock, ionization), which result from the high speed entry of a solid object from space into a gaseous atmosphere.
- A meteoroid is a solid natural object of a size roughly between 30 micrometers and one meter moving in, or coming from interplanetary space.

As a consequence, as long as a meteoroid is not in a gaseous environment, it cannot cause light emission (beside its own thermal emission). In other words, a meteor can only exist when a meteoroid enters an atmosphere. When lots of meteors are visible within a limited time (typically a few hours to a few days), all seeming to radiate from a single area in the sky (the radiant), the phenomenon is called a meteor shower. This meteor shower results from the collision of meteoroids with the molecules of the atmosphere. The ensemble of these meteoroids is called a meteoroid stream. All of this is of course well known today.

Now no one has ever (intentionally) mentioned the existence of a "meteoroid shower", simply because what is observed are meteors, not meteoroids. Similarly, if meteoroids cannot cause any visible light emission outside an atmosphere, there cannot be any meteor shower in the interplanetary space. What is ejected from comets (or asteroids) and circulates between planets are meteoroids, hence the (correct) expression "meteoroid stream". The natural consequence is that meteors are not organized as stream, but as showers (i.e. what is observed) in an atmosphere. Meteoroids are organized as stream, in the interplanetary space, where meteors (light phenomenon) cannot occur (by definition).

As a result, the expression "meteor stream" is a non-sense, since meteors cannot exist outside an atmosphere. However, meteor showers are caused by meteoroid stream, that exist in the interplanetary space.

3 Problematic

Although the distinction between meteor showers and meteoroid stream is (hopefully) clear, the expres-

[b]https://www.iau.org/public/themes/meteors_and_meteorites, consulted on 5th Nov. 2020.

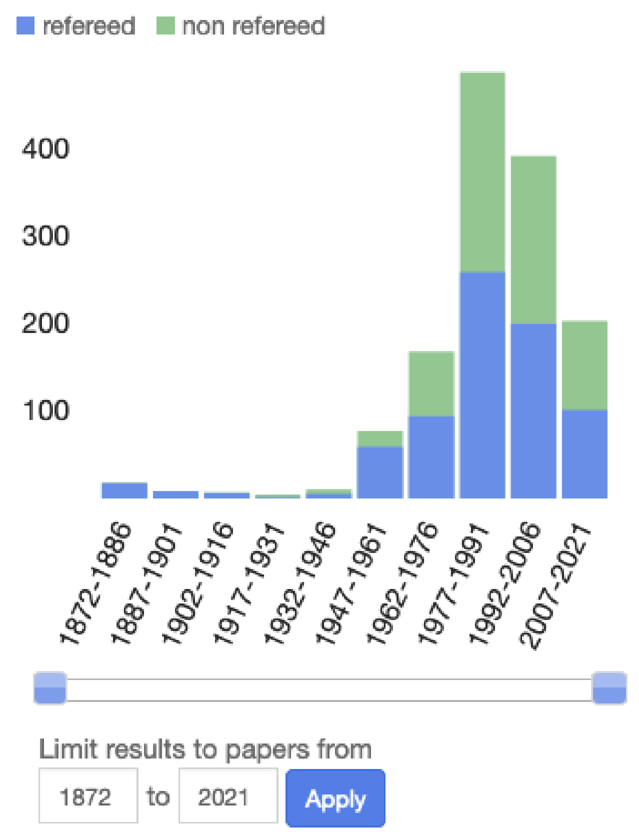

Figure 1 – Number of mentions to the expression "meteor stream" in abstracts as a function of time (data from ADS).

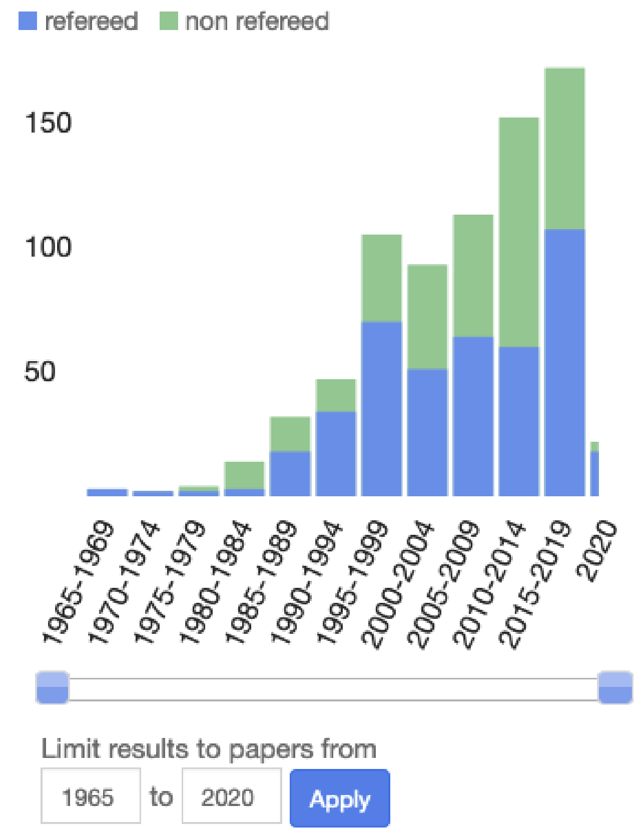

Figure 2 – Number of mentions to the expression "meteoroid stream" in abstracts as a function of time (data from ADS).

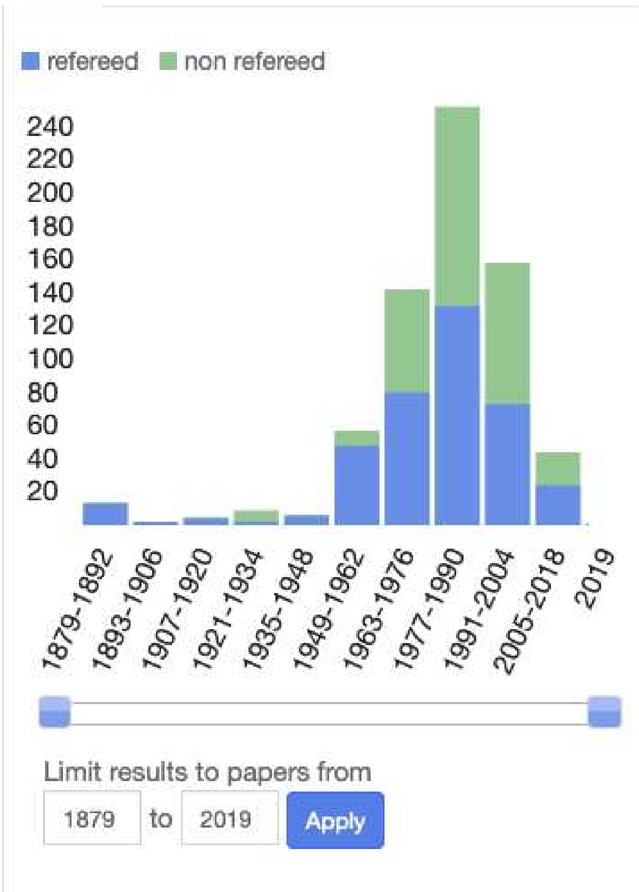

Figure 3 – Number of mentions to the expression "meteor stream" in titles as a function of time (data from ADS).

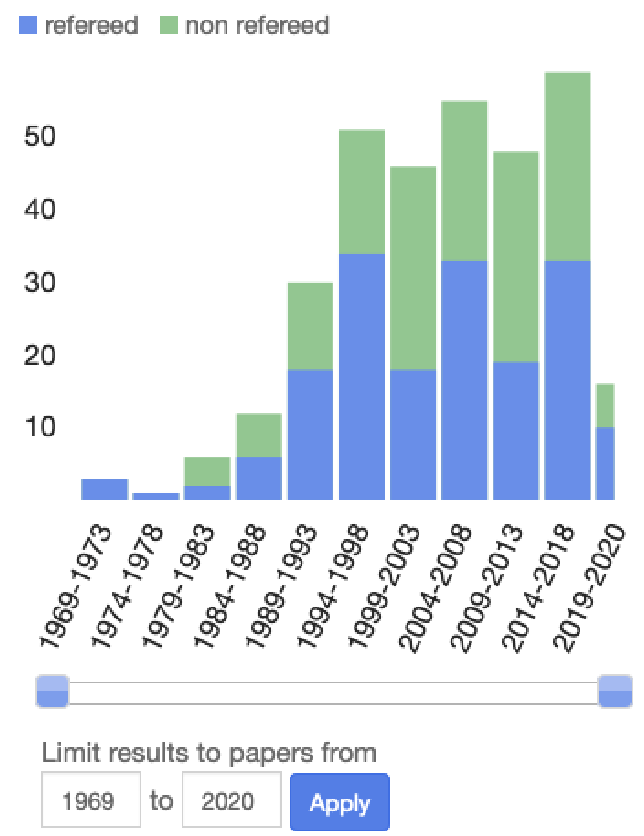

Figure 4 – Number of mentions to the expression "meteoroid stream" in titles as a function of time (data from ADS).

sion "meteor stream" has been and is still widely used today. Figures 1 to 4 shows the evolution of the number of occurrences of both expressions in abstracts and titles (according to ADS). Clearly, a better understanding between the two expressions happened during the 1990s. The relative and absolute number of usage both in titles and abstracts of "meteor stream" declines since the early 2000s, and the usage of "meteoroid stream" increases. This might be due to the popularization of meteor science with the return of comet 109P/Swift-Tuttle in 1992 (responsible for the Perseids) and that of 55P/Tempel-Tuttle (parent body of the Leonids) in 1998. Another factor might be the better understanding of what meteoroid stream are composed of and how to predict their location, in order to predict meteor showers.

4 Conclusion

It seems that the difference between a meteoroid stream and a meteor shower should be understood well enough by now, and that the expression "meteor stream" should never be used at least in the professional literature. Experience shows that this is not the case and some professionals[c] have used such expression in scientific articles. A constant effort to provide accurate vision and vocabulary to newly interested people in meteor science is to be continued, by clearly explaining why the expression "meteor stream" is a non-sense.

[c]including the author of this paper

5 Acknowledgements

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Ongoing meteor work

Southern delta Aquariids (SDA) meteor shower registered by UNIVAP stations in the triennium 2017, 2018 and 2019

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This work presents a three-year (2017, 2018 and 2019) analysis of Southern delta Aquariids (SDA) meteors recorded by UNIVAP-EXOSS Meteor Monitoring Stations and a study of the evolution of their main characteristics over those three years. The analysis showed that, in 2017, 2018 and 2019, two UNIVAP stations recorded 27, 12 and 45 SDA meteors, respectively. In 2017, the recordings occurred between July 12 and August 24, with a peak of activity on July 27. In 2018, they occurred only between July 28 and August 13. For 2019, SDA meteors were recorded between July 11 and August 13, with maximum activity on July 27. In the three consecutive years, SDA meteors presented average duration of 0.18 s, 0.27 s and 0.19 s, average apparent magnitude of −1.1, −1.4 and −0.7 and average linear velocity of 47.1 km/s, 48.7 km/s and 50.7 km/s, respectively.

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1 Introduction

Meteoroid streams are groups of meteoroids originated typically from dust grains ejected for comets. These dust grains are distributed along the orbit of parent comet, concentrated close to the comet nucleus with fewer grains further away from there. Every time the Earth passes through such a stream of dust particles (i.e. meteoroid stream), occurs what is known as a meteor shower.

A meteor shower is a celestial event in which several meteors are observe to radiate from almost the same point in the sky. As mentioned, these meteors are caused by streams of cosmic debris, called meteoroids, entering the Earth's atmosphere with extremely high speeds of order of tens of kilometers per second, on parallel trajectories. Most meteors is smaller than a grain of sand, so almost all of them disintegrate and never hit the Earth's surface.

Since meteor shower particles are all traveling in parallel paths and at the same velocity, all of them will appear to radiate from a single point in the sky to an observer on the ground. This radiant point is caused by the effect of perspective, similar to railroad tracks converging at a single vanishing point on the horizon when viewed from the middle of the tracks.

Meteor showers are usually named by the constellation in which their radiant lies at the time of shower maximum. Meteors observed near the radiant are approaching the observer and they will appear like short streaks in the sky. Meteors seen 45° to 135° from the radiant are moving in a parallel direction to the observer. These meteors will produce longer streaks in the sky. Those seen in excess of 90° from the radiant are actually moving away from the observer and their paths will be shorter than those of meteors that are going away from the radiant.

The UNIVAP integrates the EXOSS network of meteors monitoring stations, for daily recording, cataloging and characterizing the meteors that cross the Brazilian night sky. EXOSS Citizen Science Project[a] is a nonprofit institution with participation of Professional and Amateur astronomers (PRO-AM). The EXOSS network currently consists of 57 meteors monitoring stations and 77 cameras in operation installed in 14 Brazilian states, with almost 60 members from 19 educational or research institutions (EXOSS Citizen Science Project, 2018).

The Southern delta Aquariids (SDA) meteor shower, investigated in this paper, was the meteor shower with the highest number of captures from the EXOSS network stations in 2015 (EXOSS Citizen Science Project, 2015). SDA has a radiant located in Aquarius Constellation, about 3° West of the star δ-Aquarii (officially named Skat) (Universe Guide, 2018), with apparent magnitude of +3.3 and it presents a peak of activity between July 28 and 30. Figure 1 shows the SDA radiant position during the period of 2017 July 10 to August 20. Antihelion Source (ANT), α-Capricornids (CAP) and Piscis Austrinids (PAU) meteor showers also occur in Aquarius Constellation in the period of July–August. However, as shown in Figure 1, they are distinguishable showers separated from each other.

Around the maximum of this southern shower, we can observe quite a number of meteor, with zenithal hourly rate (ZHR) of about 25, according to International Meteor Organization (IMO) Shower Calendars for the years 2017, 2018 and 2019 (see e.g. Rendtel, 2016). At geographic latitudes North of about 45°, the SDA radiant never reaches a reasonable elevation above the horizon.

A study of the radiant structure of the various sources in Aquarius Constellation involving nearly 5000 me-

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NASA-ADS bibcode 2020JIMO...48..173F

[a]`http://press.exoss.org`

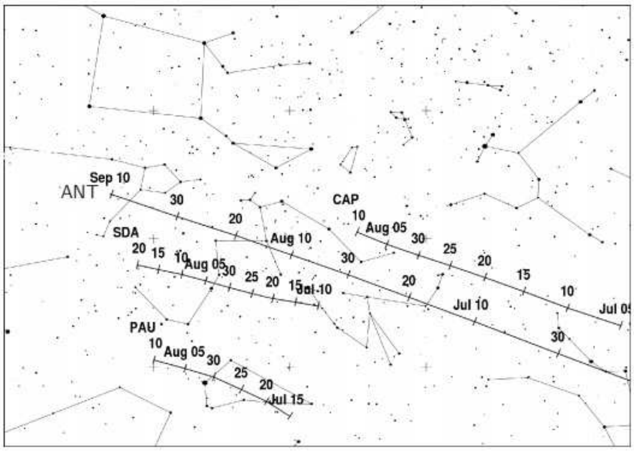

Figure 1 – Sky map of region of Aquarius and Piscis constellations showing the displacement of SDA radiant between 2017 July 10 and August 20. The varying position of the radiant of Antihelion Source(ANT), α-Capricornids (CAP) and Piscis Austrinids (PAU), for several days, is also shown (Rendtel, 2016).

teors from the Aqr–Cap (Aquariid and Capricornid) region, based mainly on data obtained from mid-northern locations, showed the Northern delta Aquariids (AUD), that now became part of the Antihelion Source, nearly occurs between July 20 and August 10. On the other hand, the SDA occurs mainly between July 20 and August 20, with peak around July 28. An analysis of video data allowed to detect the SDA meteors reliably until August 24 (Molau & Rendtel, 2009; Rendtel, 2014).

The first detailed observations of the SDA shower was reported, in 1873, by G. L. Tupman (1873). Tupman plotted 65 meteors (unidentified as SDA at that time) observed between July 27 and August 6. He, also, reported apparent beginning (RA= 340°, DEC= −14°) and apparent ending (RA= 333°, DEC= −16°) points for the radiant. These positions were corrected later. McIntosh (1990) re-plotted the path, based on a greater number of observations made from 1926 to 1933. He determined that it started at RA= $334\overset{\circ}{.}9$, DEC= $-19\overset{\circ}{.}2$ and ended at RA= $352\overset{\circ}{.}4$, DEC= $-11\overset{\circ}{.}8$.

According to Jopek (2011), an extensive study about the parent bodies for several known meteor showers found no parent bodies for the SDA. However, Jenniskens (2008) pointed the meteoroid streams that generate the SDA meteors come from the Mardsen Group of sungrazing comets, which has orbits with perihelion very close to the Sun.

