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Janus
Outburst in 2022 from Comet 73P/Schwassman-Wachmann 3?
IMO video meteors: first quarter of 2019
Twenty years of the IMO Video Meteor Network
Iron meteor spectrum from 2019 November 7

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Front cover photo

This bright fireball shot through the field of view while the photographer was photographing the conjunction of Jupiter and Saturn at $16^{h}41^{m}$ UT on 2020 December 13, from Erndtebrück, Germany. For more details on this event visit: `https://fireball.imo.net/members/imo_view/event/2020/7648`
Photo courtesy: David Feldmann.

Writing for WGN This Journal welcomes papers submitted for publication. All papers are reviewed for scientific content, and edited for English and style. Instructions for authors can be found in WGN **45:1**, 1–5, and at `http://www.imo.net/docs/writingforwgn.pdf` .

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Janus

Cis Verbeeck[1]

2020 has passed, what an awkward year! Needless to say, the year was dominated by the corona virus pandemic. In my case, this meant I started working full time from home in March, which was possible without significant impact on the quality and quantity of my work. Though of course, I miss my colleagues and the informal talks and camaraderie. I realize that I am lucky to be in such a position. I also miss social contact in general of course, with online solutions only filling in a limited part of what is great in human interaction.

I can imagine that the pandemic has a variety of impacts on people's meteor observations and meteor work. Did covid hamper your observations, or did you, on the contrary, gain more time for observing when most other activities were shut down? I would be very interested to read how the virus affected *your* observations. Please do consider writing a letter to WGN to describe your own situation.

The pandemic forced IMO to have its first online IMC ever in 2020, a very well organized and successful event hosted by the Local Organizing Committee in Hungary, with the assistance of the Scientific Organizing Committee. Though I understood from the IMC satisfaction survey that most meteor enthusiasts have severely missed face-to-face contact with each other at the IMC (just like me), the concept of an online conference was very well received and has significant merits as well. The main advantage is that an online conference attracts many people who do not or cannot normally attend the IMC due to financial reasons or difficulties traveling to the physical conference site. In the online IMC 2020, 45% of the participants attended the conference for the first time! Needless to say, this is a significant enrichment both for those new participants and for the other participants.

In the future, also after the corona era, we will schedule a mix between physical IMCs and online IMCs, as suggested by a majority in the IMC satisfaction survey. The optimal way to organize this remains to be seen, but it is clear that both have significant advantages. The present situation regarding the corona virus suggests that another physical IMC in 2021 is quite unlikely, so probably another fully online IMC will be organized. More information will follow in due time.

IMO has been gathering worldwide fireball reports and showing the results at `https://fireballs.imo.net` since 2015. In 2020, 386 large events (with at least 10 reports) were submitted, an 18% rise with respect to the 327 such events in 2019. More event statistics, including a nice movie depicting where and when large fireball events took place since 2015, can be consulted at `https://fireballs.imo.net/members/imo_fireball_stats/`.

I take this oppportunity to remind the reader of IMO's tools for the input and analysis of visual data. While preliminary automatic visual ZHR profiles can be consulted at `https://www.imo.net/members/imo_live_shower`, every single observation in IMO's Visual Meteor Database (VMDB) can be consulted and downloaded at `https://www.imo.net/members/imo_vmdb`. In the past years, Kristina Veljković has developed the powerful and easy-to-use visual meteor data analysis software MetFns. It is written in the statistical programming language R and can be freely downloaded from the CRAN webpage `https://cran.r-project.org/web/packages/MetFns`. Kristina has also developed the R shiny application MetFnsApp, which brings global analysis of visual meteor shower data within reach of everyone who is interested. The most elaborate part about analyzing visual meteor data is not how to use MetFnsApp, but selecting binning and other parameters in a clever and interactive way. This process is explicitly explained in (Rendtel et al., 2019a), where Jürgen Rendtel et al. demonstrate in detail how they went along to interpret and analyze the visual meteor data of the Perseids 2018. This paper describes the intermediate steps and iterations that were employed to derive the Perseid 2018 results in (Rendtel et al., 2019b).

A versatile tool for consulting video results was introduced in 2019. MeteorFlux 2.1 allows the user to select either the real-time view (updated every 5 minutes by MetRec, data not checked manually), the temporary view (data available after the observer has verified MetRec's meteor output), or the final view (checked by the observer and verified a second time with PostProc by an IMO network admin, backlog about 1 year). With this software you can plot the population index, ZHR, and flux of any shower and compare it to a selected reference shower (e.g., the sporadics or the average profile of the selected shower over several years) within a minute. Check it out at `https://meteorflux.org/`!

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With all these tools at hand, we much encourage you to produce your own shower analysis and share it with the meteor community through WGN or the IMO website. It goes without saying that WGN (`wgn@imo.net`) and the news editors of the IMO website (`newsitems@imo.net`) welcome all other kinds of meteor-related contributions as well!

IMO's achievements and services are only possible through the dedication of many volunteers, such as WGN's Editor-in-Chief Javor Kac, our webmaster Karl Antier, and Mike Hankey and Vincent Perlerin who developed and maintain the IMO website, VMDB, and fireball form. Essential tasks are performed by the IMO Council members and Commission Directors and many more volunteers. Without mentioning them all in detail, I want to thank them all for their part in running the International Meteor Organization! Finally, I want to thank the LOC and SOC members of the online IMC 2020 for having organized such a successful conference.

I wish you a healthy, happy, and exciting 2021 with clear skies and a lot of fireballs, and, especially, an end to the pandemic before the end of the year, so you can regain the freedom you had before, with the possible incorporation of any useful things you may have learned from these tough times.

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JANUS *was a Roman god with two faces, one looking to the past and one to the future, called upon at the beginning of any enterprise. Today he is often a symbol of re-appraisal at the start of the year.*

Ongoing meteor work

Will Comet 73P/Schwassman-Wachmann 3 produce a meteor outburst in 2022?

Joe Rao [1]

Comet 73P/Schwassmann-Wachmann 3, a member of the Jupiter family of comets, broke into several fragments in the autumn of 1995. A dramatic increase in the comet's intrinsic brightness was then seen, suggestive of a massive expulsion of dust. Orbiting the Sun about every 5.4 years, the comet has continued to disintegrate since its initial disruption. Dozens of fragments have since been identified in subsequent near-Earth passages. Three independent studies have investigated the prospects of Earth's passage through its trail of freshly ejected material which could lead to a meteor shower. One study showed that Earth will fail to interact with the ejected material, while the other two suggest a direct interaction with the trail, thus possibly producing an outburst of meteor activity at the end of May 2022.

Using an N-body integrator, we found that all three studies are plausible. However, the occurrence of a meteor shower/outburst requires a rather unique set of circumstances: One that assumes a larger-than-normal preponderance of the particles are subsequently ejected at sufficiently high velocities to overcome the effects of solar radiation pressure. Such material would tend to migrate forward of the comet's direction of motion around the Sun, ultimately colliding with Earth. We find that any detectable meteor activity would reach a maximum on 2022 May 31.21 UTC, with a mean radiant position of $\alpha = 208\overset{\circ}{.}35$, $\delta = 27\overset{\circ}{.}45$ (J2000.0).

Received 2020 November 5

1 Introduction

Meteor observing is usually a slow and meditative pursuit, but occasionally it can turn dramatic. Most meteor showers are fairly predictable. Occasionally a bright fireball will blaze into view, but there is always a chance of witnessing something truly new and unexpected – perhaps even when no shower was predicted at all.

And at the end of May 2022 things could turn exciting.

In the fall of 1995, comet 73P/Schwassmann-Wachmann 3 fractured into several pieces and left a trail of fragments in its wake which the Earth might encounter during the overnight hours of 2022 May 30–31.

On that night, a meteor shower might erupt ranking with the January Quadrantids or December Geminids; annual displays which are normally the richest of the year. Yet, there is also a small chance of something extraordinary – perhaps one of the most dramatic meteor displays since the spectacular Leonid showers which occurred around the turn of this century, with a large fraction of the meteors being bright.

Or perhaps, visually, nothing at all will be seen.

The possibility of Earth interacting with the dross of a fragmented comet may sound familiar. Indeed, most astronomy texts often make reference to the famous case regarding the splitting of comet 3D/Biela in 1842 or early 1843 and its contemporaneous association with spectacular meteor storms occurring in 1872 and again in 1885.

The question is, might there be hope for a similar performance resulting from the recent break-up of comet 73P/Schwassmann-Wachmann 3?

2 Comet 73P/Schwassmann-Wachmann 3

Diminutive visitor

Comet 73P/Schwassmann-Wachmann 3 (hereon designated "SW 3") was the third comet found by German astronomers Friedrich Carl Arnold Schwassmann and Arno Arthur Wachmann in the early 20th century. After its discovery on photographic plates exposed on 1930 May 2 at Hamburg Observatory (Bergedorf) for the regular minor planet survey, orbit calculations quickly revealed that the comet would pass only 0.0616 au from the Earth on 1930 May 31.

Astronomers believe that SW 3's nucleus probably measures only around 1.3 km in diameter (Boehnhardt et al., 2002) – hardly a significant celestial body. Consequently, the comet is intrinsically quite faint. For this reason, its peak brightness in 1930 was estimated to be between magnitudes +6 and +7. SW 3 was also seen to possess a rather faint tail measuring about $\frac{1}{2}^\circ$ in length (Kronk, 1984).

Even though SW 3 orbits the Sun about every 5.4 years, 1930 was the last time anyone saw it for quite a while. In fact, between 1935 and 1974, SW 3 came and went eight times without being observed. It finally was caught on photographs taken in Australia in 1979 (magnitude +12.5 on March 19 when 1.4359 au from Earth), missed in 1985, and recovered again in 1990 (magnitude +9.0 on April 17 when 0.3661 au from Earth; its best apparition since 1930).

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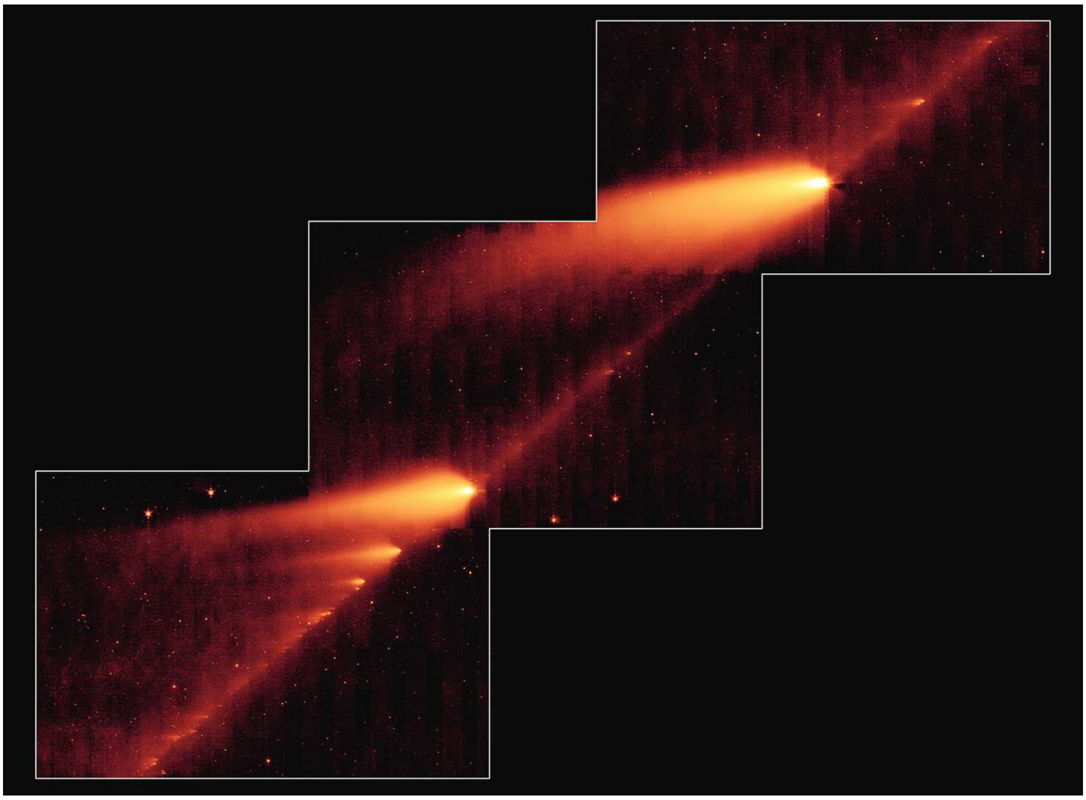

Figure 1 – Recorded on 2006 May 4–6 by the Infrared Array Camera (IRAC) on board the Spitzer Space Telescope, this image captures about 45 of 58 alphabetically cataloged large comet fragments. The brightest fragment at the upper right of the track is Fragment C. Bright fragment B is below and left of center. Spitzer's infrared view also captures the trail of dust left over as the comet deteriorated during previous perihelion passages in 1995 and 2001. Emission from the dust particles warmed by sunlight appears to fill the space along the cometary orbit. Image credit: NASA, JPL, Caltech.

Surprise!

Astronomers expected SW 3 to make another uneventful return in the fall of 1995. From September 8 through 13, however, radio-wavelength observations of the comet's emissions made at the Observatoire de Paris-Meudon's Nancay Radio Telescope, indicated a significant increase in Hydroxide (OH^-), with peak production at $2.22 \pm 0.22 \times 10^{29}$ molecules per second (Crovisier et al., 1996). This is only a factor of 10 below the peak production rates observed for the much larger Halley's Comet during its 1986 apparition (Wiegert et al., 2005).