Recent works suggested the Comet 96P/Machholz as the parent body for SDA meteors, according to NASA Science Solar System Exploration (2018). The study from Neslušan et al. (2013b), based on investigation of dynamical evolution of the meteoroid stream of comet 96P/Machholz, pointed that it supplies mainly the SDA shower and also daytime Arietid filaments. These two showers are the most abundant associated to the meteoroid stream originated from comet 96P/Machholz (Neslušan et al., 2013b).

Discovered in 1986, the comet 96P/Machholz (96P/1986 J2 – Machholz 1) has a nucleus of about 6.4 kilometers in length, a short orbital period of 5.24 years (Neslušan et al., 2013b), and its orbit is highly inclined (∼ 58°), with a very low perihelion distance of about 0.124 AU (Eisner et al., 2019).

This comet was cited for the first time in the context of meteor astronomy by McIntosh (1990), as the parent body of the Quadrantid (QUA) shower.

However, according to Neslušan et al. (2013a), the comet 96P/Machholz may not be the unique parent body of SDA meteor shower. The analysis of the dynamics of meteoroids particles released from the surface of near-Earth asteroid 196 256 (2003 EH_1), forming a complex stream structure that approaches Earth's orbit in several filaments, indicates that this asteroid may be responsible for four well-known meteor showers, daytime Arietids, the Southern (SDA) and Northern (AUD) delta Aquariids, and the Quadrantids (QUA), suggesting the origin of a singular structure regards to two parent bodies, one cometary and another asteroidal for the mentioned showers.

As it is one of the most intense meteor showers, several observations and studies on SDA have been reported in the literature, including several campaigns of observation and determination of ZHR, from 16 to 25 during some years. Among which we can cite the Johannink et al. (2008; 2012), Weiland (2016), Miskotte (2017; 2018) and Gaarder (2017) reports.

The purpose of this work is to present the statistical study of the characteristics of the SDA meteor shower for 3 consecutive years (2017, 2018 and 2019). In this way, we also intend to extend and generalize the work presented by Pimentel et al. (2018a) and Pimentel et al. (2018b), for 2017 data and supplemented for 2018 data by Silva et al. (2019), surveying and comparing the duration, velocity and apparent magnitude of SDA meteors.

2 Methodology

Monitoring and detection of SDA meteors were performed at both UNIVAP stations (UVP1 and UVP2). Each station operates in conjunction with a camera, which detects meteors in a given region of the sky every night. The UVP1 station is pointing to the azimuth of 138° and elevation of 63°, and the UVP2 is pointing to the azimuth of 63° and elevation of 58°. The horizontal field of view (FOV) of the two cameras are $64\overset{\circ}{.}25$ and $88\overset{\circ}{.}62$ for stations UVP1 and UVP2, respectively (Silva et al., 2019).

The following SonotaCo software available were used for record and analyse meteor data, in addition to software for statistical analysis:

- UFOCapture – Meteor Capture Software;
- UFOAnalyser – Meteor Analysis Software;
- UFOOrbit – Meteor Orbital Elements Calculator Software.

The software UFOCapture automatically records a video of the sky whenever a light phenomenon is captured by the camera (SonotaCo, 2009). The software UFOAnalyser allows to determine the parameters of

Table 1 – SDA meteors in 2017, 2018 and 2019 by UVP1 and UVP2 stations.

Year	2017	2018	2019
Number of meteors	27	12	45
Period of activity	July 12 – August 24	July 28 – August 13	July 11 – August 13
Peak date	July 27	July 28–30	July 27–28
Peak of meteors	7	6	12

Figure 2 – Images of SDA meteors captured by UNIVAP stations on 2017 July 27 ($04^h45^m37^s$ UT) (left image), on 2018 July 30 ($07^h30^m11^s$ UT) (middle image) and in 2019 August 02 ($02^h54^m26^s$ UT) (right image).

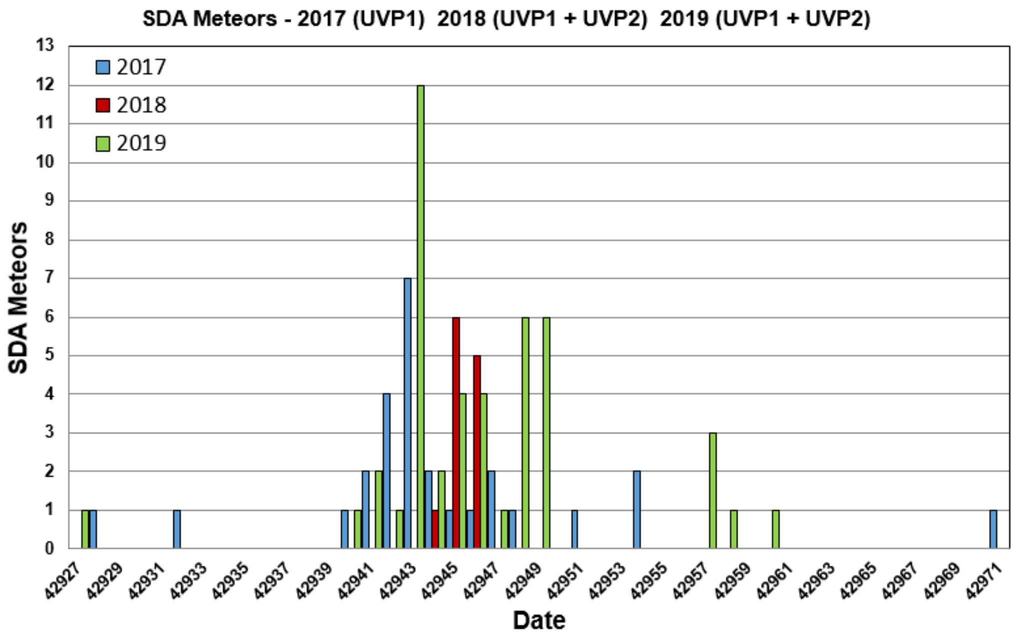

Figure 3 – Daily distribution of SDA meteors recorded by the two UNIVAP meteor monitoring stations, in the years 2017, 2018 and 2019.

the recorded meteors (SonotaCo, 2007). Thus, from the recorded data the radiant SDA was identified for the years 2017, 2018 and 2019 in both stations and, using UFOAnalyser automatic tools, the apparent magnitude, duration and linear velocity of each of the identified SDA meteors.

3 Results and Discussions

Considering the meteor shower library of the UFOAnalyzer software, the survey showed that, in 2017, 27 meteors associated with the SDA radiant were identified, recorded between July 12 and August 24, with peak of activity recorded on the night of 2017 July 27/28 (with 7 meteors). For this year, only the UVP1 station was in operation at UNIVAP. The UVP2 was put into operation only at the end of 2017.

For 2018, 12 SDA meteors were recorded by the two UVP monitoring stations, being 6 captures for each station. The meteors recordings are concentrated in the nights of 2018 July 28, 29 and 30. These numbers represent a decrease of more than 50%, compared to the number of meteors recorded in the previous year. For the same year, Silva et al. (2019) reported that the stations UVP1 and UVP2 registered a total of 15 SDA meteors, between July 18 and August 20. Such a difference in the number of recorded meteors is due to the fact that, recently, the cataloged meteor showers library was reviewed. In this way, the classification was revised and the total number of registered meteors identified as SDA decreased from 15 to 12.

In turn, in 2019, 45 meteors belonging the SDA shower were recorded by UNIVAP stations between July

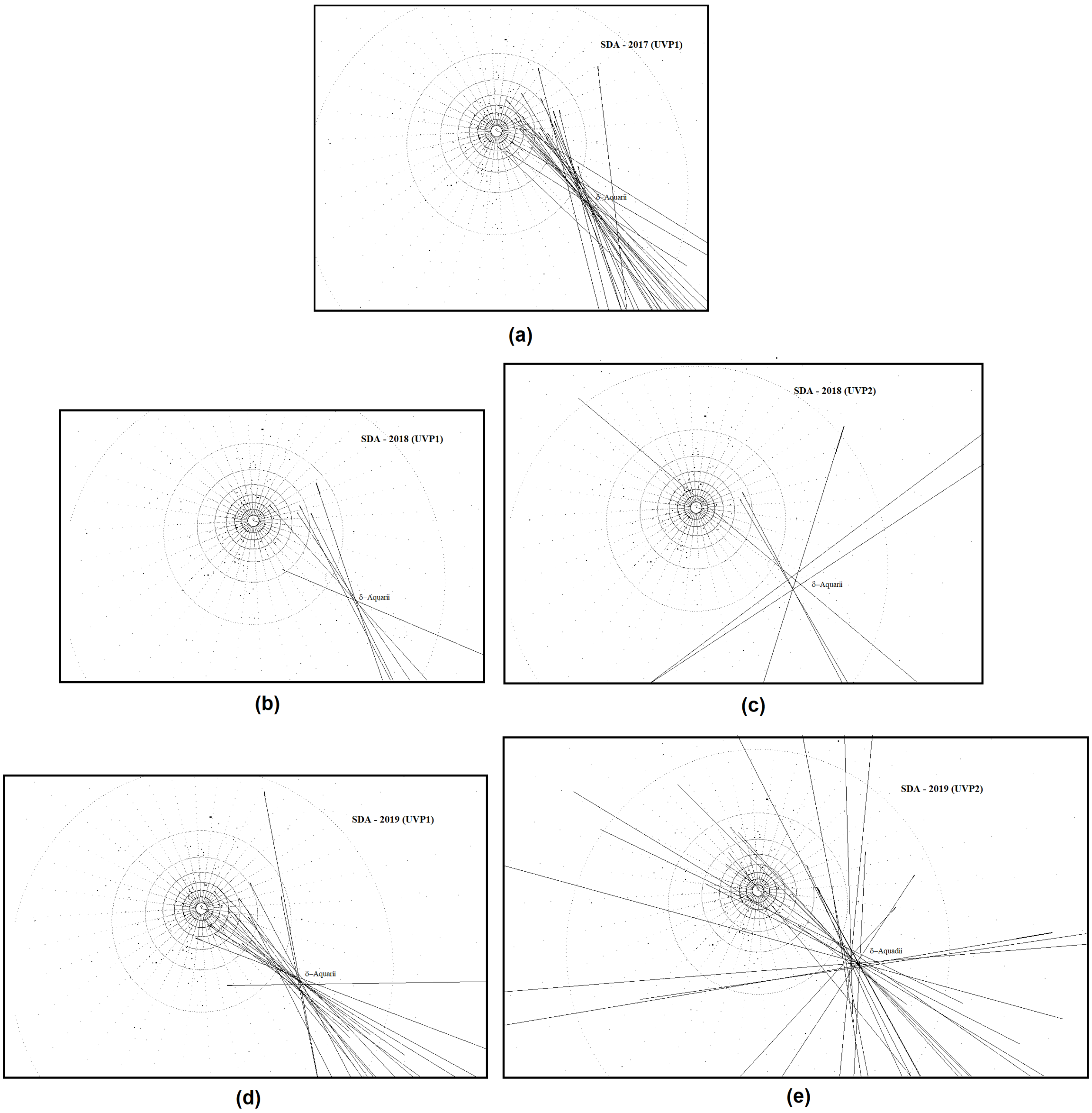

Figure 4 – Trail maps of SDA meteors recorded by the two monitoring stations in operation at UNIVAP: in 2017 by UVP1 (a); in 2018 by UVP1 (b) and UVP2 (c); and in 2019 by UVP1 (d) and UVP2 (e).

11 and August 13, and the peak of activity for this year was in the night of July 27–28, with 12 captures. Then, the number of meteors associated with SDA recorded by UNIVAP stations, in 2019, was higher then to the previous years, almost quadrupling, compare to 2018 and almost doubling compare to 2017. All these data are summarized in Table 1.

Figure 2 shows examples of the SDA meteors recorded by the UVP stations and processed using UFOAnalyzer software. The distributions of the number of meteors recorded by the two UVP stations for each year of 2017, 2018 and 2019 are shown in the Figure 3.

In order to verify possible effects of climatic conditions on the observations, which would justify the great variation in the number of recorded meteors, a survey was made on the sky conditions during the period of occurrence of the SDA shower (nights between July 10 and August 24), in three analysed years. For the year 2017, from those 46 nights, only 7 showed a partially cloudy sky, and on 2 of these nights, the clouds were not present throughout the whole night.

In 2018, 14 nights presented cloudy or partly cloudy skies during the observation period of SDA meteors. For other 14 nights, it was registered intervals with rain, mainly during the nights before the peak of the shower activity. In these nights, the two stations did not record any meteor. Consequently, it is probably the reason for the drop of the number of captures in 2018, once other places did not register this drop (Molau, 2020). For 2019, the sky was cloudy in 6 nights and rainy in 4 nights, in which no meteors was registered. We emphasize that, in the maximum activity nights, no rain was registered for all three years.

A survey of the number of sporadic meteors was also carried out for the same periods studied. In 2017, 61 sporadic meteors were recorded, in 2019 there were 87 records and in 2018, only 9, all in the night of July 29–30. Such results corroborate the assumption that, in

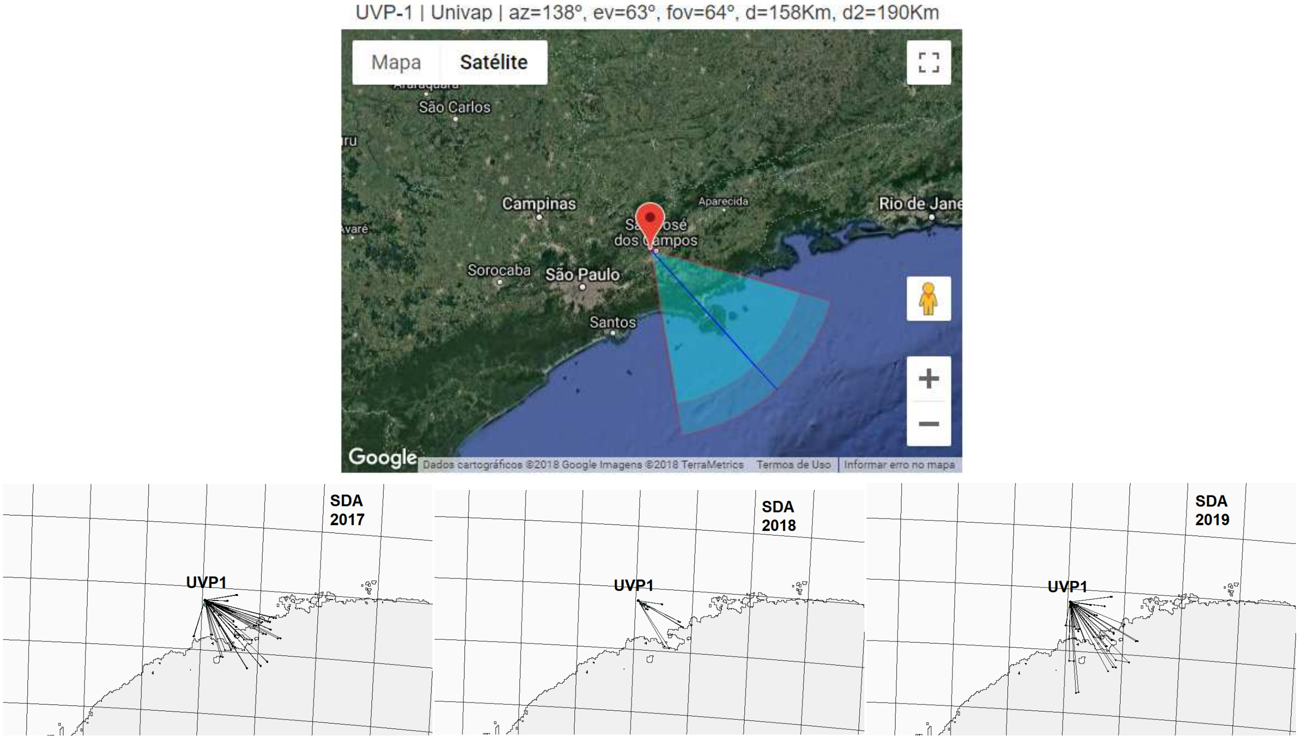

Figure 5 – Location and FOV of UVP1 station (top) and ground maps (GMap) of the SDA meteors recorded by UVP1 in 2017 (bottom left), 2018 (bottom middle) and 2019 (bottom right).

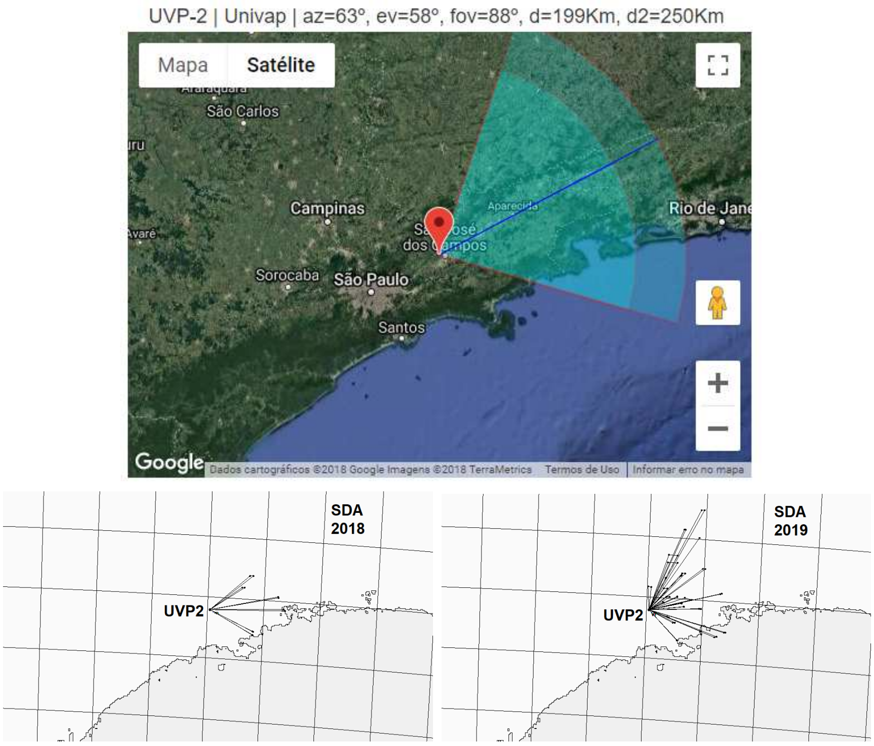

Figure 6 – Location and FOV of UVP2 station (top) and ground maps (GMap) of the SDA meteors recorded by UVP1 in 2018 (bottom left) and 2019 (bottom right).

2018, records were probably affected by adverse weather conditions.

Using the UFOAnalyzer, trail maps (TMap) were plotted for the SDA meteors recorded by the UVP1 and UVP2 stations in the three years analyzed, as shown in Figure 4. It is possible to notice that the meteors recorded in 2018 and 2019 by the UVP2 station present a greater spatial spread.

Figures 5 and 6 show the ground maps (GMap) generated by UFOAnalyzer with the SDA meteors recorded by two stations.

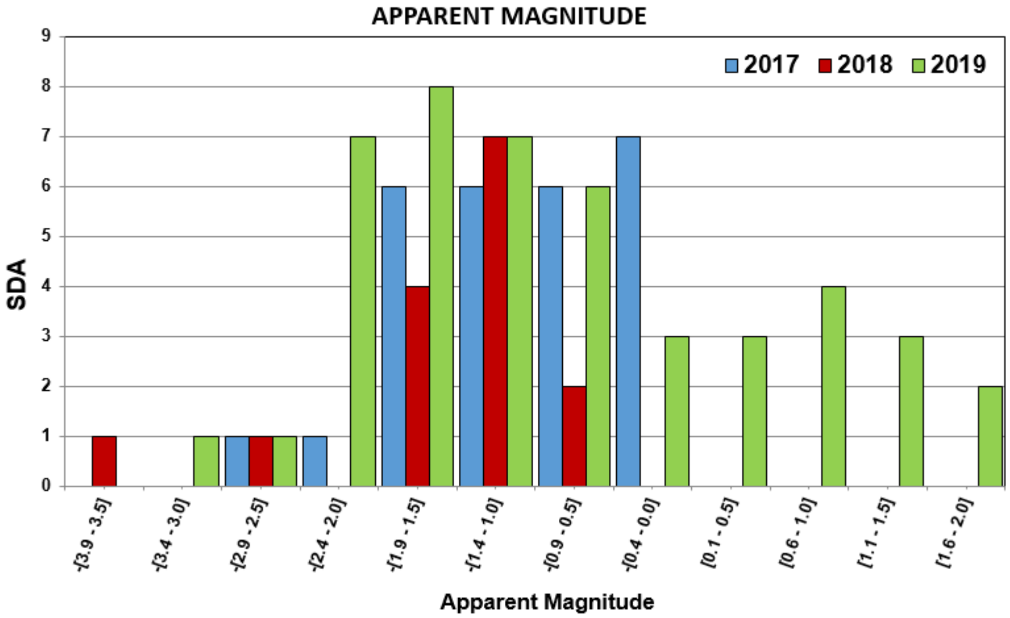

Figure 7 – Histogram of the apparent magnitude of the SDA meteors recorded in 2017, 2018 and 2019.

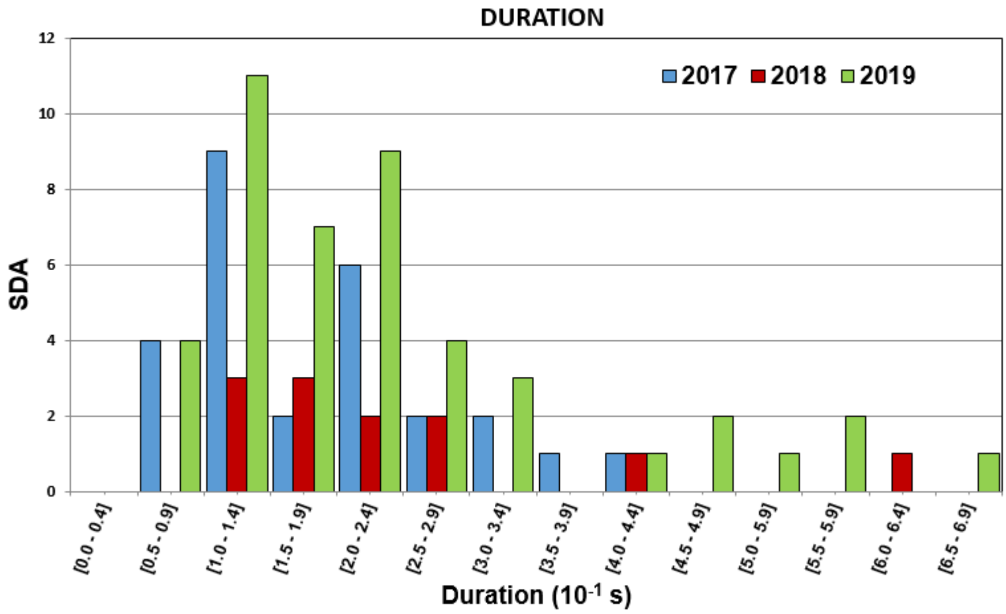

Figure 8 – Histogram of the duration of the SDA meteors recorded in 2017, 2018 and 2019.

The distribution of the values related to apparent magnitude, total duration and linear velocity, for those SDA meteors recorded by UNIVAP stations are shown in Figures 7, 8 and 9, respectively. The range and mean values for these parameters are summarized in Table 2. The velocity data presented a large variation, it seems to us a little uncommon, however the precise determination of the meteor velocity is only possible when simultaneous captures occur for two or more stations, which are separated by a large distance, allowing a triangulation between the records of the different stations and calculation of the meteor trajectory parameters. Therefore, this presented linear velocity is just a projection (estimated).

As seen in Figure 7, from the apparent magnitude distribution, in general the SDA are not very bright meteors. However, they are brighter in 2018, when 100% of the meteors presented magnitudes inferior than 0. In 2019, more than 30% of the SDA have apparent magnitude between 0 and +2. Such results, despite presenting lower magnitude values, agree with the results obtained by Weiland (2016) from observations of 250 SDA meteors recorded in Crete in 2014. Those observations showed that 48% of SDA presented magnitudes of +4 to +5, and only 12 of all SDA observed reached at least magnitude 0.

Although less frequent in 2018, SDA meteors were, on average, longer lasting and brighter and faster than in 2017 and in 2019, that show similar mean duration and mean average apparent magnitude. The linear velocity of meteors was higher in 2019 than in previous years, mainly the minimum estimated linear velocity.

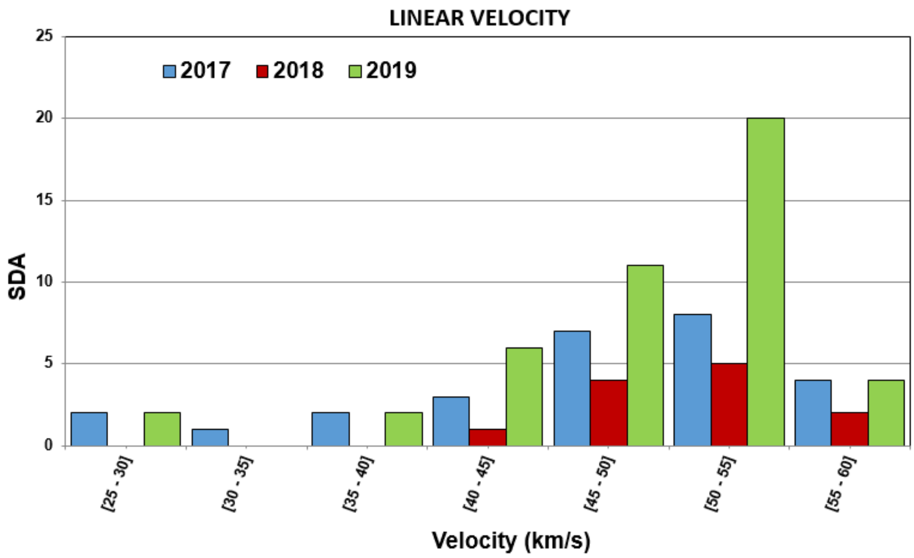

Figure 9 – Histogram of the linear velocity of the SDA meteors recorded in 2017, 2018 and 2019.

Table 2 – Minimum, maximum and average values of SDA meteors parameters (2017, 2018 and 2019) by UVP1 and UVP2 stations.

Parameter	Value	2017	2018	2019
Duration	minimum	0.06	0.10	0.07
(s)	maximum	0.44	0.68	0.66
	average	0.18	0.27	0.19
Apparent	minimum	0.0	−0.5	+1.4
magnitude	maximum	−2.6	−3.5	−3.3
	average	−1.1	−1.4	−0.7
Linear	minimum	27.4	29.0	37.5
velocity	maximum	56.3	56.2	57.2
(km/s)	average	47.1	48.7	50.7

This higher velocity, joint with the other parameters, may indicate that, in the year 2019, SDA meteors probably entered the Earth's atmosphere at a higher altitude.

4 Conclusion

In this paper, we presented the statistics of meteors recorded by UNIVAP (UVP1 and UVP2) monitoring stations, in 2017, 2018 and 2019, associated with the Southern delta Aquariids (SDA) shower. We emphasize that, in 2017, only the UVP1 station was in operation during the period of occurrence of the SDA shower. The SDA shower represents one of the most intense showers for the UNIVAP stations. The results show that the average SDA meteors linear velocity has increased over the three years, the minimum and maximum velocities also shows an increasing trend. The maximum values of each parameter in the three years are close.

In 2019, a larger number (45) of SDA meteors were recorded. Even considering that the weather conditions (presence of clouds or rain) were worse in 2018, mainly during the beginning of the period of occurrence of the SDA rain, the observations suggest, in fact, an increase in the number of meteors in 2019.

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Conferences

Luminous efficiency determination and its challenges

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The luminous efficiency τ describes the fraction of lost kinetic energy of an entering object converted into brightness. This parameter is used to calculate a meteoroid's mass from its observed brightness. Presently, the luminous efficiency is part of current research and its determination based on several assumptions. Amongst others, different meteor parameters have to be assumed. They range from the shape of the meteoroid, which changes during the flight through the atmosphere, possible fragmentation, to the composition of the meteoroid as well as of the atmosphere, and aspects of the detection themselves. The data of FRIPON, the Fireball Recovery and InterPlanetary Observation Network, was used to calculate the luminous efficiencies of their recorded meteors. First, deceleration-based formulas for the mass computation of the corresponding meteoroids were used. Then, the recorded light curves were investigated to determine the luminous efficiencies. We found τ-values in the range of $10^{-4}\%$ – 100%, whereas most are in the order of 0.1%–10%. In this work we will briefly introduce the process of obtaining these values and point out its difficulties.

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1 Introduction

Meteors and fireballs are of large public and scientific interest. Especially the brighter ones can cause a lot of attention in the general public. The AMS/IMO (American Meteor Society/International Meteor Organisation) collects and analyses witness reports of meteor sightings, see e.g. Hankey and Perlerin (2014). On social media there is a large interest on bright events, which is the reason why these platforms are used as an information source for NEMO, the NEar real-time MOnitoringsystem, which is operated by ESA's Near-Earth Object Coordination Centre (NEOCC), see e.g. Ott et al. (2020).

The initial meteoroids or asteroids are of special scientific interest since they are expected to be originated from larger asteroids or comets. These parent bodies are thought to be almost unchanged since the formation of our solar system. Hence, by studying meteors, we can learn about our Solar System's formation.

The luminous efficiency τ is a parameter which is frequently used in meteor physics. It describes the fraction of kinetic energy loss that is converted to the luminosity of the entering object along its path through the atmosphere. Although the parameter is needed to calculate the pre-entry mass of the observed body from its brightness, τ is only established relatively inaccurately. Values in the literature vary by orders of magnitude, compare e.g. Verniani (1965) who found values down to 0.02 % in the course of an analysis of meteors recorded with the Harvard photographic meteor project, and Svetsov and Shuvalov (2018) who found values as large as almost 20% based on simulations for entering asteroids and comets. These differences could be caused by different assumptions that have to be made to calculate the parameter τ.

We will show how the comparably robust method introduced by Gritsevich (2008) to determine the mass of the entering object from height and velocity observations with fewer assumptions needed than those usually used for the computations, can be utilized to compute the luminous efficiency as presented in Gritsevich and Koschny (2011).

In Section 2 the utilized method is briefly described. Section 3 presents some values of the luminous efficiency that can be found in literature. The utilized data is introduced in Section 4 and first results in Section 5. A short conclusion is given in Section 6.

2 Method

To derive the pre-entry meteoroid mass that corresponds to a detected meteor different methods can be carried out. A lot of them use the recorded brightness of the meteor as a starting point. As introduced by Verniani (1965), the relation between the emitted light intensity I, the meteoroid's mass loss dM/dt, and its pre-entry velocity v_e can be described by

$$I = \frac{-\tau v_e^2}{2} \frac{dM}{dt} \tag{1}$$

It includes the luminous efficiency τ describing the portion of the kinetic energy of the entering body that is emitted as visible radiation. Hence, the relation to compute the pre-entry meteoroid mass M_e can be described

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by

$$M_e = \frac{2}{\tau v_e^2} \int I_s ds \tag{2}$$

The term $\int I_s ds$ describes the light I that is emitted during the flight through the atmosphere in Watts and integrated over the flight path s. As is can be seen an assumption for τ has to be made affecting the resulting mass. A different way to compute the pre-entry meteoroid mass is to use the observed velocity and height information of the meteor. Based on the rate of deceleration of the entering object its pre-entry mass can be computed. This was done e.g. by Gritsevich (2008). Gritsevich and Koschny (2011) use the information found with this method to determine τ using the brightness data. As explained in the just mentioned work in detail, the proper value of τ, as well as of the shape change coefficient μ, can be found with a least-squares fit with equation (3) to the observed light curve.

$$I(v^*) = \frac{\tau M_e \; v_e^3 \; \sin(\gamma) \; f(v^*)}{2 \; h_0} \tag{3}$$

with

$$\begin{aligned} f(v^*) = v^{*3}\Big(\overline{E\iota}(\beta) - \overline{E\iota}(\beta v^{*2})\Big) \cdot \left(\frac{\beta \; v^{*2}}{1-\mu} + 1\right) \\ \cdot \; \exp\left(\frac{\beta \; (\mu v^{*2} - 1)}{1-\mu}\right) \end{aligned} \tag{4}$$

with the meteor brightness I, the angle between horizon and trajectory γ, the scale height of the Earth's atmosphere h_0, the mass loss parameter β, which is derived during the process of pre-entry mass determination as explained in Gritsevich (2008), the exponential integral $\overline{E\iota}(x)$:

$$\overline{E\iota}(x) = \int_{\infty}^{x} \frac{e^z \; dz}{z} \; , \tag{5}$$

and the dimensionless velocity

$$v^* = \frac{v}{v_e} \; . \tag{6}$$

Figure 1 – The fireball from 6 January 2020 recorded with the FRIPON station at Bedonia, Italy.