Then, during mid-October, 1995, the Central Bureau for Astronomical Telegrams suddenly began receiving "numerous reports from observers worldwide of independent discoveries" (Green, 1995a) of a comet verging on naked-eye visibility that had been sighted low in the western sky during evening twilight and sporting a dust tail 1° long.

This, however, wasn't a "new" comet at all – it was 73P/Schwassmann-Wachmann 3!

This was a huge surprise, because that year the comet never came closer to Earth than 1.3114 au on October 17. Predictively, it should have appeared no brighter than about magnitude +12; a challenging target even through large amateur telescopes. And yet there it was, shining $6\frac{1}{2}$ magnitudes brighter than anticipated – a nearly *400-fold increase* in luminous intensity! Here was a classic demonstration of how a comet can go around the Sun on numerous occasions as a staid member of the solar community, and then abruptly and unpredictably undergo some sort of violent change.

As to the cause of this tremendous outburst, the answer came on 1995 December 12–13, when observations of SW 3 made at the European Southern Observatory in La Silla, Chile revealed "at least four separate brightness peaks in the coma" (Green, 1995b). SW 3's tiny nucleus had fragmented, but unlike 3D/Biela, which simply broke in two, SW 3 apparently fractured into *four parts.*

On IAUC No. 6301, dated 1996 February 1 (Marsden, 1996), comet investigator, Zdeněk Sekanina determined that component B broke off from the primary component C "most probably about 1995 Oct. 24" ... evidently followed by a secondary splitting of component B, which gave birth to component A on, or about Dec. 1. As for component D, it seems it might have separated from C in late November. Noted Brian G. Marsden, then-Director of the Central Bureau for Astronomical Telegrams: "There now appears to be no escape from the conclusion that the brightness outburst, which apparently occurred between Sept. 5 and 8, preceded the first breakup episode by at least six weeks."

The comet was still quite bright on its next visit in the fall of 2000, when many people saw it even though it was poorly placed for observation. Two of the fragments spotted in 1995 (known as B and C) had returned, together with a new one (E), which probably was released (but undetected) during the 1995 return. C was presumed to be the largest remnant of the original comet and was thus designated as the main object, with B (about one-third the size of C) and E appearing as individual small comets trailing more than $\frac{1}{2}^{\circ}$ behind C.

In the spring of 2006, the disintegrating comet made its next return appearance. Initially, astronomers counted at least eight remnants: big fragments B and C plus smaller fragments G, H, J, L, M and N. During this apparition some of the fragments were themselves forming their own sub-fragments.

On 2006 April 18, the Hubble Space Telescope recorded dozens of pieces of fragments shed primarily by B and G (Hubblesite, 2006). Between May 4 and 6, it was the Spitzer Space Telescope's turn to image the comet (Figure 1); using its Infrared Array Camera (IRAC) it was able to observe 45 of 58 known fragments (NASA, 2006). The main fragment, C, passed closest to Earth on May 13 at a distance of 0.0735 au, with fragments B and E passing even closer at 0.0515 and 0.0505 au respectively. In all, SW 3 broke into more than 68 fragments. Perihelion was on June 9, with the comet passing the Sun at a distance of 0.9391 au.

The comet would not return to the vicinity of the Sun until 2011 October; another unfavorable apparition.

SW 3's most recent perihelion was in 2017 March. Big fragment C was still chiefly intact, but was then seen accompanied by a smaller fragment designated as BT. So, it appears that the comet was then continuing to slowly break apart, shedding new pieces with each return through the inner solar system.

Its next perihelion will occur on 2022 August 25 at a distance of 0.9729 au.

3 Meteors from 73P?

Shortly after SW 3 was discovered in 1930, two astronomers at Kwasan Observatory (Kyoto, Japan) calculated an orbit and from this, one (Shibata) predicted a possible meteor shower when the Earth passed close to the comet's node on June 9 (Nakamura, 1930). The assumed radiant was located in northern Hercules, near the fourth magnitude star Tau (τ) Herculis. The potential new meteor shower was thus christened the "Tau Herculids" (later designated #61 TAH at the IAU Meteor Data Center).

Meteoroids presumably shed by SW 3 had been sighted as meteors chiefly by Japanese observers during the final week of May into early June 1930. The observed activity, however, was very weak, producing only several possible shower members. On June 8, an announcement regarding the potential of a strong meteor shower associated with SW 3 was widely circulated in newspapers around the globe (Kronk, 1988).

Indeed, on June 9, from Kwasan Observatory in Kyoto, Japan, an outburst of 59 meteors in one hour (9:51 to 10:51 p.m. local time) was reported. On the following night, again from the same location, 36 meteors were sighted in only 30 minutes (an event rate of 72 meteors per hour) (Jenniskens, 1995).

But there is a problem in accepting that these events actually took place. The only person who claimed to see these outbursts was Kaname Nakamura, who commented that "... all of these meteors were very faint and only a few of them were as bright as 4th magnitude." However, there was a full Moon on June 11, so his observations on June 9 must have been conducted under the bright-sky conditions of a waxing gibbous Moon. Moreover, Nakamura noted that on both nights (June 9 and 10), "... bright lunar haloes were high above the southern horizon." So, despite a nearly full Moon illuminating a moonlight-scattering layer of high-altitude cirrus or cirrostratus clouds, Nakamura still managed to somehow see a bevy of very faint meteors on consecutive nights. Even the director of the Kwasan Observatory, Issei Yamamoto, later noted that "Mr. Nakamura was practically the only observer" among staff members of the observatory.[a]

Elsewhere however, Nakamura-san's suggested meteor activity was conspicuously absent. Members of the meteor section of the British Astronomical Society failed to see a single member of the Tau Herculid stream on the nights of June 5, 7 and 9, putting the blame squarely on the bright moonlight.

Any reports of possible Tau Herculid activity in the years following 1930 have ranged from exceedingly sparse to non-existent. Some meteoroid orbits inferred from meteor streaks on photographic plates taken from 1963 and 1971 (Southworth & Hawkins, 1963, pages 274 & 280; Lindblad, 1971, pages 19 & 23) have been identified with this stream.

Finally, during this past decade, minor activity from the Tau Herculids was definitely confirmed: On 2011 June 2, NASA Cameras for all-sky meteor surveillance in California (CAMS), photographed 3 members of this stream between 4^{h} and 12.2^{h} UTC.[b] Additionally, on 2017 May 30–31, between 23:39 and 00:45 UTC, five shower members were again captured by CAMS. Lüthen et al. (2001) had forecast possible activity for both years from a dust trail shed by SW 3 in 1941 and another in 1952. Actually, both predictions were thought to be somewhat dubious since the respective miss distances were considered fairly large (0.0011 au and 0.0013 au, respectively).

[a] Nakamura-san's credibility is further strained regarding another meteor shower, one in 1921, the June Boötids ("Pons-Winneckids"). During the interval from June 26th to July 9th, and observing under skies that varied from clear to mostly cloudy, Nakamura reported notable meteor outbursts on July 3rd (153-meteors in only 35 minutes; an hourly rate of 262) and July 5th (91-meteors in 41 minutes; an hourly rate of 133). Nakamura claimed to have "very sensitive eyes," as his daily estimates of the mean magnitudes of these meteors varied from 4.5 to 5.0. William F. Denning, a highly regarded British meteor observer in his own right, voiced some incredulity about Nakamura's observations, "unless," he wrote (Denning, 1922), "Nakamura is able to discern meteors of 6th, 7th and 8th magnitudes."

[b] On 2011, June 1, Pierre Martin, observing from Bootland Farm, Ontario, Canada reported that he, "... signed on at 11:20 p.m. EDT. I was able to stay on for 37 minutes before the next wave of clouds arrived. During this time, I saw a few sporadics and a single gorgeous Tau Herculid! It was a mag −1 golden-yellow meteor that descended below Lyra in the east, ending near the double star Albireo. It had a thick wake! Checking the plot on this one confirms a perfect alignment with the TAH radiant." Taken from the now-defunct Meteorobs Internet mailing list.

Ingredients for a meteor shower

The birth, life and death of a meteor stream is reasonably well understood, at least in broad outline. Whenever a comet comes near the warmth of the Sun a little of its frozen nucleus sublimates, shedding clouds of dust and rubble. In time, this material spreads out along the comet's orbit, then gradually diffuses away from the orbit. An intense shower occurs when Earth passes – albeit briefly – through a thin, concentrated band of debris inside the much larger dust stream. These dense filaments are typically found relatively near the parent comet, and in most cases, they were probably shed from it only in recent centuries.

All the ejected particles, regardless of size and unless perturbed, stay closely confined to the plane of the comet's orbit – at least until, in time, the stream degrades and drifts apart. Gravitational perturbations by the planets are a major factor in shifting and eventually breaking up a meteor stream. Tracking all of these influences is what meteor shower forecasting is about.

The old meteoroids that have had time to become widely scattered are the ones that produce the ordinary, weak annual shower. The narrow, densest part of the swarm is a ribbon whose width is poorly known; in fact, the "ribbon" may actually be a more complicated structure consisting of thin bands and sheaves.

Testing for 73P/Schwassmann-Wachmann 3

In 2004, astronomer Jérémie Vaubaillon, at the Institute for Celestial Mechanics and Computation of Ephemerides (IMCCE) in Paris, France, introduced a new type of model for the formation and evolution of comet dust trails. His ejection model is primarily based on a hydrodynamic model by Crifo & Rodionov (1997) and takes into account comets at heliocentric distances of less than 3 au which ultimately produce clouds of dusty debris. The meteoroids are ejected in a uniform manner from the comet's spherically symmetric sunlit hemisphere. For comet SW 3, numerical simulations were performed (Wiegert et al., 2005) using nearly two million particle ejections from 1801 to 2006, assigned to five size bins ranging from 0.1 to 100 mm. The typical ejection (escape) velocity V is computed in the sunlit hemisphere (Vaubaillon et al., 2005a,b), as a function of comet nucleus properties (size, fraction of active area etc.), particle size, ejection sub-solar angle and heliocentric distance, using a Monte-Carlo method and leading to a range in V up to 20 m/s ($\pm$20 m/s), with V falling to 0 m/s at sub-solar angle = 90°.

As has been previously noted, save for a scattered few, no meteor activity of consequence associated with comet SW 3 has been reported since 1930. (Even here, there is some contention as to whether heightened activity noted in that year actually took place.)

However, the nucleus fragmented in 1995 and has continued to disintegrate, producing a fresh trail of cometary material. This combined with the Earth's orbit positioned very close to the descending node of the comet, has raised the prospects for a possible meteor outburst or perhaps even a storm similar to what happened with 3D/Biela; a possibility that should certainly be investigated.

Wiegert et al. (2005) discussed the exceptionally close (0.05 to 0.07 au) approach in May 2006 of comet SW 3 and its associated fragments relative to Earth. In that paper the authors noted that, "... a swarm of comet fragments of various sizes, ranging from kilometer sized on down, will pass near the Earth in 2006, and the possibility exists that the τ Herculid shower, typically unimpressive, could be dramatically stronger than usual."

Ultimately however, such a possibility for enhanced activity was ruled out (as will later to be shown to be correct): "... partly (as a result) of the dynamics of the parent comet, which suffers frequent close encounters with Jupiter," (Figure 2) "and partly of the location and timing of the splitting event, which produces a distribution of meteoroids that does not approach the Earth particularly closely." (Wiegert et al., ibid.)

After 2006, the next possible Earth encounter for meteor activity is in 2022, but it would not originate from meteoroids released during the 1995 splitting of SW 3's nucleus. Rather, meteoroids released during pre-discovery apparitions in 1892 and 1897 reached the Earth at the end of May that year. A maximum ZHR (zenithal hourly rate) from these 19th century meteoroids of 10 is back-predicted, but based on Vaubaillon's model, no interaction of Earth with cometary material released during 1995 is forecast for 2022 (Figure 3).

Let's dance!

Out of curiosity, we attempted to model the meteoroid stream associated with the 1995 break-up of comet SW 3 using a different methodology. For the task of providing adequate orbital simulations for particles relating

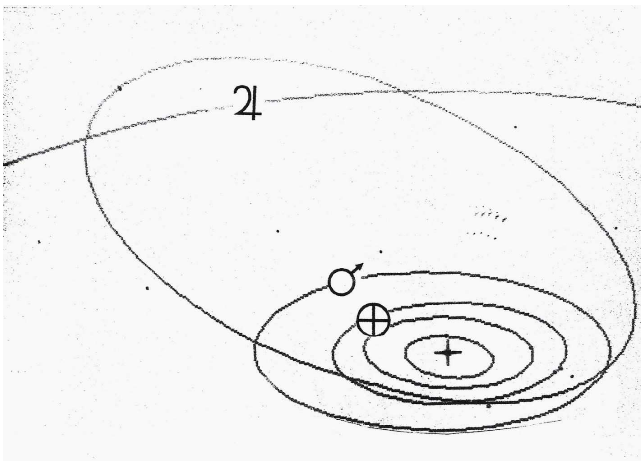

Figure 2 – Orbit of comet 73P/Schwassmann-Wachmann 3 (SW 3). It is a member of Jupiter's "comet family," a group of about 400 short period comets with aphelia near the orbit of Jupiter. The comet's orbital period is roughly 5.4 years and it arrived at aphelion in 2019 late December... 5.213 au from the Sun. Its close proximity to Jupiter's orbit means that occasionally it will be perturbed by that big planet's gravitational field. Since the comet's discovery in 1930, it has approached to within 0.68 au of Jupiter in 1953 October and within 0.29 au in 1965 November. It will make a similarly close approach to Jupiter (0.29 au) in 2025 February.