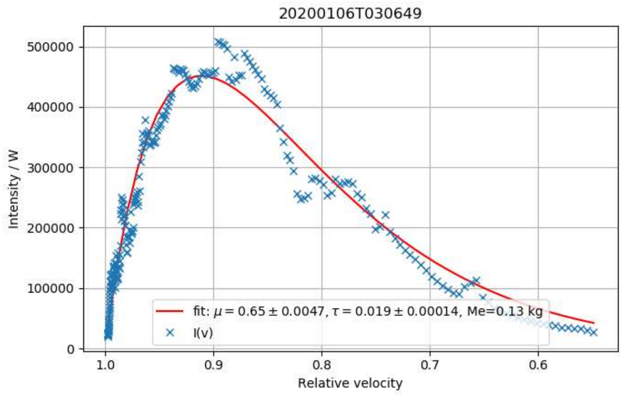

Figure 2 – The computed light curve of the fireball from 6 January 2020 with applied fit. The x-axis displays the relative velocity v^* the meteor for which each velocity value is divided by the meteor's initial velocity. The computed brightness values in Watts are shown as blue '×'. The applied fit is displayed as a solid red line.

To give an example, in Figure 1 a fireball that occurred above Italy on 6 January 2020 at 03:06:49 UTC is shown. It was detected with four stations of the FRIPON network and its absolute magnitude reached a peak brightness of about −6.3 mag. In Figure 1 the image of the fireball taken with the FRIPON station at Bedonia, Italy, can be seen. The computed light curve of this fireball with applied fit, according to Equation (3), is presented in Figure 2. For this fireball, a value of τ around 1.9% was derived.

3 Literature values

Various studies were done to compute the luminous efficiency of meteors. They include diverse types of data from analysis of optically recorded data (e.g. Verniani, 1965) and radar data (e.g. Weryk and Brown, 2013), to laboratory measurements (e.g. Friichtenicht et al., 1968) or simulations (e.g. Svetsov and Shuvalov, 2018). The obtained results differ by orders of magnitudes. As shown e.g. by Koschny et al. (2017) or Subasinghe et al. (2017) even small variations in τ can yield large differences in the computed mass of the entering object.

One main difficulty in computing the luminous efficiency or even in meteor physics in general is the large number of unknown parameters with a big impact on the result for which values have to be assumed. These include, amongst others, the shape and mass of the entering object. Additionally, the change of the shape and mass during the flight through the atmosphere are usually not known. The process of fragmentation has to be kept in mind also. Furthermore, the composition of not only the meteoroid itself but also of the atmosphere are uncertain. Uncertainties of the detection method do also affect the results, as well as the uncertainties of the observed parameters like the velocity, height, and brightness of the meteor.

4 Data

Several networks are spread all over the world which were designed for meteor and fireball monitoring. Examples are the Australian Desert Fireball Network (Howie et al., 2017), or the Canadian Automated Meteor Observatory (Weryk et al., 2013). One European network is the French FRIPON (Fireball Recovery and InterPlanetary Observation Network). The network covers the sky over France, as well as large areas of the sky above the neighbouring countries. It consists of all-sky cameras which are operated completely autonomous during night time. For more information about the FRIPON network see e.g. Colas et al. (2014) or Colas et al. (2020). Data collected and analyzed by the network as explained in Jeanne et al. (2019) is used for this study. The pipeline uses a similar approach within the data analysis of the FRIPON network as presented in Gritsevich (2008) to compute the pre-entry meteoroid mass based on the recorded deceleration data, see Jeanne et al. (2019) for details.

5 Results

Applying the method summarized in Section 2 and explained in the publications mentioned therein, we analysed data collected with FRIPON cameras. 3871 confirmed events were in the database and have been investigated (status as of 2020 July 4). Of these, a subset of 294 fireballs and their luminous efficiencies has been investigated and will be presented in this work. These fireballs were chosen based on different aspects. A very important point is that enough and good quality observation data is available for the event. A fireball that was not recorded simultaneously by at least two cameras does not have sufficient data available to apply our method to. The reason is that the brightness values derived from the recording all-sky cameras include relatively large uncertainties which are in the order of half a magnitude. Furthermore, some events did produce non-physical viable results or results with very large errors. Those were also excluded. For the 294 events the luminous efficiencies were computed and the distribution is presented in Figure 3. As it can be seen, the τ-values span a wide range of values from 10^{-4}% to 100%. Most of the calculated luminous efficiencies are in the range 0.1%–10%.

In Figure 3 it can be seen that derived values for the luminous efficiency can be as high as 100%. That is of course physically unrealistic as it would imply that all kinetic energy of the meteoroid would be transformed into (visible) light. No energy would be left for e.g. ablation and deceleration. Such high values for τ are obtained mainly for the smallest masses. They could result from a combination of observational bias, fragmentation, or break down of the analysis method for these cases. Further investigations are ongoing. As already stated in the title: it is rather difficult to derive the luminous efficiency of entering meteoroids.

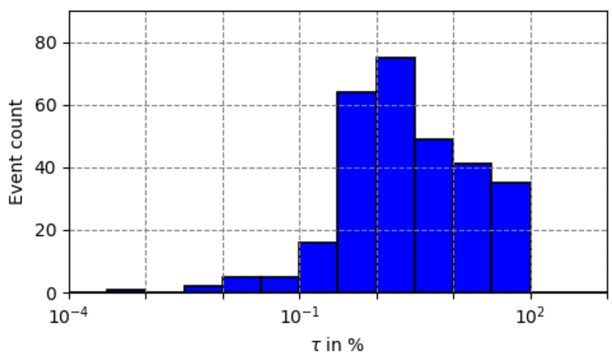

Figure 3 – Distribution of luminous efficiencies τ of 294 analyzed FRIPON fireballs in percent.

6 Conclusion

The luminous efficiency of meteors is still only poorly understood. Values that can be found in literature derived with various methods vary by orders of magnitudes. Nonetheless, this parameter is frequently used since it is needed to compute the pre-entry mass of the entering meteoroid or asteroid, respectively, from an observed meteor's recorded brightness. The lack of certainty is mainly due to the large amount of unknown or uncertain parameters that have to be assumed to determine the proper value of the luminous efficiency. These parameters include, amongst others, the mass and shape of the entering body which do change during the flight of the entering object along its way through the Earth's atmosphere. Its composition and behavior of fragmentation have to be taken into account too, as well as numerous further aspects. The method used in this work does use the deceleration data of the observed meteor to compute its mass and by comparing the shape of the observed light curve the luminous efficiency can be determined. This way fewer assumptions have to be made to calculate the luminous efficiency. Data of FRIPON, the Fireball Recovery and InterPlanetary Observation Network, was utilized since the recorded fireballs are in a promising size range and have good quality deceleration data. A subset of 294 fireball events was analyzed and the computed luminous efficiencies presented. They range from 10^{-4}% to 100%, whereas most found luminous efficiencies are in the order of 0.1% to 10%. Still, a lot of possible uncertainties have been found. Analyzing these sources of errors in more detail is the next step and part of our future work.

Acknowledgement

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Another Daylight Fireball over The Netherlands: The event of 2020 August 25

Felix Bettonvil [1,2,3]

In recent years, we notice that more daylight fireballs are reported. This initiated the development and installation of a dedicated daylight all sky camera, aiming at capturing such events with good quality. On the 25th of August 2020, yet another daylight fireball appeared, around sunset, which was captured by the daylight camera. 240 fireball reports were received. We report on the results and analysis.

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1 Introduction

Fireball patrol cameras are usually designed to capture fireballs during night time. Unfortunately, fireballs – and in particular meteorite droppers – do not only appear at nighttime: there are various examples of great fireballs that did appear at twilight or even daytime. Moreover chances for survival of bodies entering the Earth's atmosphere are larger around 18 h local time.

Thanks to the rather well-working reporting of fireball events in the Netherlands via the IMO web forms, we notice that daylight events are better reported than in the past. Notably, three of the brightest fireballs over the Netherlands in the past three years appeared during twilight or daytime (Bettonvil, 2020).

Accurate images are however rare, making analyses cumbersome. This resulted in the development of a daylight all sky camera (Bettonvil, 2020). This summer a first daylight fireball occurred with the camera in operation.

2 The fireball

The fireball appeared on 2020 August 25 at 20:50:22 CEST (18:50:22 UT), only about 10 minutes after sunset. The sky was still bright (Figure 1). The event was seen by many people. Five minutes after the event, a first visual report was submitted via the Dutch IMO fireball form of the *Werkgroep Meteoren* (IMO fireball report, event 4773-2020 (2020); see `https://fireballs.imo.net/members/imo_view/event/2020/4773`).

Ten minutes after the event the number of reports increased to eight, and within 15 minutes we had 16 reports. Since every report creates an email notification, this was also the moment that the *KNVWS Werkgroep Meteoren* got alerted. It was evident that something big was seen. In order to stimulate further reporting, the KNVWS Werkgroep Meteoren decided to initiate a tweet on Twitter ($t_0 + 22\,\mathrm{min}$) to alert because of a possible fireball event, with the request to report. Reports continued at an average rate of one per minute, with 110 reports two hours after the event. In parallel, the website of the Werkgroep Meteoren was immediately updated with actual information.

This first tweet received broad attention: the message reached $\approx 33,000$ people. Reports continued coming in also the next morning, and lasted until five days after the event. The total number of reports was 240.

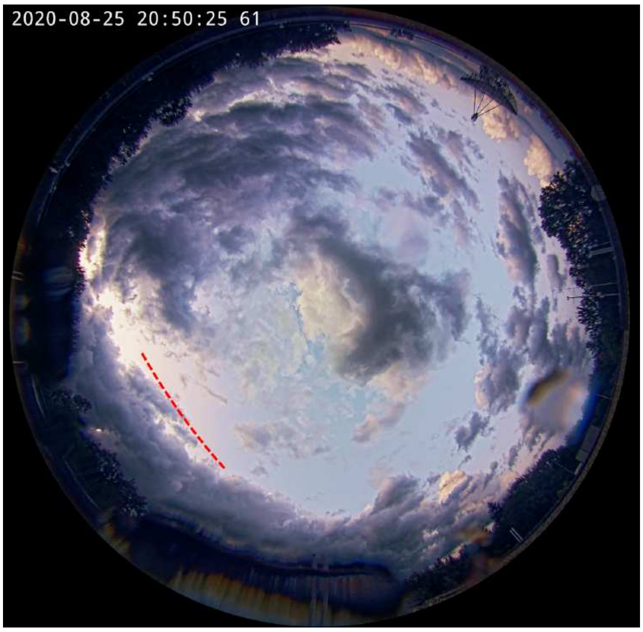

Figure 1 – Daylight allsky image, with in red indicated the trajectory of the fireball. Note the partly overcast sky, and the fact that the fireball appeared just above a cloud bank. Therefore the end of the fireball was missed.

3 Detection

A direct quick analysis showed that the event had appeared over the most northern provinces. The daylight camera was operational, but it took some time to identify a fireball registration. This was due to the uncertainty in time (±10 minutes) and partial cloud cover. It seemed the fireball was not captured, but two hours after further analysis proved the event was captured – it had appeared just above a cloud bank (Figures 1 and 2).

In the next morning, a second and third tweet were sent out with an request for more video and photo material. This did however not lead to additional pictures.

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Figure 2 – Still image from the video capture, showing two fragments at the final part of the trajectory.

4 Analysis

With only one image at hand, it was decided to perform a trajectory calculation based on triangulation of (a) the video image, and (b) the ground trajectory as automatically computed from the IMO reports.

Astrometry of the video image was straightforward, and done on the basis of an existing astrometric solution done two weeks earlier on a night time image (residual error $\pm 1.4'$). In order to perform triangulation with two stations, a virtual station was composed from the IMO data that was triangulated with the all sky video observation. This 'virtual' station was stationed on geographic coordinates where the fireball started in zenith, with one direction vector pointing towards the zenith (beginning point), and one direction vector at lower (chosen) elevation but with azimuthal direction identical to the fireball path (Figure 3).

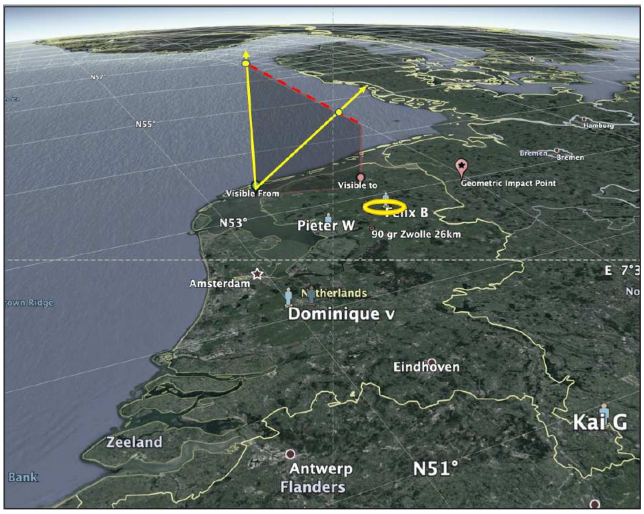

Figure 3 – Computation of the atmospheric trajectory. The yellow circle indicates the location of the daylight all-sky camera (Dwingeloo), the red dashed line the IMO trajectory as derived from the IMO fireball reports. The two yellow lines represent the virtual observation constructed from the IMO trajectory, and used for the triangulation.

Results of the calculation are shown in Table 1. The fireball lasted for 5 seconds, started at 69 km and ended at 25 km height. At that point the fireball disappeared behind the cloud bank (Figure 1), and very likely continued its path. By how much is not known. Likely in that last part, a flash happened, which was reported by several witnesses but is not seen in the video.

Witnesses also reported fragmentation, which indeed could be seen on the video (Figure 2), where a smaller fragment follows the main body at the last part of the trajectory.

Brightness could be estimated from the fortunate coincidence that also the Moon was visible. From (a) count of the total flux of both of the Moon and the fireball and (b) the size of both objects it was estimated that the brightness has been inbetween -7 and -9 mag. This is excluding the reported flash, which was not recorded.

From the velocity and the radiant the heliocentric orbit was computed, which resulted in an asteroidal orbit (Table 1, Figure 4)

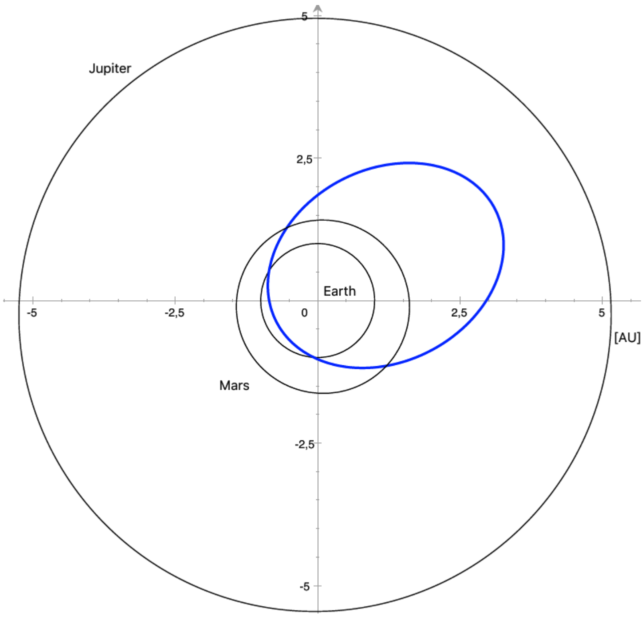

Figure 4 – Heliocentric orbit of the object, indicating an asteroidal origin.

5 Meteorite?

The heliocentric orbit, in particular when looking at the semi-major axis a and the inclination i, indicates that the origin is asteroidal (Figure 4). The terminal height in the atmosphere, the deceleration with terminal velocity of 8 km/s (derived from the video image, and possibly lower since the end of the trajectory did hide behind clouds) and the fact that at least two fragments were seen, leads to our conclusion that we can cannot exclude that meteorite fragments have reached the ground, although the reported flash may suggest that a (complete) disintegration occurred.

The large uncertainty in the trajectory made it nonetheless useless to perform a dark flight calculation and to predict a potential dropping location. A meteorite recovery campaign seemed not worth the effort.

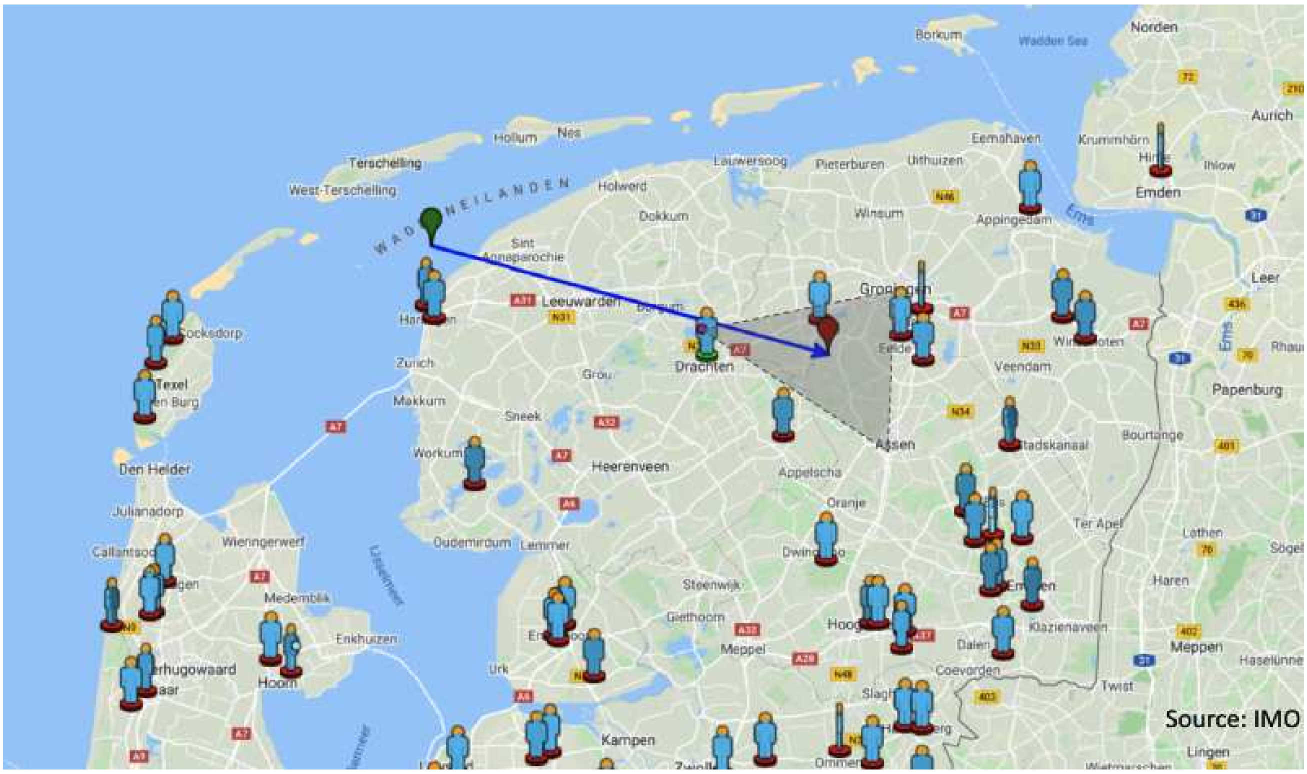

Figure 5 – IMO fireball trajectory and indicated area with for possible meteorite fragments as shared with the public.

Table 1 – Main characteristics of the orbit and the atmospheric trajectory.

Time of appearance	18:50:22 UTC
Duration	5 seconds (from video)
Beginning height	69 km
Terminal height	25 km (from video, likely lower)
Entry velocity	21 km/s
Terminal velocity	8 km/s (likely smaller)
Fragmentation	at least 2 fragments
Brightness	-7 to -9 (excluding reported flash at end)
Heliocentric orbit	Asteroidal $\Omega = 333°$ $\omega = 230°$ $a = 2.2$ AU $i = 14°$ $e = 0.62$

Instead we decided to widely broadcast a rough dropping location, a triangular area, of order 10×10 km^2 pinned by three larger towns (Figure 5), and inform the public for the possibility meteorite fragments via website and Twitter. Local media was not contacted.

Apart from one report of a stone that hit a garden table, no response was received, and so far no meteorites have been recovered.

6 Conclusions

Another daylight fireball was reported over the Netherlands. This time we succeeded to acquire our own video recording, though only a single one. From this event we learned:

- The IMO fireball reports are the trigger that something of interest happened. This information is indispensable, as automatic detection of daylight events is difficult.
- It turns out that the first message with additional information on social media is a single hit. News value diminishes quickly: the first tweet reached 33,000 people, the subsequent ones 500 – 1000, (despite their higher information content). Much emphasis should be put in adding as much information as possible immediately, e.g. requests for photo and video material, chance for meteorites, dropping area (to the preferred level of accuracy), etc., in order make maximal use of the media attention.
- Public meteorite recovery requires almost certainly more effort than only sending messages on social media channels and update of websites.
- Implementation of fixed cameras proves being easy and also crucial. For this particular case, with only one camera extra, results would have been much more certain.

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Connecting ionospheric, optical, infrasound and seismic data from meteors over Hungary

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Two synergic topics of meteor recordings are presented using observations in Hungary. Ionospheric observations linked to optical data provided the identification of sporadic E layer from individual meteor, straightening a new possible way of observations even during cloud covered sky. Another example presents the series of seismic observations of the large bolide on 2020 February 28 over Croatia and Slovenia, where the air blast sweeping above the surface produced ground movement.

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1 Introduction

Methods of meteor observations being expanded recently. Alongside the classical visual methods, digital cameras revolutionized the optical (Tóth et al., 2014) and occasionally spectral (Ferus et al., 2020) recording of meteors, and various versions of radio (Obenberger et al., 2020) and radar (Chen et al., 2020) observations are available alongside some satellite data. Infrasound detectors could also provide data of large fireball events, when even seismic recordings are possible under certain conditions. In the last decade ionospheric consequences of meteors could be also recorded. The aim of this work is to outline some connections between them and future possibilities in the linking of different observation types of meteors. This work also summarizes some results of the GINOP-2.3.2-15-2016-00003 project titled *Cosmic effects and risks.*

Below three topics are presented, where meteors have been recorded by different methods: ionospheric, infrasound and seismic, beside the optical version. During the ionospheric observations Sporadic E (Es) layers produced by meteors in the ionosphere were analyzed, which are thin regions of enhanced electron density around 80 – 150 km height. They are produced by windshear transported ions from meteors by strong winds (Whitehead, 1989; Haldoupis, 2011).

Supersonic meteors could generate infrasound waves (Pilger et al., 2015) that can be recorded by microbarometers (Edwards, 2010; Ens et al., 2012; Silber & Brown, 2014) Low-frequency infrasound waves can travel thousands of kilometer distances with little attenuation. Related seismic signals might also be recorded (Borovicka et al., 2013; de Groot-Hedlin & Hedlin, 2019; Hedlin et al., 2010; Spurny et al., 2010) from the shock wave produced by a bolide.

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2 Methods

The **optical image** below a recorded by a Watec 902H2 Ultimate camera, equipped with a Computar HG2610AFCS-HSP objective (focal length 2.6 mm, 30 mm effective lens aperture, with 122×97 degree field of view toward the zenith). This station operates with Metrec (© Sirko Molau) automatic meteor detection software. The limiting magnitude was about +2 for meteors.

The **ionospheric data** were recorded by the reflection of electromagnetic waves from ionospheric plasma. In this work Digisonde DPS-4D ionosonde was used (installed at the Széchenyi István Geophysical Observatory at 47°63 N, 16°72 E). It monitors the ionosphere with a 15 minute time resolution in standard mode using a multi-beam sounding mode by six digitally synthesized off-vertical reception beams plus a vertical beam. However for successful meteor detection, the sampling interval was shortened to 1 minute only. The received reflected beams are processed for each frequency and height on a multi-beam ionogram (Reinisch, 1996; Reinisch et al., 2005) The result of the measurement is the so-called ionogram that represents height-frequency characteristics of the ionosphere. The meteor produced layers appear as traces on the ionogram.

The **infrasound array** located in the Mátra Mountains, Northern Hungary, consists of 4 elements, with an aperture of 250 m. All the elements are equipped with a SeismoWave MB3d microbarometer with a built-in digitizer and a rosette wind-noise reduction system (Alcoverro & Le Pichon, 2005) made of flexible hoses. This is part of the international Atmospheric dynamics Research InfraStructure in Europe (ARISE) and Central and Eastern European Infrasound Network (CEEIN, HNIN) networks.

There are 57 seismological stations working in Hungary in 2020. A part of them (41) is operated by the Seismological Observatory of Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences (CSFK GGI). Six stations are borehole ones i.e. the sensor is not located directly on the surface but in a borehole at different depths (five are at 150 m and one is at 75 m). Seismometers are installed at the bottom of the boreholes which are not closed tight, so fluctuations in air pressure can actuate both the bottom and the top seismometer.

3 Results

Useful example observation was made on the night of 2019 November 19 during the Leonid campaign. The meteor indicated in Figure 1 was optically observed at $00^h48^m23^s$ UT with maximal brightness of +1.0 magnitude at high elevation around 85° above the horizon.

A faint sporadic E layer up to 5.5 MHz at 115 km elevation can be determined on the ionogram recorded at $00^h48^m40^s$ (black arrow on Figure 1). There was no observed such Es activity on the ionograms detected before and after this event (Figure 1). It is a good example for a faint, short-lived Es layer (max. 20 seconds). Furthermore, the direction of the echo can be also defined on the ionograms of the DPS-4D Digisonde thanks to the multi-beam observation technique. The direction of the detected Es layer is west (purple color on the ionogram, Figure 1) that agrees well with the optical observation.

3.1 Infrasound and seismological effect

A large bolide could be seen on the daytime sky on 2020 February 28 (Ott & Drolshagen, 2020) at the Croatian-Slovenian border region. A 1.5 m diameter meteoroid entered the atmosphere at around 09^h30^m UTC, and exploded at 34.5 km releasing 0.34 kt by its explosion (Carbonari, 2020). The detected infrasound effect can be seen in Figure 2. Although it was an atmospheric event, seismometers recorded the acoustic signal as the shock wave caused ground movement (Figure 3).

Comparing the observations of different stations, the disturbance sweeping across the network can be seen in the case of almost all stations. By measuring the arrival times of this signal at each station, the apparent speed of the disturbance can be calculated (Figure 4). According to our calculation the apparent speed of this signal is 312 m/s which is very close to the speed of sound in the air. This suggests that the shock wave in the air generated by the exploding bolide was strong enough to be recorded by seismometers even at a distance of several hundreds of km.

4 Discussion and conclusion

Comparing different observational types of meteor phenomena, complementary aspects could be identified. While ionospheric effects have been observed for moderately bright meteors, infrasound and seismic effects refer to only huge fireballs. Although such observations do not present such accurate orientation data as optical images, they might be still useful to detect meteors in daytime or under cloud cover – however further improvements are necessary. While ionospheric observations could detect meteors only above the observer (probably emerge at least 40°–50° above the horizon), while optical meteors could be observed in case of bright ones closer to the horizon, infrasound and related seismic effects beyond the horizon. Depending on the energy of explosion, really large events could be observed even globally.

Rapid sampling ionosondes could identify single meteors, however they need to occur at high elevation

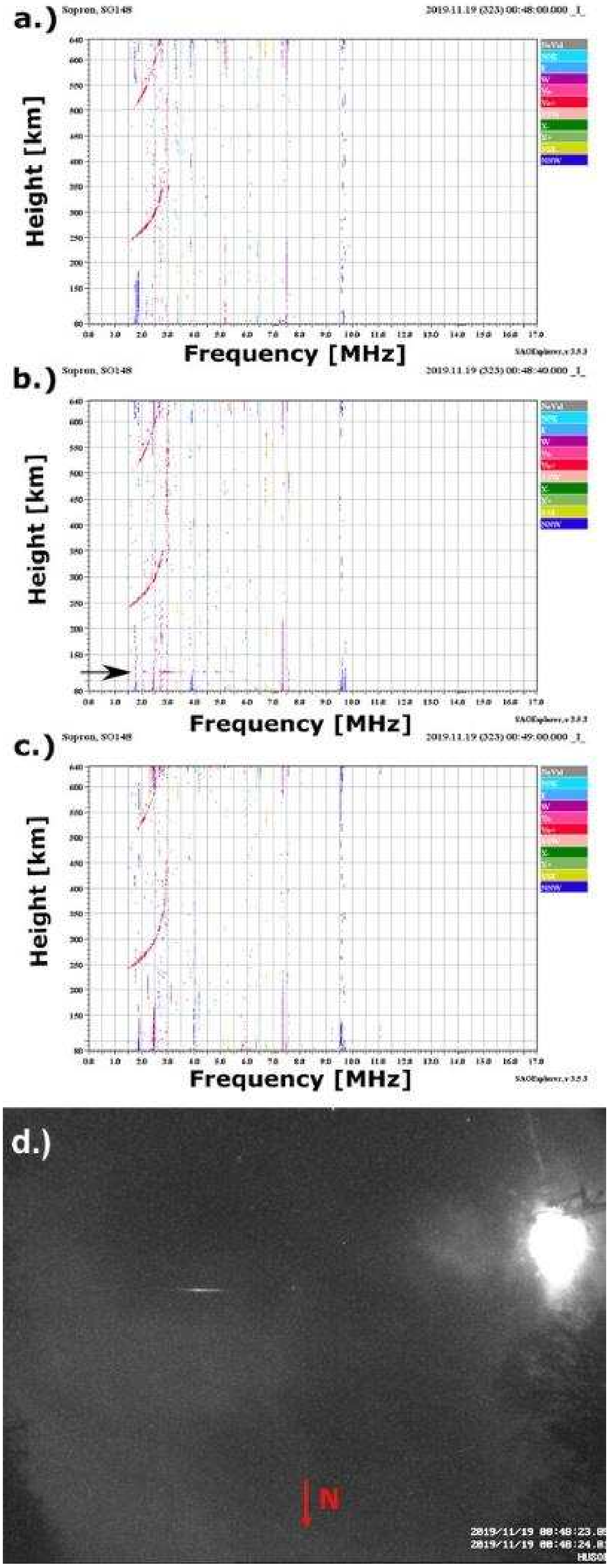

Figure 1 – Ionograms recorded at Nagycenk station at $00^h48^m00^s$ (a.), $00^h48^m40^s$ (b.) and $00^h49^m00^s$ (c.) respectively on 2019 November 19. The color of the detected traces indicate the direction of the received signal. The black arrow shows the detected faint Sporadic E echo. (d.) Optical observation of the meteor at $00^h48^m23^s$ on the same day, with full moon at right.

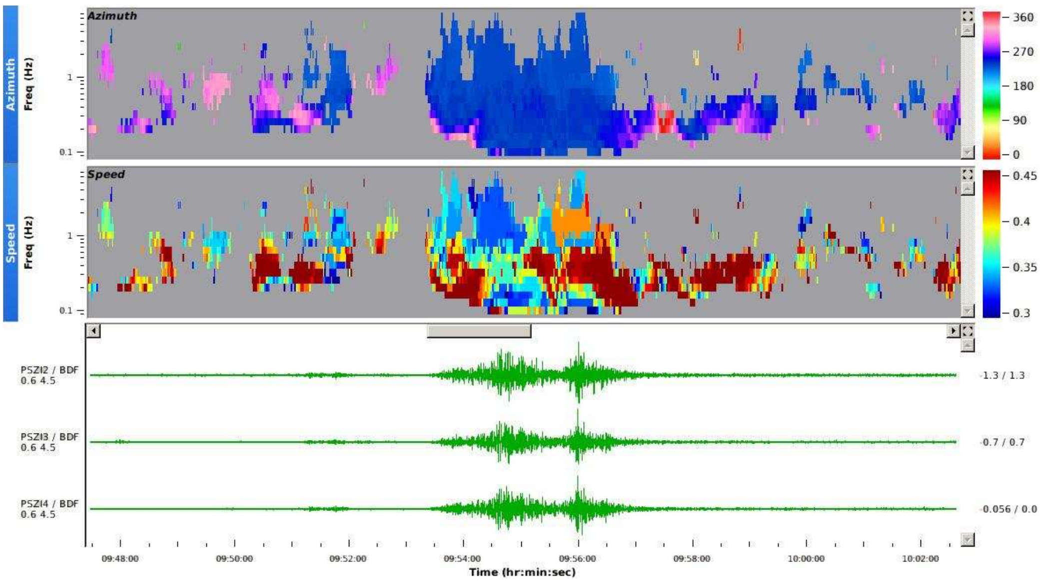

Figure 2 – Waveforms of the 2020 February 28 bolide detected at the Piszkés-tető infrasound array, and the apparent velocity (middle) and azimuth (top) of the infrasound detections, color-coded by frequency.