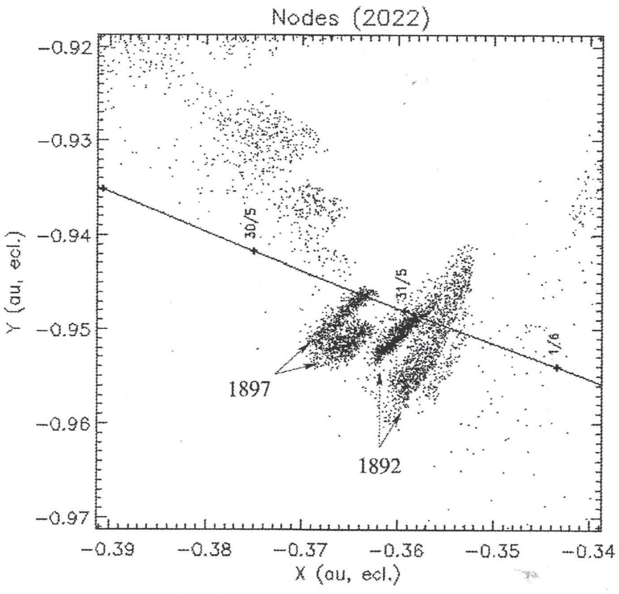

Figure 3 – The nodal crossing points of meteoroids (depicted as small dots) ejected from SW 3 at all perihelion passages back to 1801 based on the Vaubaillon model, plotted relative to the Earth's orbit for the year 2022. Only meteoroids whose descending node occurred within one week either before or after Earth's passage are shown. The relevant dust trails are marked by arrows indicating their year of origin. Earth interacts with dust ejected from 1892 and 1897, but not with the dust trail produced by the fracture of SW 3's nucleus in 1995. Image credit: Jérémie Vaubaillon (original source Wiegert 2005, figure 6).

to SW 3, the computer program Dance of the Planets (Arc Science, 1994) was chosen. It is an N-body integrator; the incremental movement of each body due to the gravitational influence of all others is continuously calculated, closely approximating the action of gravitation. One unfortunate limitation of the program is it does not take into account non-gravitational forces; an effect that accelerates or decelerates a comet's motion, changing its orbital period.

Our attempt was made solely to corroborate Vaubaillon's model prediction as to how closely SW 3 meteoroids would approach Earth. First, epoch 1995 positions of 73P/Schwassmann-Wachmann 3 were obtained from orbital elements developed by Kenji Muraoka, derived from 226 observations (1989 to 1996) (Yoshida, 1997). Second, to simulate a trail of meteoroids, an additional 19 comets (the maximum possible for this software program) were generated, positioned along a radius vector diametrically opposed to the Sun. Third, for the representation of the respective meteoroid "cloud" orbits, Muraoka's orbital elements from the 1995 apparition of SW 3 were copied onto the program's "CMT" files:

$$
\begin{aligned}
T &= \text{1995 September 22.88978 UTC} \\
q &= 0.93278 \\
e &= 0.694848 \\
\omega &= 198\overset{\circ}{.}7693 \\
\Omega &= 69\overset{\circ}{.}9466 \\
i &= 11\overset{\circ}{.}4239
\end{aligned}
$$

The only alterations made were in the respective perihelion distances (q) of the other 19 comets from the Sun. Starting with "parent comet" 73P/Schwassmann-Wachmann 3 at 0.93278 au, all 20 comets were aligned within a space measuring 0.01076 au (1.609 million km or 1 million miles); each comet separated incrementally by increasing distances from the Sun of 0.00053789 au (80 000 km or 50 000 miles).

The speed of the orbital simulation is set using the tunable Dance parameter "Pace" (the apparent time acceleration). Very large values can diminish simulation accuracy. "True" is real time. For heliocentric space views, the maximum pace simulated by Dance is 240k; one-minute equates to about 385 years. It was determined for adequately simulating a trail of meteoroids, the Pace should be set at a much slower unit of 1000 (where one minute equates to roughly 16 years). There is also a tunable magnification function, "Zoom" which for heliocentric space views runs upwards to 512×. A Zoom of 1× corresponds to a naked-eye view. For our simulations a Zoom of 64× was employed.

So, starting from perihelion in 1995, the 20 comets were set into motion at Pace = 1000 and Zoom = 64×. Moving forward in time, the comets gradually separated from each other along their corresponding orbital paths.

Moving forward in time from 1995 to 2006, the "parent" comet, SW 3, and the next six comets in the presumed meteoroid trail, swept past the Earth near the comet's descending node at distances of less than 0.2 au as shown in Table 1.

Table 1 – SW 3's 1995 meteoroid trail proximity to Sun and Earth; r = heliocentric distance, Δ = geocentric distance when comet reaches descending node.

Comet	UTC Date	r (au)	Δ (au)
SW 3	2006 May 20.27	0.960	0.184
#2	2006 May 23.60	0.961	0.132
#3	2006 May 26.95	0.961	0.084
#4	2006 May 30.29	0.962	0.053
#5	2006 Jun. 2.69	0.962	0.069
#6	2006 Jun. 5.96	0.963	0.113
#7	2006 Jun. 9.39	0.963	0.164

In this simulation, the parent comet arrived at perigee *one week after* the actual perigee passage of the main fragment ("C") and two smaller ones ("B" and "E"). This likely can be attributed to nongravitational forces on the fragments as they approached the Sun. Such a relatively large displacement implies that the comet is either very active or very low-mass (in this case, more likely the latter as opposed to the former).

However, these values support the 2005 findings of Wiegert and his colleagues, i.e., in spite of this very close approach of the comet and its fragments to Earth, even a distance of ~0.05 au was not close enough to produce any noticeable meteor activity.

As for 2022, once again Earth will apparently be spared from any interaction with material shed by the 1995 break-up of SW 3. Using Dance, it was determined that Earth will arrive at the descending node of SW 3, 65.9 days *prior* to the arrival of the comet and its accompanying train of meteoroids (Figure 4). So, it would seem that, as was the case in 2006, there is no possibility of an outburst or enhancement of the Tau Herculid shower, again corroborating the findings of Wiegert et al. using the Vaubaillon model.

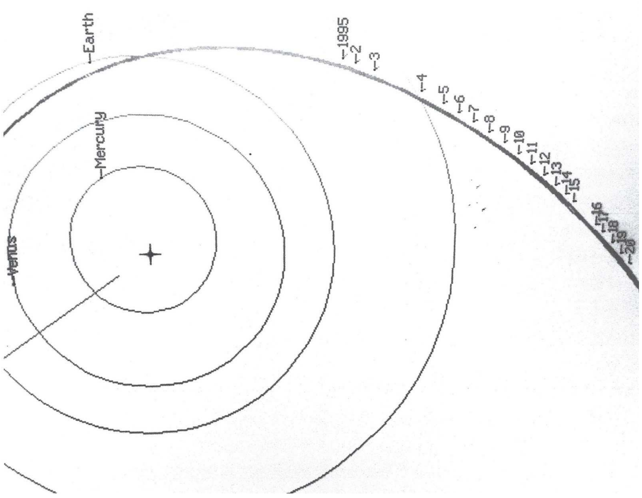

Figure 4 – Positions of Earth, SW 3 and presumed train of meteoroids on 2022 May 31 using Dance of the Planets orbital simulator. Note that the orbits of the comet ("1995") and its meteoroid train appear somewhat displaced from their original 1995 orbits – the year of the breakup of the comet nucleus. Assuming meteoroids are *trailing behind* the parent comet, no interaction with the Earth can take place, supporting the findings of the Vaubaillon model.

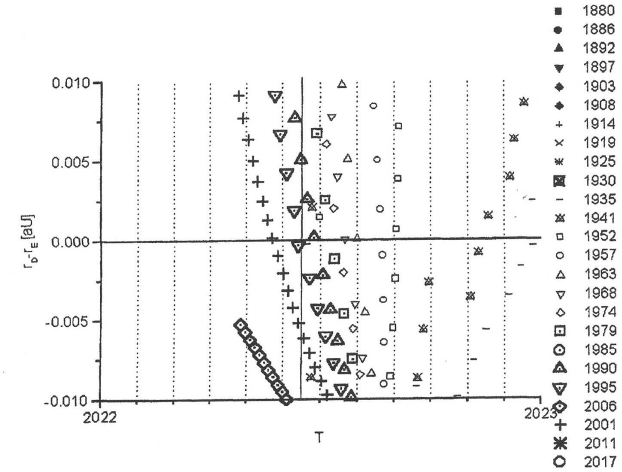

Figure 5 – Diagram from the study by Lüthen et al. (2001), depicting the distance of the particle at the node from the orbit of Earth ($r_{\mathrm{D}} - r_{\mathrm{E}}$) as a function of perihelion time T. The particles reaching the node at the same time as Earth are marked with the vertical line. Dust trails of particles from parent comet SW 3 that reach perihelion in 2022 are shown. On May 31.21 UTC, Earth will pass the richly populated 1995 dust trail at a distance of only about 0.0004 au. Image credit: Rainer Arlt.

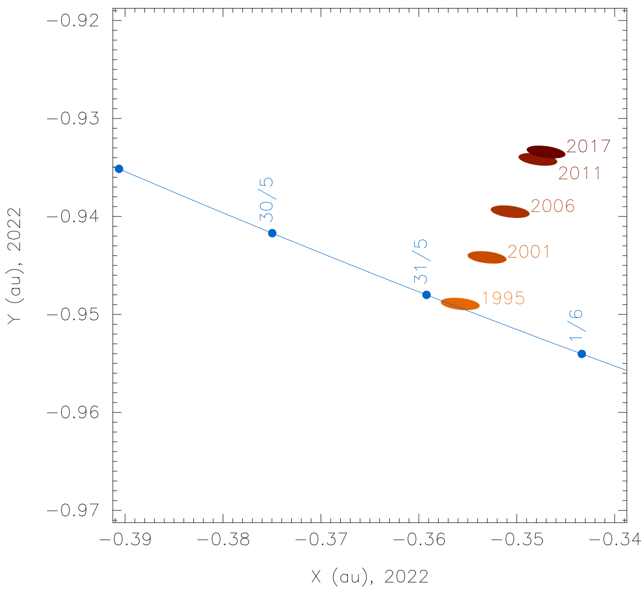

Figure 6 – Diagram, on the same scale as Figure 3, depicting the location of the intersection with the ecliptic plane of the dust trails of 1995, 2001, 2006, 2011 and 2017, as computed in table 1 of the study by Horii et al. (2008). The continuous line represents the path of the Earth in 2022. On May 31.21 UTC, the dust trail ejected in 1995 is forecast to approach the Earth as closely as 0.00038 au, in excellent agreement with the study by Lüthen. Image credit: David Asher, adapted from a diagram by Mikiya Sato.

4 Another solution

Our above conclusion would seemingly close the book on the prospects of observing a meteor shower created in the wake of the 1995 break-up of SW 3. Except … there is yet another possibility.

Interestingly, the first investigators to put forward a countering solution (Figure 5) were Lüthen et al. (2001), who forecast that: "Probably the best chance to see an SW3-id display will come in 2022, when we pass the 1995 trail at about only 0.0004 au distance. The display is especially promising: the disintegration of P/SW3 in 1995 should have introduced a lot of dust particles into the trail."

A later independent study (Figure 6) by Horii et al. (2008) buttressed the findings of Lüthen et al. (2001), by indicating that "the dust trail ejected in 1995 will approach the Earth as closely as 0.00038 au … in 2022 meteors due to this dust trail are highly expected."

The obvious question is, what is the cause of this discrepancy? Why does Wiegert et al. and our study show that the fragmented material released by SW 3 in 1995 clearly misses Earth in 2022, while two other studies predict otherwise?

Cometary ejection

In the case of predictions for most meteor showers, it is assumed that the ejection velocity of material shed from the nucleus of the parent comet would be within the range between −30 and +30 m/s, where "+" is in the direction of the body's motion and "−" in the opposite direction. In the case of Vaubaillon's model, the typical ejection velocity considered for a 1-mm sized particle is 20 m/s (± 20 m/s).

In comparing the breakup of comet 3D/Biela to SW 3, the former presumably split either in 1842 or early 1843, near aphelion (Marsden & Sekanina, 1971). That resultant splitting was slow and subtle and was not detected until nearly the end of 1845 and did not contribute to any noticeable increase in the apparent brightness of that comet. It was determined that Biela split with a relative velocity between the two portions of only 1 m/s.

In contrast, the breakup of SW 3 apparently took place in early October 1995, within just a couple of weeks after perihelion on September 22nd. Additionally, the breakup was accompanied by a brightness spike of more than six magnitudes which occurred over just a fortnight in early October 1995, likely due to a sudden and massive expulsion of dust. Horii et al. noted that "... since meteoroids were ejected from the split nuclei of the comet, these meteoroids were likely to have higher ejection velocity than usual." Their study computed an ejection velocity of −26.71 m/s, meaning that the dust was ejected in the opposite direction of the comet's motion.

But there is yet another important factor to consider.

Size matters

That other factor is the size of the ejected particles. In the case of most of the annual meteor showers, the majority of visible meteors are caused by particles generally ranging in size from about that of a small pebble (∼2 mm) down to a grain of sand (∼0.3 mm), and generally weigh less than 1–2 grams.

As is important in understanding the physical break up of a comet nucleus, is that its constituent particles are expected to vary in size from sub/micron-sized flecks of dust to multi-millimeter grains of sand and even larger pebbles and "rocks". How such large particles are spatially distributed depends in part on the spin of the comet's nucleus and the locations of its outgassing regions. Small particles (≤0.1 mm) are pushed away more rapidly by solar radiation pressure regardless of the direction they leave the nucleus, and this pressure of sunlight helps to force such dust particles to a position trailing behind the comet. Larger particles, however, are greatly unaffected by solar radiation pressure.

In Horii et al. (2008), the effects of solar radiation pressure *were not considered*. This combined with negative ejection velocities suggest that large particles from 1995 would preferentially migrate to a position *forward* of the comet, not behind, while smaller particles would be "blown out" from this part of the meteoroid trail.

Lüthen et al. (2001) also did not take solar radiation pressure into consideration with their calculations. In exploring the prospects of meteor activity from four different meteoroid trails shed by SW 3 dating back to 1908, this study considered trails from 1941, 1952 and 1995 which were, "on orbits which radiation pressure cannot assist particles to achieve (occurring at a negative Δa_0[c])."

[c] Δa_0 is defined as the initial difference in semi-major axis after ejection from the comet that allows the nodal crossing to occur at exactly the relevant time in late May or early June of the year in question. The "0" refers to ejection time (i.e., "time zero"), the "a" refers to semimajor axis and the Δ refers to difference from the parent comet. Thus, it is the difference between the meteoroid's semimajor axis and the comet's semimajor axis at the time of ejection. The units are the units of the semimajor axis of an orbit.

The big question of course is, how many large particles can be expected to be ejected with velocities of −26.71 m/s? Typically, not many for most meteoroid trails. Stream modeling predicts the consequences – in terms of observable meteors – for a given distribution of ejection velocities. The implication of the Horii et al. study is that the more particles are ejected at −26.71 m/s (normalized to tangential ejection at perihelion), the greater an outburst will result. Jenniskens (2006) discusses ejection speeds and how they scale with meteoroid size. The required −26.71 m/s is a little on the high side, but not excessively so and moreover we can expect some meteoroids to acquire velocities in excess of the nominal value (Jones, 1995; Brown & Jones, 1998; Jenniskens, 2006).

Put simply, the 1995 trail is rather unique, having been formed in the wake of the major 1995 disruption of SW 3. Based on current knowledge of comet ejection processes, the ejection velocity range from 73P should (just) encompass the required value, for meteoroids of visual meteor size.

Hence the reasons for anticipating a possible meteor outburst in 2022.

Compilation of Earth passages

In Table 2 we compare the predictions of Lüthen et al. (2001) and Horii et al. (2008) for the Earth's encounter in 2022 with the material shed in 1995 by SW 3. The two independently predicted times of encounter with the 1995 trail *differ by only four minutes* and the difference in the distance between the orbit of the trail and the Earth's orbit ($r_\mathrm{E} - r_\mathrm{D}$) is practically negligible, only 0.00002 au.

The entry velocity (V_g) of the prospective meteors through the Earth's atmosphere is just over 12 km/s in both studies. To this Horii et al. notes that, "... it is a disappointing point that the value of V_g is lower than general meteor showers." As noted by Lüthen et al., "The geocentric velocity V_g (given in km/s) needs to be increased by about 4 km/s for observing purposes due to the gravity of the Earth."

The Leonids are the *swiftest* of all shower meteors, $V_g \approx 72$ km/sec. This is almost the highest theoretical speed for meteors belonging to the solar system due to their head on trajectories relative to Earth's orbit. Contrarily, meteors from SW 3 with $V_g \approx 12.5$ km/sec, would be practically the *slowest* of all known shower meteors. This is due to the fact that they are moving in the same general direction as Earth and must overtake the Earth in their orbit in order to be seen.

Last dance

As previously noted, the Lüthen et al. (2001) and Horii et al. (2008) studies both suggest that in the wake of the 1995 breakup of SW 3, larger meteoric particles were ejected in the direction opposite to the comet's motion. So, while starting out behind the comet, they ultimately may have ended up *moving ahead/forward of the comet* because they are moving in smaller orbits. In this context we repeated our original Dance methodology of creating a meteoroid trail for SW 3 using orbital

Table 2 – Predictions for 1995 trail in 2022.

	Date of encounter	Time (UT)	$r_{\mathrm{E}} - r_{\mathrm{D}}$ (au)	Longitude of node	Trail	V_g (km/s)
Lüthen	2022 May 31	4:55	0.00040	$69\overset{\circ}{.}440$	1995	12.10
Horii	2022 May 31	4:59	0.00038	$69\overset{\circ}{.}448$	1995	12.84

elements from 1995, but this time, 19 comets were positioned along a radius vector directed towards the Sun. Starting with the 1995 perihelion distance of SW 3, each comet was again separated incrementally by *decreasing distances from the Sun* of 0.00053789 au or 80,000 km (50,000 miles). A Pace of 1000 and a Zoom of 64× were again utilized.

On 2022 May 31, at 05:00 UTC, Earth was positioned between comet samples #12 and #13 (Figure 7).

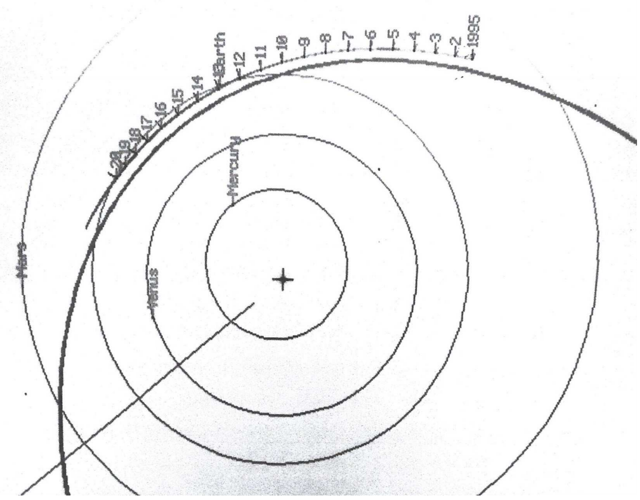

Figure 7 – Positions of Earth, SW 3 and presumed train of meteoroids on 2022 May 31 using Dance of the Planets orbital simulator. Assuming meteoroids are moving *ahead* of the parent comet (“1995”), interaction with the Earth takes place between comet samples #12 and #13. A second computation was then made regarding this particular segment of the train to narrow down the time when meteoroids would be closest to Earth’s vicinity. Five comet samples were found, falling within a 2.99-day time frame which encompassed the date and time of maximum ascertained by Lüthen et al. (2001) and Horii et al. (2008).

After the orbital elements were determined for these two cometary proxies, elements for another 18 objects were closely approximated by linear interpolation; these 20 objects would then represent that particular segment of the trail of meteoroids that would come near enough to interact with Earth.

Starting from 2022 May 1, these 20 new objects were set into motion, but this time using a much slower Pace of 100 (in which one minute equates to about 20 months).

In Dance, when a sample comet approaches very close to a planet – in this case Earth (“E”) – its orbit may be significantly modified. In this particular case, five out of the 20 comets underwent some degree of perturbation as shown in Table 3 with comet samples 16 through 20: the second column is the Earth-comet distance in Earth radii when the comet sample began to be perturbed. The fourth column is the UTC of least separation, and the fifth column the corresponding distance, again in Earth radii.

The case of comet sample #16 shows least separation occurring only 62 minutes after the mean of Lüthen et al. and Horii et al., while the nearest of these five approaches to Earth (sample #18) comes just 1.49 days prior. So, it would appear that our Dance methodology worked quite well in simulating Earth’s 2022 interaction with a meteoroid trail composed of large particles shed by the 1995 break-up of SW 3, and is in good agreement with the findings of both Lüthen et al. and Horii et al.

Intensity/duration “guesstimates”

It is problematic to try and predict meteor rates for a possible 2022 display of SW 3 meteors, primarily because Earth has never interacted with this particular meteoroid trail before. As noted previously, on 2017 May 30–31, between 23:39 and 00:45 UTC, five shower members from SW 3 were captured by NASA Cameras for all-sky meteor surveillance in California (CAMS). Lüthen et al. (2001) had forecast possible activity from a dust trail shed by this comet from 1941; the miss distance ($r_{\mathrm{E}} - r_{\mathrm{D}}$) was considered somewhat large (0.0011 au), yet slight activity was still recorded.

Compared to 2017, $r_{\mathrm{E}} - r_{\mathrm{D}}$ in 2022 is reduced to about one-third, to roughly 0.0004 au. That would suggest, at the very least (from a scalability argument), a potential hourly rate for 2022 of about 14.

However, the impending interaction with the 1995 trail will likely be composed of a far-more dense concentration of debris having been discharged in the wake of the fracturing of SW 3’s nucleus compared to the 1941 trail. But just *how much denser*, and what that could ultimately translate to in terms of overall meteor numbers is unknown.

A ten-fold increase would suggest rates of 140 per hour; a strong outburst similar to the annual Geminid or Quadrantid displays, while a one-hundred-fold increase would suggest 1,400 per hour; a full-fledged meteor storm.

It is probably prudent to have conservative expectations and focus on the former, lower rate possibility, although as we are about to see, we certainly cannot discount the latter possibility.

Bielids revisited?

In meteorology, “analog forecasting,” (as the technique is called), operates on the straightforward principle of making predictions by comparing current weather patterns to similar patterns (or analogs) from the past. Some call this type of forecasting pattern recognition. The question now arises: Can we use an “analog methodology” to forecast a meteor shower?

Table 3 – Earth interaction with 1995 meteoroid trail from SW 3.

Sample	Pert. dist. Earth radii	Date	UTC of min. distance	Min. dist. Earth radii
E-20	261	2022 May 28	06:11	229.3
E-19	260	2022 May 28	23:52	162.1
E-18	260	2022 May 29	17:06	130.1
E-17	260	2022 May 30	11:23	154.9
E-16	260	2022 May 31	05:59	229.3

Table 4 – Circumstances of 3D/Biela dust trail encounters in 1872 and 1885 compared with the 73P/SW 3 (1995 trail) encounter in 2022.
* ZHR values for 1872 and 1885 are based on an analysis by P. Jenniskens.

Year	Comet	Trail	Δa_0 au	$r_{\mathrm{E}} - r_{\mathrm{D}}$ au	f_M	ZHR*
1872	3D	4 revolutions	+0.0222	−0.00119	0.249	7400
1885	3D	6 revolutions	−0.0060	−0.00032	0.285	6400
2022	73P	5 revolutions	−0.0220	+0.00039	0.240	????

A study concerning dust trail density and variations of ZHR for past and future Leonid storms (McNaught & Asher, 1999) used three statistical parameters, $r_{\mathrm{E}} - r_{\mathrm{D}}$, Δa_0 and f_M[d]. But the Leonid parent comet (55P/Tempel-Tuttle) is a "Halley-type" comet with a period of 33 years in a highly-inclined orbit, so we cannot use this comet for a comparison to SW 3.

However as previously mentioned, there was the splitting of the nucleus of comet 3D/Biela in 1842–43, which was followed by spectacular Bielid (or "Andromedid") meteor storms radiating from Andromeda on 1872 November 27 and again in 1885. And like SW 3, 3D/Biela was a member of Jupiter's comet family, with an orbital period of 6.6 years. In the absence of any previous data points (trail encounters) with material that was shed by SW 3 in 1995, then the next best thing is to work by analogy with different streams. In this case, Jenniskens & Vaubaillon (2007) determined that the 1872 and 1885 storms were caused primarily by dust released by 3D/Biela in 1846, with only "minor contributions from dust ejected in 1839 and 1852, respectively." Thus, we decided to concentrate solely on the 1846 dust trail.

In Table 4 we compare the dust trail parameters of the resultant 1872 and 1885 Bielid storms with the upcoming situation for SW 3 in 2022. At first glance, the comparison of the 19th century storms produced by 3D/Biela with the upcoming situation in May 2022 for SW 3 appears supportive for a strong outburst; possibly even a storm.

With similar orbits, the conversion factor from meteoroid ejection speeds to Δa_0 will also tend to be similar. This is relevant since the strength of the outburst depends on the quantity of meteoroids (of a given size, which will correspond to the meteor brightness) at the given Δa_0.

It should be stressed, however, that comet 3D/Biela was brighter (an absolute brightness, pre-splitting, of H_{10} =+7.5 mag. versus +13.2 mag. for SW 3) and its nucleus considerably larger in diameter (∼4 to 6 km[e]) than SW 3. These two factors, unfortunately work against us, probably meaning fewer meteoroids are generated overall by SW 3. And furthermore, the material shed from 3D/Biela congregated *behind* the comet, as opposed to SW 3, where the material shed in the wake of the 1995 fracture of its nucleus, is assumed to be *in the front* of the comet. So, in spite of the similarity of all three dust trail parameters, such a difference in the orbital geometry for the SW3 trail is, unfortunately, not exactly comparable with the two trails cited for 3D/Biela.