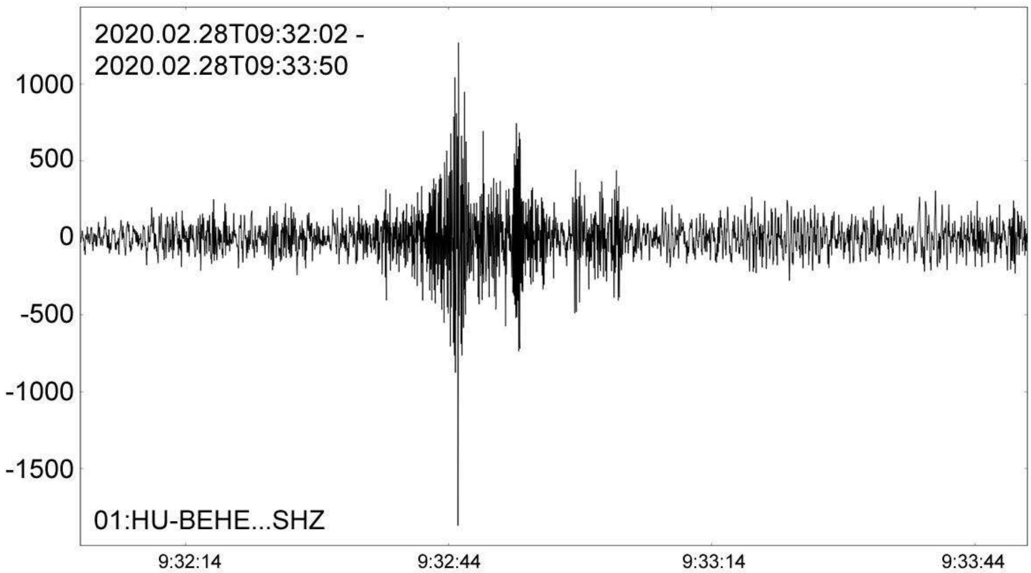

Figure 3 – The vertical ground movement at BEHE (Becsehely, Hungary) station at a distance of 160 km (length of this section is 1.5 minutes).

above the horizon. In this work with the presented observation confirmed this possibility, similar to earlier by meteor showers (Goldsbrough & Ellyett, 1976; Maruyama et al., 2003; Maruyama et al., 2008). Despite the successful observation there is an obvious knowledge gap on the identification of ionospheric effects linked to specific meteors, and increased frequency observations is necessary. Therefore, the installation of the zenith optical meteor camera next to the DPS4D Digisonde at the Széchenyi István Geophysical Observatory provided an exceptional opportunity for us to observe and determine plasma trail of meteors with the one to one comparison of the optical observations and the high cadence ($\approx$ 30 s) ionograms.

While in the case of normal Es layer the height and frequency are stable on the consecutive ionograms while in the case of meteors there is obvious difference in such parameters comparing consecutive ionograms (Haldoupis, 2011). Furthermore, the observed echoes of meteor trails are weaker compared with the typical echoes from the sporadic E and F layers, which also agrees with the results of the previous studies (Maruyama et al., 2003; Maruyama et al., 2008). The **direction** of the sounding pulse reflected from the spontaneous Es layers could be also identified and agreed well with the optical observation. The angle of a multibeam Digisonde is $\pm 45°$ from the zenith (Reinisch, 1996), which means a $\approx$ 100 km radius at the height of the Es layers (100–120 km). This is the reason why a similar ionosonde at 200 km distance (Pruhonice station) did not observe the meteor's echo.

The appearance of the seismological signal produced by the atmospheric blast obviously differed from the characteristic seismological events, but its characteris-

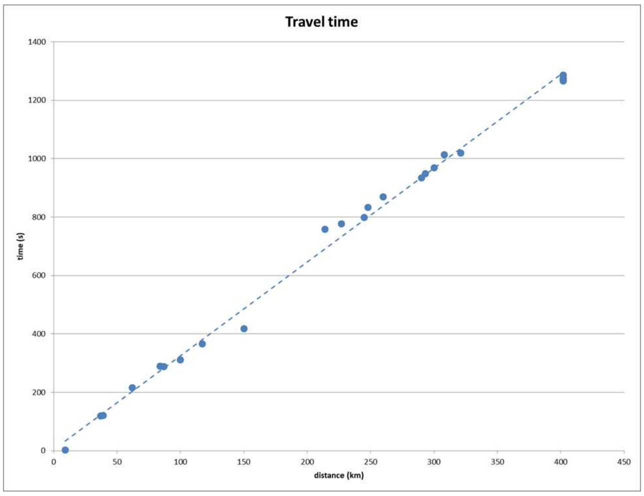

Figure 4 – Travel times of the disturbance measured at different seismic stations vs. epicentral distance. Slope of the fitted line shows the apparent velocity of the shock wave which is 312 m/s in this case.

tics are far not understood yet, however in an earlier case for example fragmentation events could be identified (Atanackov et al., 2009).

There is different **threshold limit of observations** (bolide size, brightness, meteor spatial, temporal occurrence) between the presented methods. The smallest meteoritic bodies (down to cm size) could be identified optically, while the effect of this sized meteoritic bodies could be also identified on the ionosphere, although probably larger objects could be better identified. The infrasound and the related seismic effects should be identified from objects with an order of magnitude larger sized about 1 m diameter. It is expected using the joint evaluation of various observations together provides a **better coverage of the number of happened meteor events**. The ionospheric effects could be observed in daytime too – however it is not well known what is the difference between the behavior of nighttime and daytime reactions of the ionosphere. The infrasound effects provide data on the large explosions also above the oceans and including daytime hours, where and when optical monitoring is not possible.

There are several aspects that should be explored in the future. As the ablating meteors deposit a range of metallic ions there including Fe+, Mg+, Si+, Na+, Ca+, K+, Al+ the ionospherc observations might link to optical spectra of various meteor streams (Ferus et al., 2020; Koukal et al., 2016), but more detailed information is required to get more insight into the **composition of meteors**. The energy deposition of breakup events during the flight depends on the fragmentation style, internal strength and explosion height. Elevated metal ion density increases ionization and electron density of the given zone in the ionosphere – however the wind shear could make the situation complex, but some **compositional or structural characteristics might be roughly estimated** in the future.

The interaction between the atmospheric blast wave and the **elastic seismic waves** generated in the ground is poorly understood, but joint observations of height/energy of exploding events and seismic reactions where known, specific input parameters help the better estimation of the characteristics of the seismic waves (Svetsov & Shuvalov, 2014). For example, the Chelyabinsk fireball produced a seismic event magnitude of 3.8, while the seismic magnitude of the Tunguska event of 1908 is estimated between 4.8 to 5.0. Estimates for the total energy release based on infrasound observations alone are derived from atmospheric nuclear explosions of 10 kT or larger events. Exploiting the correlation between the atmospheric and seismic effects could improve the understanding of the air blast energy, and it might be more accurately estimated from the joint analysis of seismic and infrasound recordings.

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Does a meteor's "color" reflect its spectral classification?

Althea V. Moorhead[1], *Aaron Kingery*[2]

The current best way to obtain information about a meteoroid's composition is to measure meteor spectra at a resolution fine enough to distinguish between emission lines. However, simple color filters are cheaper and easier to use than a grating or radiometer, and it is therefore tempting to try to use a set of filters to characterize a meteor's "color" despite the extremely coarse spectral resolution of this approach. To test whether color filters can provide useful information about meteoroid composition, we convolved the light curves from a catalog of meteor spectra (Vojáček et al., 2015) with B, V, R, and I Bessell filters. We find that the Borovička et al. (2005) meteor spectra classifications cannot be retrieved using color alone, with the possible exception of iron meteoroids.

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1 Introduction

Color – or, more precisely, color index – is a useful measurable quantity for certain astronomical objects. For instance, because stars resemble black bodies in their emission spectra, color index can be used to determine a star's temperature. Furthermore, there is a predictable relationship between the brightness and color of main sequence stars, which in turn enable astronomers to determine the distance and age of stellar clusters using a Hertzsprung-Russell diagram. The utility of color in astronomy is not, however, limited to stars; there is also evidence that asteroids redden as they age due to weathering processes (Jedicke et al., 2004). Given the wealth of information that can be derived from the colors of astronomical objects, it is tempting to measure the color index of meteors.

Unlike stars and asteroids, meteors have spectra that are strongly line-dominated (see Figure 1). As a result, it is possible that two meteors with very different emission spectra could have a similar difference in apparent brightness when viewed through two different color filters (Gural, 2015).

There have been many previous attempts to survey or use meteor color measurements. Many of these studies relied wholly or partially on visual observers' assessment of color (e.g., Jacchia, 1957; Ceplecha, 1959; Ceplecha et al., 1965; McBeath, 1990, 1991; Zay, 1993). However, human color perception is influenced by factors such as contrast (McBeath, 1990), after-image color (McBeath, 1990), or the Purkinje effect (Purkyně, 1825; Usanin et al., 2019). Visual color has generally not been found to be a useful meteor measurable, aside from reports that Geminids reliably differ in color from other showers (Sperberg, 1990).

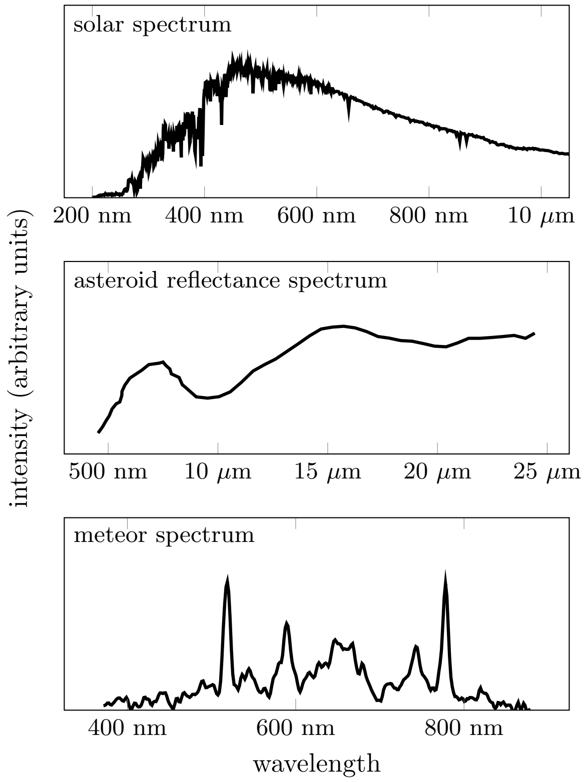

Figure 1 – Sample spectra from the Sun, an asteroid, and a meteor. In contrast with stellar and asteroid reflectance spectra, meteor spectra are heavily dominated by emission lines. Solar spectrum data are provided by DOE/NREL/ALLIANCE, asteroid spectrum data are adapted from Binzel et al. (2010), and meteor spectrum data are taken from Vojáček et al. (2015).

These visual studies have been accompanied and followed by a series of photometric color surveys (Kohoutek, 1963; Hajduková, 1972; Hajduková, 1973; Usanin et al., 2019). Despite the quantitative benefits of using systems that are less subjective than visual observations, these color surveys have not reported many useful color trends (one possible exception is the report by Usanin et al., 2019, that shower members cluster together in color-color space). Full spectra appear to be far more useful in classifying meteors (Borovička et al., 2005; Drouard et al., 2018).

It is still possible that color index may correlate with meteoroid composition, but this clearly must be tested. In this work, we conduct such a test by generating synthetic color magnitudes from published meteor

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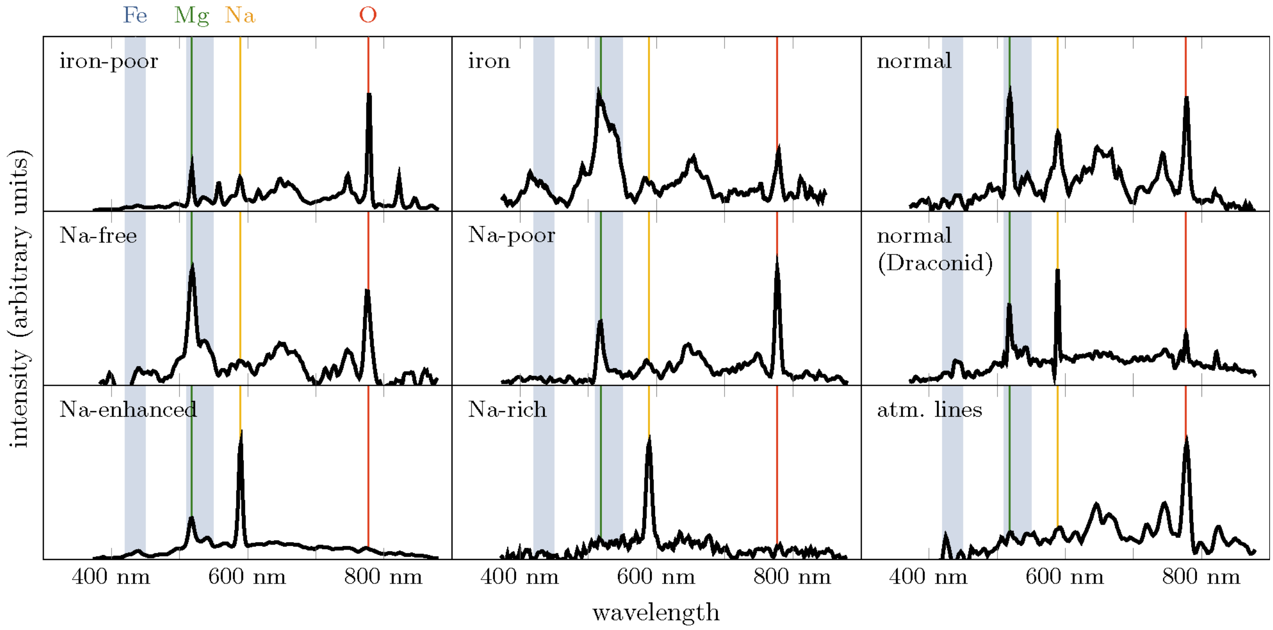

Figure 2 – Sample meteor spectra from Vojáček et al. (2015). Seven different classes or sub-classes are represented in their catalog, plus one meteor that did not fit into the Borovička et al. (2005) classification scheme ("atm. lines"). In this figure, we show at least one example from each class (two "normal" meteor spectra are shown, one of which is a Draconid). We also label key emission lines that show up repeatedly in meteor spectra: the Mg I (552.8 nm) line, the Na I (589.2 nm) line, the O I (777.4 nm) line, and the $\sim 420 - 450$ nm and $\sim 510 - 550$ nm intervals that encompass many contributing Fe I emission lines.

spectra. We use the 84 representative meteor spectra published by Vojáček et al. (2015) as our test data. This library contains examples of seven different meteor classes or sub-classes as defined by Borovička et al. (2005). In some cases, only a few meteors of a particular class are available, but the "normal", "iron", "sodium-free", "sodium-poor", and "sodium-enhanced" classes are well-represented (i.e., have at least 5 examples in the data set). We convolve these spectra with Bessell B, V, R, and I transfer functions (Bessell, 1990) to predict their apparent color-magnitudes and search for any visible separations between meteor classes in color-space (Ocaña, 2017, used the same approach to generate synthetic colors using Johnson-Cousins B, V, and R filters).

2 Data and Methods

Vojáček et al. (2015) have made their data publicly available; these data include both a master table specifying the characteristics of each meteor, including class, and the individual meteor spectra. These meteor spectra files include relative intensity measurements ranging from 380 to 900 nm, although not all meteors have measurements that cover this entire range. Nine sample meteor spectra from Vojáček et al. (2015) are shown in Figure 2.

These meteors are classified based on the strength of key emission lines, which we have marked in Figure 2 with vertical colored lines. We refer readers to Borovička et al. (2005) for a full description of spectral classifications, but, in brief, meteors are placed into the following categories:

- **Iron** meteor spectra have broad features at 420-450 nm and 510-550 nm corresponding to multiple unresolved Fe I lines.
- **Sodium-free** meteors are non-iron meteors that also show no sodium emission.
- **Sodium-rich** meteors have spectra that are dominated by sodium emission.
- **Mainstream** meteors show a combination of iron, magnesium, and sodium emission lines that is closer to what is expected from a chondritic composition. They are divided into the following subclasses:
  - **Normal** meteor spectra have close to the expected proportion of Mg, Na, and Fe contributions.
  - **Sodium-poor** meteors have spectra in which the sodium line is weak but still visible.
  - **Sodium-enhanced** meteor spectra have a strong, but not overwhelmingly dominant, sodium line.
  - **Iron-poor meteoroids** have spectra with close to the expected combination of sodium and magnesium, but with a weak iron contribution.
- Vojáček et al. (2015) published one meteor spectrum (labeled SX1101 in their catalog) that lacks iron, magnesium, *and* sodium emission lines, and was dominated by **atmospheric lines**.

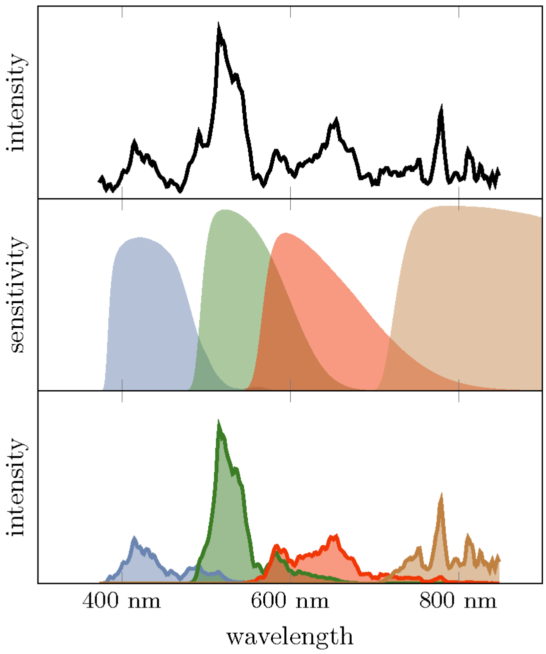

Figure 3 – Illustration of our basic methodology. We take a meteor spectrum from Vojáček et al. (2015) (top), convolve it with Bessell B, V, R, and I transfer functions (middle), and integrate the resulting curves (bottom) to obtain color magnitudes.