Historically, however, there are certainly many other streams, including the Bielids, where $r_{\mathrm{E}} - r_{\mathrm{D}}$ values of a few earth diameters have yielded outbursts or storms. This and the moderately good f_M provide us with a bit of encouragement.

Sluggish streaks . . . short duration

Once again, there is also the vexing problem of the very slow entry velocity of these meteors through Earth's atmosphere. A large proportion may end up appearing predominately faint (magnitude +4 or +5) or even meteors perceptible only by using radio or radar techniques (>+6). On the other hand, if many of the associated meteoroids end up much larger than normal, that could offset their slow speeds and make for a somewhat bright display. As a comparison, the Bielid/Andromedid meteors of 1872 were described as primarily "slow, faint and evanescent," (Galea, 1995) but some exceeded 1st magnitude, often appearing "red, with trains of orange sparks" (Ottewell, 1989).

Regarding the duration of any potential outburst, like many other similar cases, it is likely to be short-lived, probably lasting on the order of several hours or less, with a sudden commencement and an abrupt end. Observers are urged, however, to watch for any forerunners that might be noted a day or two in advance

[d] Defined as the "mean anomaly factor," it is dust density compared to that in the unperturbed one-revolution dust trail. Or put another way, the ratio of the perturbed to the unperturbed dust density of the dust trail measured averaged over one revolution.

[e] An estimate that we made by comparing other comets with similar absolute brightness. See Hughes (2002).

of the main display; and maybe a straggler or two a day or so afterwards.

5 Radiant, area of visibility, moonlight

Until now, meteors associated with SW 3 have been referred to as "Tau (τ) Herculids." These are most likely directly related to Shibata's 1930 prediction of a possible meteor shower when the Earth passed close to the comet's node. That forecast was based on possible meteoroids *trailing behind* the parent comet.

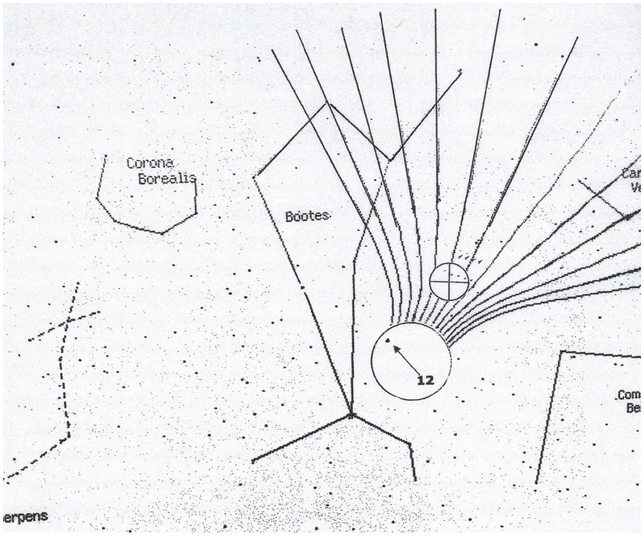

Figure 8 – Position of the radiant (using Dance of the Planets) for a possible meteor outburst near 5^{h} UTC on 2022 May 31 at $\alpha = 210\overset{\circ}{.}17$ $\delta = +25\overset{\circ}{.}03$. Rather than a small patch, it appears that the potential radiant, in the constellation of Boötes could measure several degrees or more in width. An arrow points to the +4.8-magnitude star 12 Boötis. The smaller circle encompassing a cross, is a positional consensus based on our position combined with that of Lüthen et al. (2001) and Horii et al. (2008). This mean radiant position of $\alpha = 208\overset{\circ}{.}35$ $\delta = 27\overset{\circ}{.}45$ is near the border of Boötes and Canes Venatici, less than a couple degrees southeast of the globular cluster Messier 3.

However, our forecast for 2022 is based on meteoroids that are traveling *forward or ahead* of SW 3. The end result is a possible radiant positioned not in Hercules, but within the boundaries of the constellation of Boötes, about 6° north-northwest of Arcturus and very close to the +4.8-magnitude star 12 Boötis (Figure 8). And rather than a small patch of sky, it appears that the potential radiant may measure several degrees or more in width. This may be due in part to the "special circumstances" of this interaction, as well as the low geocentric velocity of this meteor shower, as other similar studies have shown (Sato & Watanabe, 2014).

If so, then any prospective display of SW 3 meteors in 2022 will appear to materialize from a relatively large region of the sky.

Table 5 compares our results to those of Lüthen et al. (2001) and Horii et al. (2008).

As for the region of visibility (Figure 9), a large portion of the contiguous United States, south-central and eastern Canada (including the Maritime Provinces), Mexico, Central America, South America as well as a small slice of West Africa are the regions of the world well positioned for this event. In the U.S. the altitude of the radiant ranges from around 50° in eastern New England to 80° or more in southern California and the Desert Southwest.

Table 5 – Expected position of radiant (J2000.0).

	α	δ
Lüthen	$205\overset{\circ}{.}40$	$+29\overset{\circ}{.}20$
Horii	$209\overset{\circ}{.}48$	$+28\overset{\circ}{.}13$
Rao	$210\overset{\circ}{.}17$	$+25\overset{\circ}{.}03$

Across parts of the Pacific Northwest, northern Rockies and Great Plains, as well as for a slice of the Canadian Prairies, northern Ontario, central Quebec, most of Newfoundland and Labrador, the peak is expected to come during astronomical twilight (Sun 12 to 18° below the horizon), but the sky should still be sufficiently dark for sighting the brighter stars as well as any bright meteors.

Unfortunately, for far western and northern North America, as well as for the rest of the globe, the twilight sky will either be too bright, bathed in sunlight or facing away from any incoming meteors, precluding a view of any possible display.

So far as the situation regarding the Moon, it will arrive at new phase on May 30 (11:30 UTC) and will provide absolutely no interference.

6 Conclusion

In the aftermath of the break-up of the nucleus of comet 73P/Schwassmann-Wachmann 3 in 1995, two possibilities exist: Either the resultant material expelled will completely miss the Earth, or we will have a direct interaction with a swarm of large meteoric particles at the end of May in 2022. Our simulations confirm that both prospects are possible. The former case would result visually in little or nothing being observed. The latter case might possibly result in a prolific display of very slow, bright and colorful meteors. However, because of their slow speed, the meteors could also end up appearing very faint or not visible at all to the unaided eye. Unfortunately, this is all something new, and without knowledge of the exact orbital parameters and physical circumstances, a precise forecast is well-nigh impossible to make.

Such are the difficulties in meteor shower forecasting: At what mass-loss rate and precisely what velocities is a comet releasing debris? Some ejection directions/speeds will provide very efficient delivery of fragmented meteoritic material to Earth while others will not. Comets also are rather erratic in their dust production, jetting, (and break-ups of course) that only complicate matters. Additionally, particles of different sizes, morphologies, and compositions also react differently to the effects from the pressure of sunlight. So, as to exactly what might be expected at around 5^{h} UTC on 2022 May 31 is anyone's guess.

With no Moon, at least we are confident that skies will be dark. But will the meteors be bright?

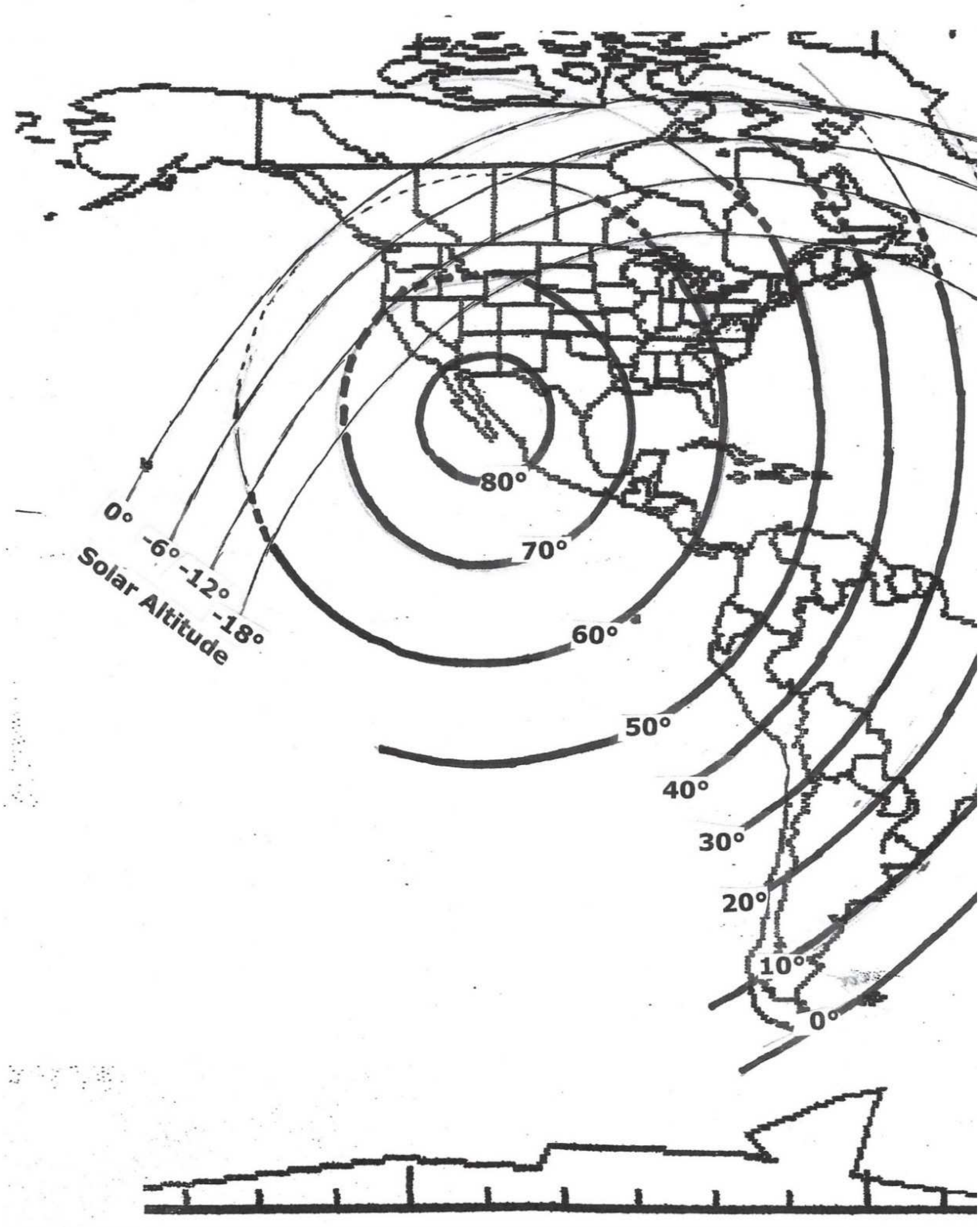

Figure 9 – The map presented here, shows the geographic visibility of the potential meteor outburst and is based on the assumption that peak activity will occur close to 5^h UTC on 2022 May 31. Zenithally attracted (apparent) radiant elevations are presented as concentric circles at 10° intervals. Also plotted are zones for civil twilight (Sun 0 to 6° below the horizon), nautical twilight (Sun 6 to 12° below the horizon) and astronomical twilight (Sun 12 to 18° below the horizon). Skies should be dark enough in the astronomical twilight zone to see a fair number of stars as well as any bright meteors. From near the Mexican resort town of Loreto, Baja California Sur, the presumed radiant will be at, or very close to the zenith. In contrast, from southernmost Chile and Argentina, as well as a slice of westernmost Africa (not pictured here), the radiant will be less than 10° above the horizon, likely resulting in true Earth grazers; very long-pathed meteors moving parallel to the Earth's surface. Radio and radar observations are possible from any location on the map (save for Antarctica) at the predicted peak time.

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The author dedicates this paper to the memories of Sune Engelbrektson, Kenneth L. Franklin, Fred C. Hess and Thomas D. Nicholson, astronomers at New York's Hayden Planetarium.

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Preliminary results

Result of the IMO Video Meteor Network – First Quarter 2019

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

The IMO Video Meteor Network cameras recorded over 33 000 meteors in more than 9 000 hours of observing time during 2019 January, more than 26 000 meteors in almost 13 000 hours of observing time during 2019 February, and almost 22 000 meteors in over 11 500 hours of observing time during 2019 March. Flux density and population index profiles are presented for the Quadrantids. High-resolution profile revealed maximum on 2019 January 4 at $02^{h}43^{m}$ UT ($\lambda_{\odot} = 283.^{\circ}175$) with a flux density of more than 35 meteoroids per 1 000 km^2 per hour.

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1 Introduction

Starting with this report, we switch to quarterly reporting of the IMO Video Meteor Network. At the same time, we will also update the format. The result section will, as usual, contain the statistics for the individual cameras, but we omit the technical details of them. This makes available sufficient space for all three months to be included in the table.

We present the details of the effective observing times and meteors per night in a graphical format. This gives a quick overview of the statistics in this quarter. Unfortunately, we cannot present all numbers in a single graph, because that would be too confusing. In the first diagram (Figure 1), we show the number of active video cameras (grey bars) and the effective observing of these cameras (red line). In the second diagram (Figure 2), we show the average number of meteors per hour (grey bars) and the absolute number of recorded meteors (red line).

1.1 First quarter overview

The year 2019 started with nice weather, and as a result almost 70 cameras were in operation during the Quadrantid maximum on January 3/4. Combined with a high rate of 15 meteors per hour, this allowed us to record almost 8 000 meteors during that night alone. Thereafter weather deteriorated significantly and reached a low by the end of January. In February, the weather was pleasant again with only short interruptions, much better than on average. Looking at the effective observing time, we see that the nights are already getting shorter in March.

If we ignore the outlier due to the Quadrantids, the hourly meteor rate started at above three per hour, but, as happens in other years, dropped back to about two meteors per hour in mid-January, which marks the annual low.

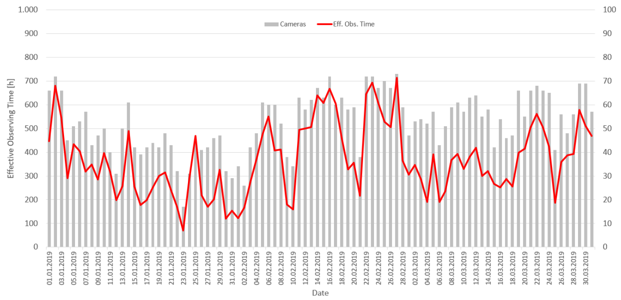

Figure 1 – Number of active cameras per night (grey bars) and effective observing time of these cameras (red line) in the first quarter of 2019.

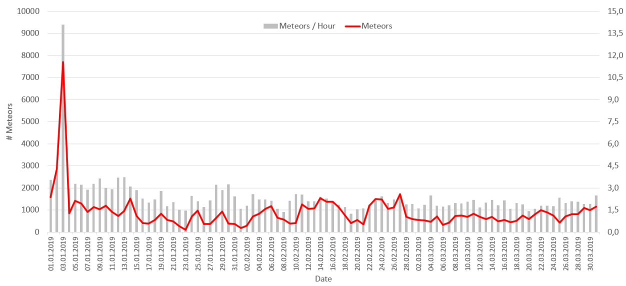

Figure 2 – Average number of meteors per hours (grey bars) and number of recorded meteors per night (red line) in the first quarter of 2019.

1.2 January

Comparing the results of January 2019 with previous years, we find that the number of observing hours was similar to the previous four years – only in 2017 did we collect 25% more hours under exceptionally good conditions (Molau et al., 2017). The meteor count of January 2019, however, only fell short of the record level of 2017 by a small amount. The hourly average was higher than in any year since 2011.

1.3 February

February 2019 was a record-breaking month. With over 12 700 observing hours we topped the typical yield by 50%, and with respect to the meteor number the previous February record was topped by 20%. In the absence of significant meteor showers, the hourly meteor rate varies typically between 2.0 and 2.2, and 2019 was no exception in this respect.

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IMO bibcode WGN-491-molau-2019q1
NASA-ADS bibcode 2021JIMO...49...15M

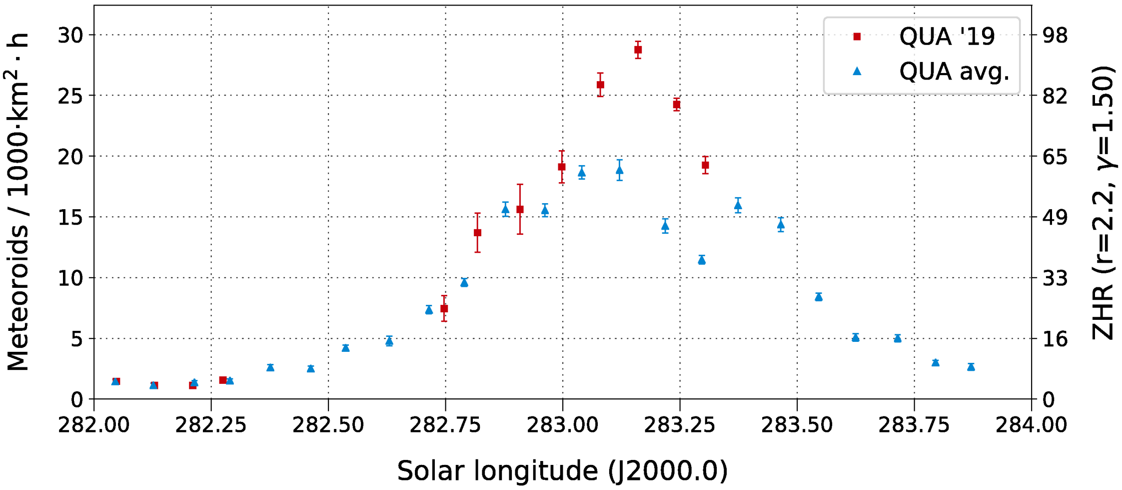

Figure 3 – Flux density of the Quadrantids in 2019 (red) along with the average of the years 2011–2018, derived from observations of the IMO Network.

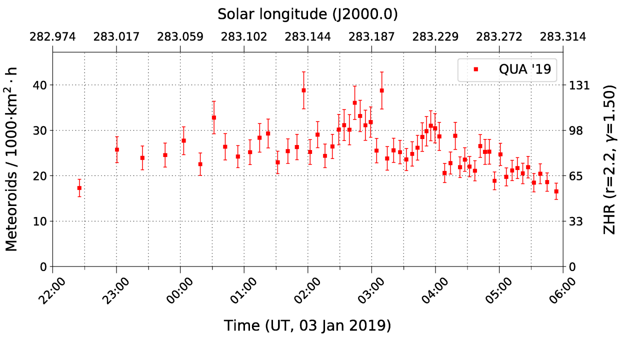

Figure 4 – High-resolution flux density profile of the Quadrantid peak 2019.

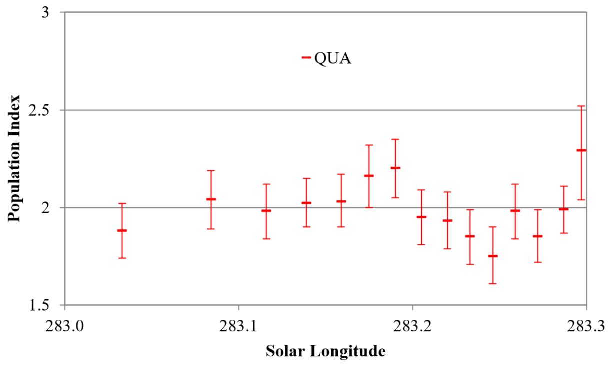

Figure 5 – Population index of the Quadrantids during the 2019 maximum.

1.4 March

Over 11 500 observing hours in March was above average, and the second-best yield for this month after 2014 (Molau et al., 2014). The meteor total was even slightly higher than five years earlier.

Hence, 2019 provided a very good start, and 85 cameras contributed to that result.

2 Quadrantids

Let us have a closer look at the Quadrantids. Figure 3 compares the activity profile of 2019 with the average profile of the years 2011–2018. It is obvious, that we were not only lucky with respect to the weather, but that we also directly hit the shower maximum during the night of January 3/4. Now when two out of three success factors are given, we can be sure that a bright full moon will light up the sky like daylight. But no, the peak happened just two days before New Moon, so it was one of these perfect Quadrantid peaks which you may enjoy only every twenty years or so.

Thanks to the large yield of over 5 000 shower meteors on 2019 January 3/4, we could derive a high-resolution flux density profile of the peak night (Figure 4) with a maximum resolution of down to 5 minutes per bin at best.

At the start of night, the density of data points is still low. That comes as no surprise, as the radiant is circumpolar in northern Europe, but it is located very low in the northern sky during the evening hours. Only after midnight local time is it gaining altitude, which manifests itself in increasing meteor counts. If we ignore individual outliers at 01^{h}56^{m} UT (283°141 solar longitude) and 03^{h}09^{m} UT (283°193 solar longitude), the activity profile is remarkably smooth. Peak activity is reached at 02^{h}43^{m} UT (283°175 solar longitude) with a flux density of more than 35 meteoroids per 1 000 km^2 per hour, which is somewhat less than the flux density of Perseids. The calculated peak ZHR of 120 is, however, what we expect from very rich Perseid years.

Remarkable is the wave-like shape of the profile with a secondary peak after the primary at 03^{h}55^{m} UT (283°226 solar longitude). By this time, the radiant has further climbed and twilight is not yet an issue, which is why the meteor yield and the temporal resolution is highest at that time.

Figure 5 shows the r-value profile of the peak night during the same time interval as Figure 4. The population index is nearly $r = 2.0$, before it reaches a small peak with $r = 2.2$ at 03^{h}04^{m} UT (283°190 solar longitude) and thereafter a more significant low of $r = 1.75$

at 04^h24^m UT (283°.246 solar longitude). There is no direct correlation with the peaks in the activity profile.

We compared our results with visual observations collected by IMO (International Meteor Organization, 2019). The automated analysis of roughly 1 500 visual Quadrantids with a fixed population index of $r = 2.1$ yielded a peak at 02^h20^m UT (283°.16 solar longitude) with a ZHR of 115. Hence, the peak occurred half an hour earlier, but the ZHR is almost identical. Fine structures like the secondary peak are not visible due to the lower temporal resolution.

3 20th anniversary of the IMO Network

Finally, a word about the 20th anniversary of the IMO Network, which we had celebrated in March 2019. On this occasion, we look back at the history in a separate article (Molau, 2021). However, one question is to be answered in this quarterly report: Did we really manage to record over a million observing hours and over four million meteors during these twenty years?

Yes, we did! We were able to surpass both values, in late January and early February 2019 respectively. Statistically speaking, our camera network observed as much as a single camera recording the clear sky for roughly 115 years in a row and detecting a meteor every 15 minutes.

Table 1 – Overall statistics from twenty years of IMO Video Meteor Network.

Year	Obs. Nights	Eff. Obs. Time [h]	Meteors	Meteors per Hour
1999	117	1 022.4	8 351	8.2
2000	248	2 514.1	12 852	5.1
2001	293	4 503.2	31 646	7.0
2002	318	5 862.5	23 258	4.0
2003	357	9 652.7	36 381	3.8
2004	351	7 403.5	25 209	3.4
2005	356	9 560.7	40 770	4.3
2006	365	14 995.1	69 844	4.7
2007	364	16 956.0	75 053	4.4
2008	366	22 937.5	92 323	4.0
2009	365	32 286.7	138 766	4.3
2010	365	35 489.3	192 049	5.4
2011	365	69 065.0	312 110	4.5
2012	366	93 558.7	353 627	3.8
2013	365	86 641.9	350 003	4.0
2014	365	100 391.3	368 680	3.7
2015	365	122 147.3	481 218	3.9
2016	366	114 713.8	477 736	4.2
2017	365	118 282.0	433 047	3.7
2018	365	113 760.4	444 033	3.9
2019	90	33 627.0	81 510	2.4
Sum	6877	1 015 371.1	4 048 466	4.0

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Table 2 – Observational statistics for first quarter of 2019.