We will defer to Vojáček et al. (2015) in classifying these meteors; thus, we will test whether other authors' meteor classifications can be retrieved using color measurements.

The Vojáček et al. (2015) meteor spectra files contain four columns providing the wavelength, measured relative intensity, calibrated relative intensity corrected for the spectra response of the instrument, and an associated uncertainty. For this experiment, we have opted to use the uncalibrated, measured relative intensity for the purposes of determining color, implicitly assuming that the spectral response of the camera used by Vojáček et al. (2015) is representative of meteor cameras.

We then convolve the spectrum with the Bessell transfer function to obtain the color magnitude. We use the subscript i to enumerate the wavelength bins, and the wavelength and relative intensity corresponding to that bin are λ_i and I_i; thus, the total intensity in our arbitrary units is $I = \sum_i I_i$. Then, if we use f_B to denote our Bessell B transfer function, we can obtain the corresponding color magnitude as follows:

$$I_B/I = \textstyle\sum_i f_B(\lambda_i) I_i \,/\, \sum_i I_i \qquad (1)$$

$$B = -2.5\log_{10}(I_B/I) + M \qquad (2)$$

where M is the peak meteor magnitude provided by Vojáček et al. (2015). A visual representation of our approach is shown in Figure 3.

We use this approach to generate synthetic B, V, R, and I color magnitudes. We do not attempt to measure U-band magnitudes because this band covers wavelengths shorter than those measured by Vojáček et al. (2015).

3 Results

With our four Bessell transfer functions we calculate four color magnitudes, which we will call B, V, R, and I. Vojáček et al. (2015) also provides the peak magnitude for each meteor, M. A summary of all color data is presented in Figure 4. Few trends are present; the color values of different spectral classes overlap substantially. However, iron meteoroids are offset from other types in all four panels, most strongly in $B-M$ and $R-M$.

Because the iron-type meteor spectra appear both bluer and less red than other spectra, we present a similar plot of $B-R$ in Figure 5. We see that iron meteoroids are fairly well separated from other spectral types in this color index. Most meteors have $B-R$ values of approximately 2, while iron meteoroids cluster around 0.5. However, there are exceptions to both trends. One iron meteoroid has a $B-R$ value of ~ 2, placing it in the center of the non-iron distribution. And one normal meteoroid is an extreme outlier with a $B-R$ value of ~ 6. Disregarding outliers, $B-R=1$ is the dividing line between iron-type meteors and all other meteors in this data set.

We attempted to find a similar color probe of sodium abundance without much success. We did note that Na-enhanced and Na-rich meteors tended to be "greener" and "redder" than Na-free and Na-poor meteors. This is due to the fact that the Bessel V and R bands overlap with the primary sodium emission line. We further attempted to extract meteors with strong sodium emission by combining the two colors into a single $V-M+R-M$ value (see Figure 6). However, while this approach serves to separate sodium-rich from sodium-poor meteors, it does not separate these classes from the "normal" and iron meteor types. We auto-generated plots of all $\binom{5}{2} = 10$ possible color indices: B-M, B-V, B-R, B-I, V-M, V-R, V-I, R-M, R-I, and I-M. None proved to be a useful tool for distinguishing any spectral types other than iron.

Because color reportedly varies with both magnitude (Kohoutek, 1963; Hajduková, 1972) and speed (Hajduková, 1974), we constructed scatter plots of $B-R$ vs. magnitude (Figure 7) and speed (Figure 8). These plots demonstrate that the color separation between iron and non-iron meteors cannot be attributed to a difference in magnitude or speed. No trend with magnitude is apparent in Figure 7. A trend with speed is apparent in Figure 8 ($V-R$ also displays such a trend; see also Ocaña, 2017), but it is not large enough to explain the separation between iron and non-iron meteoroids.

4 Conclusions

Our results indicate that color index, as measured using standard Bessell color filters, is a poor indicator of meteor class. Most classifications show no visible or statistically significant separation in color-space. The sole possible exception are the iron meteoroids, which are both bluer and less red on average. In the data we examined, only iron meteoroids have values of $B-R$ less than one, and this could not be attributed to a difference in magnitude or speed. The $B-R=1$

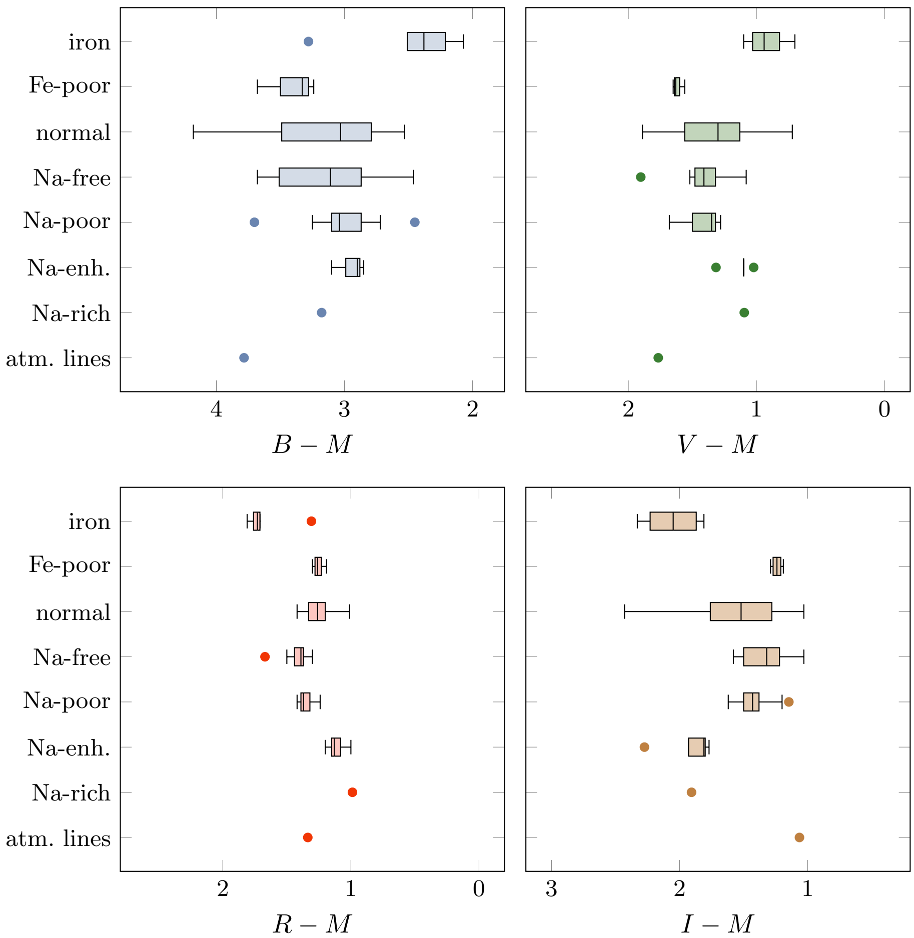

Figure 4 – Tukey box plots of four color indices. For each spectral type, we show the central two quartiles (boxes), upper and lower adjacent values (whiskers), and outliers (points) of the depicted color index. Color index is inverted so that, for instance, "bluer" values appear towards the right of the top left panel.

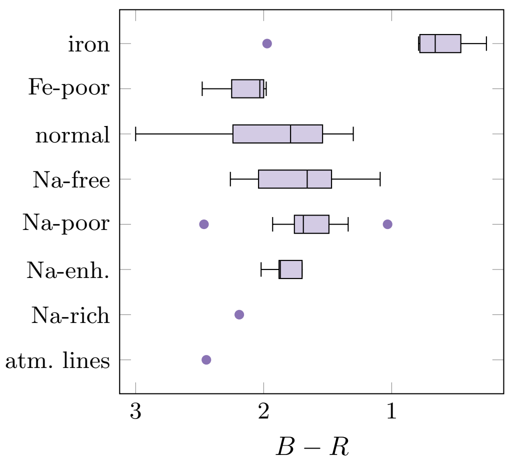

Figure 5 – Tukey box plots of $B - R$ color index. For each spectral type, we show the central two quartiles (boxes), upper and lower adjacent values (whiskers), and outliers (points). Color index is inverted so that "bluer" values appear on the right.

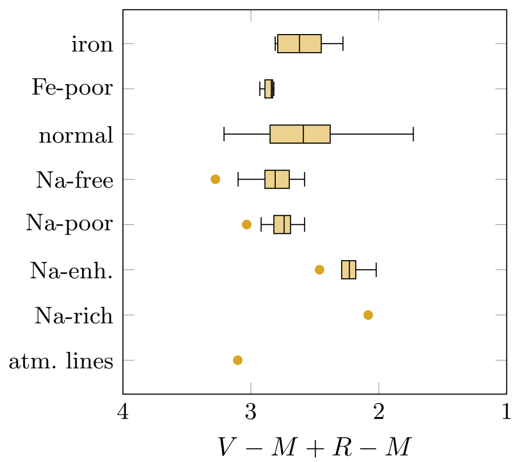

Figure 6 – Tukey box plots of hybrid color index $V - M + R - M$. For each spectral type, we show the central two quartiles (boxes), upper and lower adjacent values (whiskers), and outliers (points). Color index is inverted so that "greener" values appear on the right.

boundary, however, is not perfect; one out of six iron meteoroids had a $B - R$ value consistent with other meteoroid types.

Thus, this small sample of meteor spectra suggests that standard Bessell B and R color filters could potentially be used to identify probable iron meteoroids. However, Bessell filters do not appear promising for distinguishing between any other meteoroid spectral types. Narrow filters centered on the primary emission lines (Ocaña et al., 2012; Ocaña, 2017) might be more effective, if the corresponding reduction in brightness and other trade-offs (Gural, 2015) can be tolerated. Full

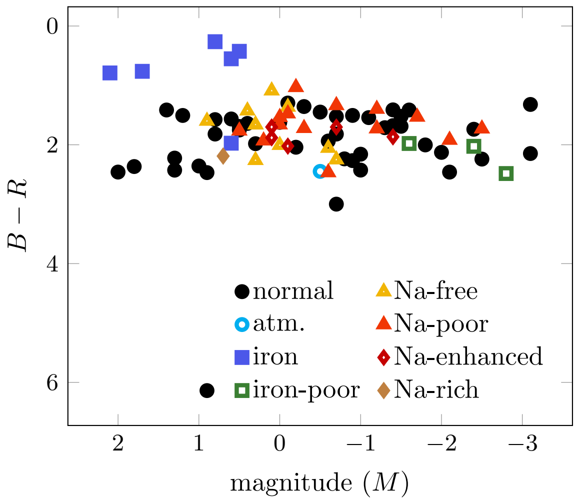

Figure 7 – Color index (here, $B-R$) vs. magnitude for meteors in the (Vojáček et al., 2015) catalog.

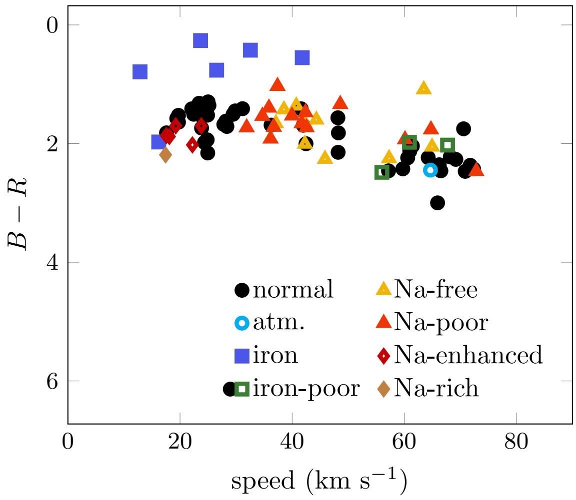

Figure 8 – Color index (here, $B-R$) vs. in-atmosphere speed for meteors in the (Vojáček et al., 2015) catalog.

meteor spectra, of course, are the most useful tool for analyzing a meteor's composition.

5 Acknowledgments

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Lyrids 2020 observations by AMOS, spectral, visual and photographic methods

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We present observations of the 2020 Lyrid meteor shower by different techniques from Slovakia and the Canary Islands. The visual observations have been supported by video observations using the AMOS systems and are in good agreement with IMO visual data. We also present data of a Lyrid fireball observed on 2020 April 21 at $23^{\rm h}53^{\rm m}20^{\rm s}$ UTC by multiple stations of AMOS, AMOS-Spec and by a digital photographer. The fireball was about -4.5 magnitude and left a dust trail photographically visible for about 22 minutes. Just several minutes before, very long fireball was observed at $23^{\rm h}45^{\rm m}29^{\rm s}$ UTC by AMOS stations as well as another photographer from Košice. The images illustrate the beauty of the night sky.

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1 Introduction

The visual observation of the 2020 Lyrids were initiated as a distant social activity of the faculty staff and students of the Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava during the COVID-19 lockdown in Slovakia and the Canary Islands. Our two colleagues, former faculty members, who are currently working in the Czech Republic and in Boston, joined the observations too, though under limited weather conditions. We have used visual, video, spectral-video and photographic techniques to cover the Lyrid meteor activity at its peak on 2020 April 21–22. The weather conditions were favourable in Slovakia and La Palma, Canary Islands, where our AMOS meteor cameras were operating smoothly. The main idea was to integrate new and former students into meteor observations from their homes and surrounding countryside during the period of limited social activities due to the pandemic. It may serve as a good example to enjoy the sky and celestial phenomena with psychological prophylaxis in similar situations in the future.

2 Observations

The actual observations by different methods covered the night of April 21/22, from $19^{\rm h}40^{\rm m}$ UTC (Slovakia) till $05^{\rm h}45^{\rm m}$ UTC (Canary Islands). Because the AMOS system (Tóth et al., 2015) is deployed in different locations, we can extend our observations over larger ranges of longitude and time. We have obtained data from three visual observers uder suitable conditions: at the Astronomical and Geophysical Observatory (AGO) Modra (P. Zigo), in Brezno (D. Žilková) and in Spišské Hanušovce (A. Pisarčíková). The AMOS system was running at the AGO Modra, at the Arborétum T. Mlyňany, at the Kysucké Nové Mesto Observatory, at Važec,and at the Observatory Roque de los Muchachos (ORM) of the IAC at La Palma). Spectral observations were conducted at AGO Modra. Photographic observations were performed from Blýskavica (South of Central Slovakia) and Košice.

3 Results

The visual observations from three locations in Slovakia cover the activity of the Lyrid meteor shower from 2020 April 21, $21^{\rm h}00^{\rm m}$ UT till April 22, $02^{\rm h}30^{\rm m}$ UT. The conditions were favourable with limiting magnitude in the range of $5.5 - 6.0$. The video observations by the AMOS systems also provided good data from both Slovakian stations and the La Palma station, which extend the observation coverage to (European) late morning hours. The activity profile can be seen on Figure 1, where the visual and video observations are compared with ZHR and effective ZHR from the AMOS systems, respectively. There are several peaks in the activity profile from AMOS stations in Slovakia, which are supported by the visual observations. Moreover, the activity profile derived from IMO visual database is in very good agreement with our data. Even more important, the activity coverage from Slovakia is continuing with data from Canary Islands with the same AMOS system providing important observations of Lyrids during the maximum activity at the double peak at 2020 April 22, $03^{\rm h}45^{\rm m}$ UT and $04^{\rm h}45^{\rm m}$ UT at the level of effective ZHR ≈ 35. These times correspond to Solar longitude $32\overset{\circ}{.}208$ and $32\overset{\circ}{.}249$, respectively.