Code	Name	Place	Camera	January			February			March		
				Nights	Time [h]	Meteors	Nights	Time [h]	Meteors	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	LUDWIG2	19	98.1	361	23	158.8	464	24	118.4	300
BERER	Berkó	Ludanyhalaszi/HU	HULUD1	4	28.3	123	—	—	—	—	—	—
BIATO	Bianchi	Mt. San Lorenzo/IT	OMSL1	13	22.1	162	17	181.1	295	26	213.0	320
BOMMA	Bombardini	Faenza/IT	MARIO	21	173.9	901	27	245.4	631	30	243.2	522
BREMA	Breukers	Hengelo/NL	MBB3	13	71.2	95	14	99.7	107	—	—	—
BRIBE	Klemt	Herne/DE	HERMINE	18	100.9	218	21	171.0	322	19	99.2	151
		Berg. Gladbach/DE	KLEMOI	5	14.7	41	—	—	—	—	—	—
CARMA	Carli	Monte Baldo/IT	BMH2	28	289.4	1627	25	267.1	1059	25	243.6	813
CASFL	Castellani	Monte Baldo/IT	BMH1	18	190.6	495	25	265.7	432	25	239.1	357
CINFR	Cineglosso	Faenza/IT	JENNI	20	178.8	807	26	250.3	654	30	258.4	520
CRIST	Crivello	Valbrevenna/IT	ARCI	26	212.3	949	25	216.2	497	27	207.5	426
			BILBO	26	234.1	1229	25	241.1	674	29	211.6	509
			C3P8	25	199.4	715	25	208.1	320	22	173.2	266
			STG38	25	161.3	1326	23	136.0	513	25	116.3	409
ELTMA	Eltri	Venezia/IT	MET38	18	141.3	656	19	168.8	342	23	174.5	246
FORKE	Förster	Carlsfeld/DE	AKM3	10	17.8	127	18	109.5	337	11	52.5	121
GONRU	Goncalves	Foz do Arelho/PT	FARELHO1	1	0.2	1	1	0.2	1	3	1.2	8
		Tomar/PT	TEMPLAR1	26	244.3	836	26	254.4	575	29	244.8	569
			TEMPLAR2	25	238.5	766	26	254.1	496	28	240.8	419
			TEMPLAR3	22	218.9	300	21	209.6	146	26	216.7	144
			TEMPLAR4	25	228.0	751	25	239.9	397	28	231.1	345
			TEMPLAR5	22	208.3	613	22	180.1	291	28	204.8	313
GOVMI	Govedič	Središče ob Dr./SI	ORION2	23	126.6	262	24	169.2	199	28	162.9	197
			ORION3	21	131.7	205	20	166.0	100	26	188.0	129
			ORION4	18	80.4	164	21	100.5	103	28	108.0	103
HINWO	Hinz	Schwarzenberg/DE	HINWO1	12	83.8	161	20	170.2	335	16	101.0	169
IGAAN	Igaz	Hodmezovasar./HU	HUHOD	14	54.8	116	19	163.3	134	25	160.8	145
		Budapest/HU	HUPOL	10	65.9	53	21	170.0	68	24	155.5	54
JONKA	Jonas	Budapest/HU	HUSOR2	12	77.9	158	19	162.9	130	23	150.9	124
KACJA	Kac	Kamnik/SI	CVETKA	8	27.6	94	17	137.9	417	22	163.1	393
			REZIKA	10	36.6	187	17	135.6	485	22	155.7	437
			STEFKA	8	22.5	73	17	135.3	299	21	154.1	256
		Ljubljana/SI	SRAKA	16	86.4	256	22	159.7	336	22	145.6	272
KOSDE	Koschny	La Palma/ES	ICC7	—	—	—	—	—	—	22	70.7	194
			ICC9	21	203.2	759	12	79.9	312	23	129.8	480
			LIC2	18	140.0	1808	10	61.7	624	27	124.6	1285
KWIMA	Kwinta	Krakow/PL	PAV06	3	22.1	8	14	76.7	38	8	47.4	18
			PAV07	3	17.6	13	12	112.1	60	13	70.1	47
			PAV79	3	16.1	16	16	140.6	139	13	91.8	84
MACMA	Maciejewski	Chelm/PL	PAV35	8	10.2	26	14	55.3	101	23	68.9	110
			PAV36	6	13.8	23	16	97.4	178	24	118.4	170
			PAV43	3	13.9	8	11	24.5	113	23	74.7	179
			PAV60	11	43.8	78	17	120.6	302	24	155.9	347
MARRU	Marques	Lisbon/PT	CAB1	21	153.4	489	27	243.1	420	27	227.4	412
			RAN1	24	232.7	622	23	186.8	319	26	218.8	251
MISST	Missiaggia	Nove/IT	TOALDO	20	171.5	492	18	160.3	225	18	142.0	275
MOLSI	Molau	Seysdorf/DE	AVIS2	18	81.1	331	22	158.5	612	24	150.7	492
			DIMCAM1	5	10.6	80	—	—	—	—	—	—
			DIMCAM2	11	57.1	401	23	161.1	1038	26	145.3	775
			ESCIMO2	14	82.2	119	20	148.7	245	21	117.4	171
		Ketzür/DE	REMO1	21	103.5	412	19	139.5	379	25	120.6	342
			REMO2	20	111.0	631	21	170.5	716	25	139.0	447
			REMO3	21	128.3	426	23	192.4	514	22	149.3	358
			REMO4	20	118.5	584	23	173.4	654	26	147.7	516
MORJO	Morvai	Fülöpszallas/HU	HUFUL	18	94.4	120	21	204.5	138	25	191.9	119
MOSFA	Moschini	Rovereto/IT	ROVER	24	128.8	485	23	127.7	256	27	97.4	192
NAGHE	Nagy	Budapest/HU	HUKON	10	59.5	177	23	143.7	334	27	108.5	232
		Piszkestetö/HU	HUPIS	20	83.6	320	23	172.3	339	28	170.1	315
		Zamardi/HU	HUZAM	16	104.9	255	21	186.3	195	25	158.9	157
OTTMI	Otte	Pearl City/US	ORIE1	15	18.7	84	1	0.5	2			
PERZS	Perkó	Becsehely/HU	HUBEC	19	106.3	488	25	175.6	363	29	184.1	305
ROTEC	Rothenberg	Berlin/DE	ARMEFA	10	66.9	90	17	130.5	147	19	111.3	106
SARAN	Saraiva	Carnaxide/PT	RO1	21	176.5	332	23	155.4	178	5	38.9	33
			RO2	18	148.3	324	18	133.2	172	10	69.2	85
			RO3	22	157.3	453	19	159.7	239	10	85.8	155
			RO4	19	153.2	141	19	117.8	81	9	78.1	43
			SOFIA	24	147.0	400	21	139.5	200	9	72.2	75
SCALE	Scarpa	Alberoni/IT	LEO	20	131.0	300	22	140.4	145	26	177.1	109
SCHHA	Schremmer	Niederkrüchten/DE	DORAEMON	21	116.7	242	20	158.2	228	20	107.6	144
SLAST	Slavec	Ljubljana/SI	KAYAK1	12	88.5	117	20	151.6	130	17	119.2	85
			KAYAK2	12	95.4	132	23	185.3	136	16	125.9	63
STOEN	Stomeo	Scorze/IT	MIN38	27	176.0	1100	23	183.9	630	29	207.1	540
			NOA38	26	183.5	1130	23	198.8	645	28	225.2	520
			SCO38	25	175.3	1211	23	199.7	655	29	213.4	618
STRJO	Strunk	Herford/DE	MINCAM2	20	114.5	427	25	150.6	501	24	109.5	250
			MINCAM3	18	122.2	188	20	157.2	222	21	113.1	108
			MINCAM4	15	64.6	105	20	145.4	151	18	71.1	62
			MINCAM5	17	104.6	164	22	154.8	183	23	102.4	104
			MINCAM6	20	116.7	216	20	147.3	186	22	98.9	114
TEPIS	Tepliczky	Agostyan/HU	HUAGO	20	123.8	407	19	172.3	261	25	161.8	206
			HUMOB	11	74.6	236	21	179.3	214	23	141.2	139
WEGWA	Wegrzyk	Nieznaszyn/PL	PAV78	12	55.5	95	17	58.9	148	20	39.7	79
YRJIL	Yrjölä	Kuusankoski/FI	FINEXCAM	10	79.3	186	14	81.3	138	18	98.7	166
ZAKJU	Zakrajšek	Petkovec/SI	PETKA	20	147.3	904	23	186.0	677	26	193.7	632
			TACKA	18	123.2	245	19	183.5	206	25	190.1	191
Sum				31	9335.3	33228	28	12712.0	26248	31	11508.1	21937

20 Years of IMO Video Meteor Network – in Numbers!

Sirko Molau [1]

In March 2019 we celebrated the 20th anniversary of the IMO Video Meteor Network. On this occasion (a little belated) we would like to reflect how the network has developed over the years, and present the results from different perspectives in a statistical way.

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1 Introduction

In March 2019 we celebrated the 20th anniversary of the IMO Video Meteor Network. On this occasion (a little belated) we would like to reflect how the network has developed over the years, and present the results from different perspectives in a statistical way.

Everything started on the balcony of my flat in Aachen (Figure 1), where I had installed my image-intensified camera AVIS in early 1999.

Figure 1 – The start of the IMO Video Meteor Network at my Aachen flat in March 1999 (top left). The camera AVIS was installed on the balcony (top right, bottom left) and fed the video signal live into the analysis computer (bottom right).

Up until that time we had used our meteor cameras only for observing campaigns of showers like the Perseids, Geminids, Leonids or Quadrantids. All observations were recorded on video tape and inspected later. After the meteor detection software MetRec became capable to check video data in real-time, I let the camera AVIS run without a video recorded during the night of 1999 March 11/12, and analysed the video stream directly with MetRec. By the end of the night, I had recorded 18 meteors in seven hours of effective observing time. The age of real-time video meteor observation had started.

Whenever clear weather was predicted in the days and weeks to come (and whenever I could do without my computer), I repeated the procedure. I soon found my first supporters for this project. Jürgen Rendtel started regular observation on July 9/10, and occasionally we got additional data from Ulrich Sperberg, Mirko Nitschke and the Institute of Atmospheric Physics in Kühlungsborn, which was a driving force behind the development of MetRec. In the following year, we welcomed our first international observers in our network with Ilkka Yrjölä (Finland) and Orlando Benitez-Sanchez (Spain).

In 2003 we managed to observe during 357 nights, and thus during almost every night of the year. In 2006 we had grown to 20 observers, collecting an overall total of 10 000 hours of observing time. The night of 2007 May 28/29 was the last in which we could not record a single meteor because of weather conditions – since then there has been at least one camera successful in ever night. By the end of 2011 we had collected our first million meteors and the number of observers had grown to 50. To date, our most successful year has been 2015, when we recorded over 480 000 meteors in more than 120 000 hours of effective observing time. Since then, the annual totals have remained at a constantly high level.

On the occasion of the 20th anniversary, I would like to present some statistics which reflect the network from different view points. In order to do so, I first had to put the observing database onto a new basis. Since the first days of the camera network, the monthly output (number of active cameras, observing nights, effective observing time and number of recorded meteors) had been collected in an Excel spreadsheet. The more observers contributed to the network, the bigger the Excel file became and the more complicated and error-prone was the data collection. In the last few years, the MetRec logfiles were parsed script-based, and the sums were copied into the file. Recently the number of columns reached a level that only the latest Excel versions were still able to handle. The base table with the monthly outputs alone had over 200 000 cells in the end!

For this reason, I parsed the original logfiles another time and imported all observations into a Postgres database. The advantage (or disadvantage?) of a database is that you can easily implement consistency checks. Even though the data had been checked repeatedly and was therefore of high quality, I found again a number of minor inconsistencies. On some occasions the number of meteors in the logfile and the PosDat files did not match, then the IMO site codes did not agree. On some occasions the monthly statistics contained observations which were missing from the logfiles, then there were observers at locations to which they did not be-

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long. In the end, the number of erroneous records was only a few *per mille*, but with a total of 175 000 individual observations there were still hundreds of data sets to be analysed and manually corrected, which took me several weeks. Quality assurance was only finished, after the number of observing nights and meteors in the old Excel file and the new Postgres database matched by 100%.

In a next step, I also imported the data of four million single meteors from the PosDat files into a new database table. Once more I had to correct hundreds of small errors and inconsistencies over several weeks, until the number of meteors matched exactly to the observing statistics.

The clean-up was really laborious, but it was a one-time effort. Using the database I can now create analyses within seconds and without any line of program code, a task which had been laboured or impossible in the past. All it needs is a more or less complex SQL query.

Let us start with the base statistics. Table 1 lists all observers who contributed at least 100 observing nights in the twenty years between March 1999 and March 2019 to the IMO Network. Here is the corresponding SQL query:

```
SELECT observer, firstname, lastname, country,
       COUNT(DISTINCT(TO_CHAR (date,'YYYYMM')))
       AS obsmonths,
       COUNT(DISTINCT(TO_CHAR (date,'YYYY')))
       AS obsyears,
       COUNT(DISTINCT(date))
       AS nightsum,
       ROUND(SUM(obstime)::numeric,1)
       AS obstimesum,
       SUM(meteors)
       AS metsum,
       ROUND(SUM(meteors)/SUM(obstime)::numeric,1)
       AS metperh FROM observations
INNER JOIN observers ON observer = imocode
WHERE date>='1999-03-01' AND date<='2019-03-31'
GROUP BY observer, firstname, lastname, country
HAVING COUNT(DISTINCT(date)) >=100
ORDER BY nightsum DESC
```

I must confess that this query is long, but it does not only yield the number of observing nights, observing hours and meteors per observer, but also the number of months and years in which the observer was active, and the average number of recorded meteors per hour.

Unsurprisingly the list is spearheaded by observers who have been with the Network from early on, and who operated more than one camera. The table was sorted by the number of observing nights.

The IMO Network had started in Germany, but in the last few years the Italian observers have been particularly successful. So what does the distribution by country look like, if we look at the complete 20 years? That can be seen in Table 2.

Only with respect to observing nights are the German observers clearly in the lead. They collected 23% of the total observing time, and 25% of the meteors. The Italian observers are (still) a short distance behind with 20% less observing time and 24% less meteors. Portugal, Hungary and Slovenia are ranked 3rd to 5th with about half of these values each.

So, do the Italian observers have more sensitive cameras or better skies than the Germans? The next table gives a detailed breakdown over all cameras which contributed at least 300 observing nights to the IMO Video Meteor Database. The threshold is on purpose relatively large to filter out cameras which were only selectively active at major meteor showers. Table 3 is sorted by the average number of meteors per hour. Additionally we calculated the first and last month of operation, the number of possible observing nights between the first and last month of activity, and the usual statistics (real number of observing nights, observing hours, meteors).

The first five cameras are image-intensified systems with a large tube – four of them record the night sky under perfect conditions on the Canary Islands, the last one is located north of Munich. They are followed by Mintron cameras with Computar lenses, many of which are located in Italy. If you add the years of activity, only four cameras remain which have recorded over 100 000 meteors on their own – three of them in Italy.

And what about the weather? To find out which camera had the longest uninterrupted observing series, it required a more complex SQL query, which took me two evenings to compile. Here is finally the result of all observing series with at least 50 consecutive observing nights in a row (including the start and end date of the series).

By far the longest series was provided by Stefano Crivello, who managed to observe with Sco38 between 2017 May 18 and September 17, in 123 nights in a row. Alongside him, there are almost exclusively Italian and Portuguese cameras in the list. The German record is "only" 53 nights in a row by Remo2.

Let us have a look at further records: Which camera was most active over a full year? The following table shows all cameras with 300 and more observing nights in a single year. The first three places are hold by Carl Hergenrother with his camera Salsa3 in Arizona, only after that do we find the Italian and Portuguese observers. Other countries are not present in this list.