One of the brightest Lyrid meteors in that night was observed by various techniques at $23^{\rm h}53^{\rm m}20^{\rm s}$ UTC. The spectrum of a meteor of about -4.5 absolute magnitude was recorded by the AMOS-Spec system (Matlovič et al., 2019) from AGO Modra. Using multi-station

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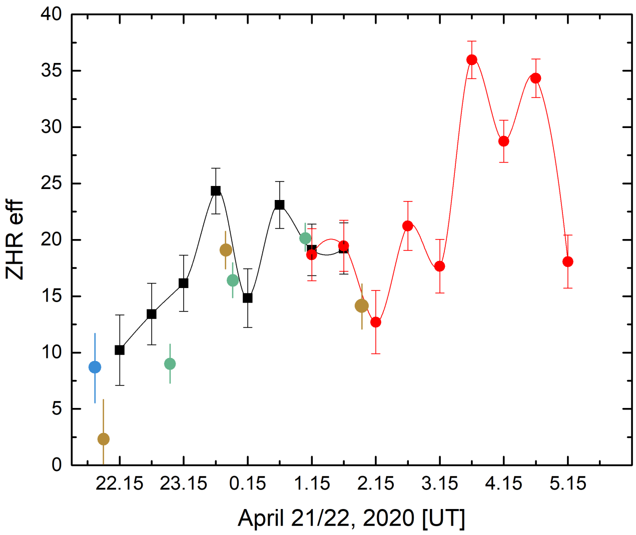

Figure 1 – The activity of the 2020 Lyrids around the peak of April 21/22 as observed by AMOS systems and visual observers from Slovakia and the Canary Islands. Black line with black squares – observations from AMOS stations in Slovakia (AGO Modra, Arborétum T. Mlyňany, Kysucké Nové Mesto Observatory and Važec). The mean activity corrected to the radiant height with the uncertainties are equivalent to the effective ZHR (assumed population index $r = 2.1$). Similarly, the red line with red dots represent the activity from the AMOS station on La Palma at the ORM observatory of the IAC. Visual observations: D. Žilková, Brezno (blue dots); P. Zigo, AGO Modra (brown dots); A. Pisarčíková, Spišské Hanušovce (green dots). ZHR values with an assumed population index $r = 2.1$.

Figure 2 – Photographic observation of Lyrid fireball at $23^{\mathrm{h}}53^{\mathrm{m}}20^{\mathrm{s}}$ UT from Blýskavica by S. Kaniansky; Sony A7 III + Sony $f/d = 2.8$, $f = 16 - 35$ mm crop field.

AMOS observations, we have calculated its trajectory and heliocentric orbit. The resulting parameters are presented in Table 1 and are in good agreement with our previous paper focused on the Lyrid orbital properties (Tóth et al., 2011). This fireball was also observed photographically by S. Kaniansky from Blýskavica (Figure 2), who detected its dust trail, which was visible photographically for about 22 minutes.

Another fireball of the same night, which did not belong to Lyrids, was observed just few minutes before at $23^{\mathrm{h}}45^{\mathrm{m}}29^{\mathrm{s}}$ UTC by the AMOS system in Slovakia as well as by astrophotographer R. Barsa from Košice (Figure 3). The sporadic fireball was about -4 absolute magnitude, lasting for almost 9 seconds, entering the atmosphere on a very shallow angle. The total length of the trajectory observed by AMOS was 221 km. Its heliocentric and trajectory parameters are presented in Table 1. It should be noted that the geometry of this fireball for Važec and Kysucké Nové Mesto AMOS stations was far from ideal, e.g. the convergence angle between these two stations and the fireball was only 13.7 degrees.

The spectral profile of the Lyrid meteor observed at $23^{\mathrm{h}}53^{\mathrm{m}}20^{\mathrm{s}}$ UT is presented in Figure 4. The spectrum shows characteristic features of a relatively fast cometary meteoroid: strong atmospheric lines of O I and N I, and main lines of Mg I – 2 and Na I – 1 originating in the ablating meteoroid. The intensity of Fe lines is low, as often seen in cometary meteoroids. Among other detected lines above the noise level is the high-temperature Hα line, which is considered a tracer of water and organics in the meteoroid composition (Jenniskens and Mandell, 2004). The monochromatic light curves of the Lyrid (Figure 4) show an early onset of the Na emission and later increase of the Hα emission at lower altitudes. This behaviour reflects the low excitation of sodium and later onset of the high-temperature spectral component (Borovička, 1994). Overall, the presented spectrum is consistent with previously observed Lyrid spectra (Vojáček et al., 2015), showing partial imprint of the compositional signature of the parent comet C/1861 G1 (Thatcher).

4 Conclusions

We have presented the observations of the Lyrid meteor shower at its peak of 2020 April 21/22 obtained by different observational methods. The initiative was to organize and involve students and colleagues into common meteor activity and support our regular video ob-

Table 1 – The orbital elements (in AU or degrees), geocentric radiant (equinox 2000.0, in degrees) and velocity (in km/s), the absolute magnitude and beginning and end height (in km) of the Lyrid fireball observed at 2020 April 21, $23^{\mathrm{h}}53^{\mathrm{m}}20^{\mathrm{s}}$ UT and a sporadic fireball observed at 2020 April 21, $23^{\mathrm{h}}45^{\mathrm{m}}29^{\mathrm{s}}$ UT, determined from AMOS stations at AGO Modra, Kysucké Nové Mesto Observatory and Važec.

Date-Time (UT)	Shw.	a	q	e	i	ω	Ω	α_g	δ_g	v_g	M_{abs}	H_B	H_E
20200421 23:53:20	LYR	39.9	0.923	0.977	79.03	213.55	32.050	271.76	33.83	46.7	−4.5	105.0	73.3
		—	±0.001	±0.012	±0.11	±0.23	—	±0.04	±0.05	±0.15	±0.5	±0.3	±0.2
20200421 23:45:29	SPO	6.3	0.679	0.893	20.7	108.13	32.040	22.49	40.29	24.91	−4	104.4	79.9
		±0.8	±0.001	±0.013	±0.3	±0.18	—	±0.16	±0.11	±0.30	±0.5	±0.7	±0.5

Figure 3 – Photographic observation of a non-Lyrid fireball observed at $23^h45^m29^s$ UTC obtained in Košice by R. Barsa.

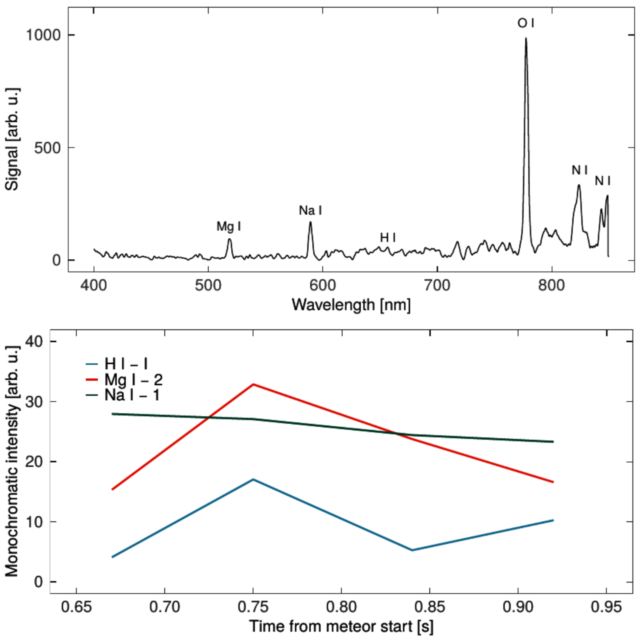

Figure 4 – The spectral profile (upper panel) and monochromatic light curves showing relative intensities of H I – 1, Mg I – 2 and Na I – 1 lines along the meteor flight (lower panel) of Lyrid meteor observed by the AMOS-Spec system on April 21 at $23^h53^m20^s$ UT.

servations by the AMOS systems. We were able to confirm relatively high activity of Lyrids during the early morning hours from Canary Islands. We also provided interesting spectroscopic, trajectory and orbital information of a Lyrid fireball, which also produced a dust trail. Moreover, we presented a very nice photo of a sporadic fireball that night, which illustrates the beauty of the night sky with meteor phenomena. We can conclude that this initiative was more successful as originally expected, yielding reliable data and outputs. We recommend performing similar activity in future as a possible socialization form during pandemic restrictions.

Acknowledgement

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Low-cost setup using a night vision device for video recording of faint meteors

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The setup for faint meteors video recording is built based on DSLR camera and night vision device of 2^{nd} generation. This setup field of view was 20° and the equivalent ISO was 16 million. The limiting magnitude of $+8^{m}$ for stars and $+5^{m}$ for meteors in green light pollution zone was obtained. Tests near the maximum of Perseids 2018 demonstrate that the setup captures up to 10 meteors per hour, which is 4–10 times more effective than typical meteor photo and video cameras in terms of their field of view.

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1 Introduction

As it is known, faint and telescopic meteors are poorly studied due to the difficulty of observing and registering them. However, the bulk mass of meteoric material is in the form of small dust particles that cause such faint meteors. In addition, many meteor showers with small ZHRs are poorly studied or even undiscovered (especially in the Southern hemisphere) due to the predominance of small particles in them (Jenniskens et al., 2018).

Thus, it is possible to visually detect meteors no fainter than $+5^{m}$, taking into account the typical experience of observers and the illumination of the sky. At the same time, photometry of meteors and determination of their coordinates by the eye is usually not very high-quality. Photo and video recording allows you to get a more accurate estimation of the brightness and coordinates, and can be saved the data for further processing (Rendtel, 2002). The limit of brightness of meteors recorded by this equipment usually does not exceed $+5^{m} \ldots +6^{m}$ and does not exceed $+8^{m}$ for best professional equipment (Jenniskens et al., 2011). The most modern ultra-sensitive sensors allow you to directly shoot faint meteors (Slansky, 2016), but this equipment is not available for most astronomy enthusiasts due to the high cost.

Fortunately, joint development of digital photography technology (new ultra-sensitive and low-noise matrices) and night vision technology makes it possible to study faint meteors even for astronomy enthusiasts with a budget of about 1700 EUR. More affordable for enthusiasts are classical night vision devices of 2^{nd} generation due to their high quality-cost ratio (Borissova, 2015). Newest devices of 3^{rd} generation have excessive light sensitivity for amateurs (an extremely dark sky is required otherwise field of view will be completely over-illuminated) and a significantly higher cost. Class 4 devices have extremely high characteristics and cost and are only available for the military and special services.

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Figure 1 – Disassembled and assembled setup.

The aim of this work is to develop and to practically test a device for video recording of faint meteors using an affordable night vision device.

2 Setup and shooting conditions

The setup for faint meteors video recording is built using the Canon EOS 1300D digital camera with kit Canon EF-S 18–55 mm $f/3.5$–5.6 IS II lens and the PN21K night vision device (2^{nd} generation, light amplification 2500 times, field of view 40°) and the Microstage II adapter (Figure 1).

We chose this camera as the cheapest with the video function at that time and as having a large pixel size, which increases the signal-to-noise ratio important for astronomy. The PN21K device was used as reliable and high quality dual-purpose equipment (Shvabe holding, Russia). The resulting setup field of view was 20° and

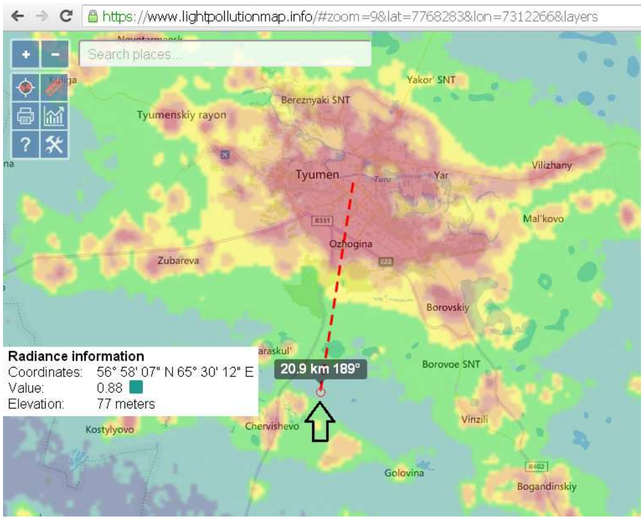

Figure 2 – Light pollution map at the observation point marked with a black arrow (forest in 21 km from Tyumen city).

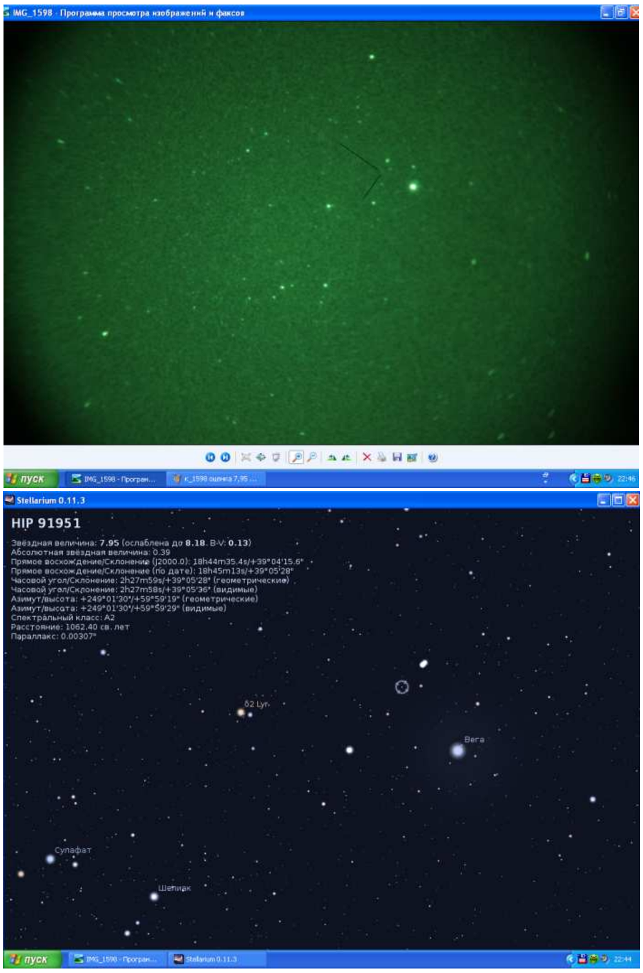

Figure 3 – Estimation of the setup limiting magnitude by stars. Photo of the Lyra constellation via our setup. Selected with the lines star is HIP 91951 ($+8^m$). Half of the photo field of view in the STELLARIUM program.

the equivalent maximum ISO was 16 million using the following formula:

$$\text{ISO } 6400 \times 2500 = \text{ISO } 16 \cdot 10^6 \tag{1}$$

Figure 4 – A Perseid of 2018 August 7 with brightness of $+1.5^m$, near alpha Persei. Canon EOS 1300D camera, Canon EF-S 18–55 mm $f/3.5$–5.6 IS II lens without optical stabilization, $f/5.6$, $F = 36$ mm, camera ISO 6400, 1/30 seconds with PN21K night vision device. Adding 7 frames of video recording (640×480, 25 frames/s) in 0.3 seconds. The brightness of the stars visible on the frame is brighter than $+7.1^m$.

where ISO 6400 is the Canon 1300D maximum ISO[b], and 2500 is the PN21K light amplification.

The actual ISO was 5–6 times lower, because the night vision device automatically reduces the light amplification in the presence of light pollution of sky. Under the conditions of the "green zone" (level 5 on the Bortle scale) (Figure 2), the limiting magnitude of $+8^m$ for stars and $+5^m$ for meteors was obtained (Figure 3). The estimation for extremely dark skies (level 1 on Bortle scale) gives the limiting magnitude for meteor of $+7^m$, i.e. under ideal conditions, telescopic meteors will be visible via our setup.

The process of meteors capture was as follows. The device was mounted on a tripod and directed at the Perseids radiant. Video was recorded to fragments of 11 or 30 minutes for frame resolution of 1920×1080 or 640×480, correspondingly, at ISO 6400 and a frequency of 25 frames/s. The frame exposure time was $^1/_{30}$ *s*.

A total of 8 hours of video were shot on 2018 August 7–8 and 11–13. Video processing was performed on a computer by frame-by-frame viewing and simple counting of detected meteors in the AVIDEMUX 2.7.1 program, but any video viewer could be used.

3 Results and Discussion

Tests near the maximum of Perseids 2018 demonstrated that the setup captures up to 10 meteors per hour with a field of view of 20° (Figure 4), which is 4–10 times more effective than classical meteor photo and video cameras in terms of their field (Molau et al., 2018; Watanabe & Marks, 2018).

The cost of our setup was 1700 EUR. It is from 1.2 to 11.2 times less than analogues of Sony α7S and

[b]With an extended ISO of up to 12800, the matrix of Canon EOS 1300D is noisy for astronomy.

Table 1 – Characteristics of our setup and analogues.

Device	Cost, EUR	ISO	ISO / Cost
Our setup	1 700	16 000 000	9 412
Sony α7S	2 000	400 000	200
Canon ME20F-SH	19 000	4 000 000	211

Canon ME20F-SH, excellently using professor P. Slansky (2016) (Table 1). Moreover our setup has 4–40 times the best ISO characteristics and 45 times the best ISO-cost ratio. But unfortunately, it has a small field of view (20° and no more than 40°) and a monochromatic image. These disadvantages are not so significant if we study telescopic meteors.

4 Conclusions

Due to the relatively low cost, simplicity and availability of components, the combined setup discussed in this work (simple DSLR camera and night vision device of 2nd generation) is available to individual astronomy enthusiasts and astronomical clubs, which allows the possible future widespread use of such solutions in the practice of amateur astronomy at low cost.

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