As an observer who has to cope with less favourable weather conditions, you can cheat by operating cameras at different observing sites. Hence, the table with observers who collected more than 300 nights per year, looks a little different (Table 6).

And while we are talking about observing sites: Which site is the "headquarter of video meteor observation"? Table 7 lists all IMO sites at which more than 100 000 meteors were recorded. On top is Venice, the observing site of Enrico Stomeo. The next sites are from Rui Goncalves (Portugal), Stefano Crivello (Italy) and the two observing sites of Sirko Molau (Germany).

So far, we have focused on observers and cameras – now we want to analyse the observing results with respect to seasons and meteor showers.

During which night did we record most meteors? The Perseids are represented seven times in the Top-10, the Geminids three times. The Leonids are not present

Table 1 – Results of the observers with more than 100 observing nights in the 20 years of IMO Video Meteor Network.

Observer	First Name	Last Name	Country	Obs. Months	Obs. Years	Obs. Nights	Eff. Obs. Time [h]	Meteors	Meteors per Hour
MOLSI	Sirko	Molau	DE	241	21	5529	94 084.9	520 113	5.5
STRJO	Jörg	Strunk	DE	222	20	4274	58 053.9	187 351	3.2
KACJA	Javor	Kac	SL	184	17	3546	52 459.2	225 279	4.3
CASFL	Flavio	Castellani	IT	160	15	3433	30 637.9	101 266	3.3
GONRU	Rui	Goncalves	PT	134	12	3383	86 245.8	280 482	3.3
STOEN	Enrico	Stomeo	IT	164	15	3335	51 234.9	312 654	6.1
BRIBE	Bernd	Klemt	DE	149	14	3260	24 369.0	80 216	3.3
CRIST	Stefano	Crivello	IT	140	13	3255	51 844.9	257 341	5.0
KOSDE	Detlef	Koschny	NL	186	20	2944	36 008.1	278 436	7.7
IGAAN	Antal	Igaz	HU	119	11	2744	30 808.3	81 344	2.6
HERCA	Carl	Hergenrother	US	106	10	2701	20 734.6	51 592	2.5
SLAST	Stane	Slavec	SL	194	18	2639	17 672.9	40 099	2.3
GOVMI	Mitja	Govedič	SL	120	11	2575	27 468.4	82 510	3.0
SCHHA	Hans	Schremmer	DE	116	11	2503	11 869.6	39 163	3.3
TEPIS	Istvan	Tepliczky	HU	116	11	2393	21 516.2	71 347	3.3
SARAN	Carlos	Saraiva	PT	94	9	2366	57 550.5	134 603	2.3
YRJIL	Ilkka	Yrjölä	FI	186	21	2311	12 352.8	43 469	3.5
ELTMA	Maurizio	Eltri	IT	149	15	2251	14 454.1	62 154	4.3
PERZS	Zsolt	Perko	HU	106	10	2164	12 587.4	63 277	5.0
OTTMI	Mike	Otte	US	110	10	2154	11 172.6	32 393	2.9
MORJO	Jozsef	Morvai	HU	103	10	2098	12 568.8	25 531	2.0
JONKA	Karoly	Jonas	HU	100	10	2068	17 254.7	37 475	2.2
MACMA	Maciej	Maciejewski	PL	93	9	2055	33 796.8	121 892	3.6
HINWO	Wolfgang	Hinz	DE	134	14	2005	11 396.7	53 502	4.7
ROTEC	Eckehard	Rothenberg	DE	134	13	1982	10 094.8	26 254	2.6
TRIMI	Mihaela	Triglav	SL	111	11	1972	8 100.7	27 533	3.4
BOMMA	Mario	Bombardini	IT	85	9	1937	11 837.0	61 002	5.2
BREMA	Martin	Breukers	NL	93	9	1767	12 463.3	29 920	2.4
ARLRA	Rainer	Arlt	DE	81	8	1618	8 245.1	42 688	5.2
SCALE	Leo	Scarpa	IT	83	9	1573	8 845.0	23 009	2.6
MARRU	Rui	Marques	PT	56	6	1488	18 194.9	58 881	3.2
BERER	Erno	Berko	HU	97	10	1395	16 972.9	78 727	4.6
MOSFA	Fabio	Moschini	IT	60	6	1267	4 649.1	16 697	3.6
OCHPA	Paolo	Ochner	IT	87	10	1260	5 951.0	17 527	2.9
NAGHE	Henrietta	Nagy	HU	52	6	1131	7 036.3	26 606	3.8
BENOR	Orlando	Benitez-Sanchez	ES	110	13	1033	5 301.6	13 959	2.6
MARGR	Grigoris	Maravelias	GR	59	6	1031	6 541.2	20 087	3.1
FORKE	Kevin	Förster	DE	61	6	976	5 448.7	23 487	4.3
DONJE	Jenni	Donati	IT	41	4	950	6 291.7	37 314	5.9
KISSZ	Szabolcs	Kiss	HU	46	5	903	4 921.2	5 461	1.1
CSISZ	Szilard	Csizmadia	HU	48	6	840	3 244.6	9 758	3.0
PUCRC	Rok	Pucer	SL	45	4	834	4 796.2	16 332	3.4
LUNRO	Bob	Lunsford	US	60	6	803	5 105.4	33 229	6.5
MASMI	Mikhail	Maslov	RU	55	6	750	3 124.6	16 363	5.2
KERST	Stephen	Kerr	AU	44	5	748	5 063.3	36 047	7.1
CARMA	Maurizio	Carli	IT	33	4	732	5 230.8	31 936	6.1
CINFR	Francesca	Cineglosso	IT	27	3	675	3 937.8	17 413	4.4
RENJU	JÃijrgen	Rendtel	DE	57	6	638	3 790.7	17 070	4.5
BANPE	Peter	Banfalvi	HU	47	6	599	1 886.5	7 034	3.7
WEGWA	Wala	Wegrzyk	PL	31	4	596	2 721.5	7 865	2.9
LOJTO	Tomasz	Lojek	PL	56	6	583	3 410.9	10 352	3.0
LOPAL	Alvaro	Lopes	PT	31	3	570	2 912.2	5 022	1.7
EVAST	Stephen	Evans	UK	78	10	457	2 800.2	11 411	4.1
BIRSZ	Szofia	Biro	HU	22	3	437	2 530.3	6 989	2.8
ZAKJU	Jure	Zakrajšek	SL	20	3	406	3 713.1	11 720	3.2
QUIST	Steve	Quirk	AU	20	2	341	3 050.0	10 109	3.3
BIATO	Thomas	Bianchi	IT	15	2	304	1 446.5	4 960	3.4
LERAR	Arnaud	Leroy	FR	22	3	303	1 395.6	1 819	1.3
ROBBI	Roberto	Biondani	IT	22	4	294	1 583.3	5 320	3.4
ZELZO	Zoltan	Zelko	HU	42	5	290	1 808.5	4 497	2.5
OCAFR	Francisco	Ocaña	ES	14	2	251	1 516.6	1 691	1.1
JOBKL	Klaas	Jobse	NL	25	4	251	1 801.9	20 090	11.1
NITMI	Mirko	Nitschke	DE	46	5	207	921.6	4 842	5.3
STORO	Rostislav	Stork	CZ	75	15	189	1 782.3	31 637	17.8
UEBST	Stefan	Überschär	DE	21	3	173	893.1	1 788	2.0
SPEUL	Ulrich	Sperberg	DE	41	8	166	1 064.0	4 647	4.4
MISST	Stefano	Missiaggia	IT	6	2	122	964.6	5 210	5.4
CURMA	Malcolm	Currie	UK	12	2	122	532.9	2 133	4.0
BASLU	Luc	Bastiaens	BE	19	5	118	431.1	528	1.2

Table 2 – Distribution of observations of the IMO Video Meteor Network over countries.

Country Code	Country Name	Obs. Nights	Eff. Obs. Time [h]	Fraction of Eff. Obs. Time	Meteors	Fraction of Meteors
DE	Germany	6363	231 088.4	22.8%	1 006 265	24.8%
IT	Italy	4376	198 908.6	19.6%	953 803	23.5%
PT	Portugal	3476	164 973.2	16.2%	479 025	11.8%
HU	Hungary	3224	133 166.6	13.1%	418 121	10.3%
SL	Slovenia	4509	114 559.4	11.3%	405 141	10.0%
PL	Poland	2199	40 523.7	4.0%	140 532	3.5%
US	USA	3811	37 012.6	3.6%	117 214	2.9%
ES	Spain	3075	34 101.0	3.4%	264 934	6.5%
NL	Netherlands	2855	23 085.6	2.3%	80 742	2.0%
FI	Finland	2311	12 352.8	1.2%	43 469	1.1%
AU	Australia	1153	8 710.8	0.9%	51 824	1.3%
GR	Greece	1031	6 541.2	0.6%	20 087	0.5%
UK	UK	581	3 363.5	0.3%	15 553	0.4%
RU	Russia	750	3 124.6	0.3%	16 363	0.4%
CZ	Czech Rep.	213	1 832.9	0.2%	32 701	0.8%
FR	France	303	1 395.6	0.1%	1 819	0.0%
BE	Belgium	127	630.6	0.1%	873	0.0%

in this list, because a comparably small number of meteor cameras was active during the Leonid storms of 1999 and 2001.

If, instead, we look at observing hours rather than meteors, the long winter nights clearly have an advantage. Weather conditions are typically not as good as in Summer, but if there is a widespread sky clearance, our cameras are driven to maximum performance. In the best night we observed for effective 35 days!

Also, in the Top-10 of the best observing months, the Perseid month August is represented seven times. In addition, the Orionids are present twice (October) and the Geminids once (December).

The dominance of the Perseids is broken when we look at individual nights and cameras. Here they are not present at all in the Top-10, but we find six Geminid and four Leonid observations.

And overall? Which shower is present most in the four Million meteors of the IMO Network database? Here is the list of meteor showers which make up for at least one part *per mille* of the total population. Nearly two third of the meteors in our database are sporadic. Effectively nothing has changed in this respect in the last 15 years, because in the first automated meteor search in 2006, which was based on only 5% of the current database, I had identified a sporadic share of about 2/3 (Molau, 2007).

The Anthelion source including the Northern and Southern Taurids makes up for more than 10%. Their activity is low, but they are active all year long. After these we find the first "real" meteor showers with the Perseids (8.6%), Orionids (3.7%) and Geminids (3.4%). The higher Orionid count results from the longer activity period compared to the Geminids.

If the average limiting magnitude of the cameras is identical over all meteor showers, then the average meteor brightness is a measure for the population index of the shower. The smaller the population index, the larger the fraction of bright meteors, and the lower the average meteor magnitude. We cannot calculate the absolute population index this way, but we can suppose that the Perseids, Leonis Minorids and sigma Hydrids have a particularly small population index, whereas the Anthelion source including the Taurids, the alpha Capricornids, Draconids and delta Leonids have a particularly large population index. This contradicts in many cases the r-values which are given in the IMO meteor shower list (Rendtel, 2014). Hence there is scope for further investigations.

Ok, let us finish the number gambling here. The question is what we want to achieve with the observations? In the first ten years of the IMO Network, we searched for (unknown) meteor showers and determined their basic properties such as the activity interval, velocity and radiant position. In the last ten years, our prime focus was on flux density profiles and population indices of meteor showers. The last automated meteor shower search dates back ten years, when the database had only a quarter of today's size. For this reason, we started a new search. However, this time we do not focus on weak, but on short meteor showers, which may have fallen through the grid so far. For this purpose, we increase the temporal resolution by a factor of 10. Since June 2019 a radiant search has been running on two of my PCs with 6 CPU cores round the clock. The job only finished in early November 2020. I am curious to see which new insights we will gain from the subsequent analysis, which is probably like looking for the needle in a haystack.

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Table 3 – Distribution of observations over the participating cameras in the IMO Video Meteor Network.

Camera	First Action	Last Action	Possible Obs. Nights	Obs. Nights	Eff. Obs. Time [h]	Meteors	Meteors per Hour
LIC2	12/2015	—	1205	570	4 087.6	45 367	11.1
AVIS2	08/2004	—	5347	2832	15 377.2	157 863	10.3
LIC1	08/2009	04/2018	3170	512	3 662.1	36 616	10.0
ICC9	02/2013	—	2236	1397	9 625.9	91 516	9.5
ICC7	09/2011	—	2753	1361	9 701.3	73 791	7.6
GOCAM1	01/2010	02/2014	1489	748	5 063.3	36 047	7.1
SCO38	03/2009	—	3663	2786	16 768.3	111 577	6.7
AVIS	03/1999	03/2004	1845	747	3 974.8	26 173	6.6
REZIKA	01/2006	—	4815	2034	12 232.4	79 573	6.5
BOCAM	03/2006	08/2011	1980	803	5 105.4	33 229	6.5
HULUD1	10/2010	01/2019	3016	1348	8 754.8	56 465	6.4
MIN38	08/2005	—	4984	3180	18 883.7	115 880	6.1
STG38	08/2007	—	4236	2798	17 152.1	105 141	6.1
REMO4	10/2013	—	2005	1535	8 722.6	51 614	5.9
LUDWIG2	12/2013	—	1932	1498	7 524.6	41 839	5.6
NOA38	05/2009	—	3601	2623	15 539.5	85 136	5.5
REMO1	06/2006	—	4657	3420	17 023.7	92 291	5.4
AKM2	06/2001	06/2011	3659	912	5 261.9	28 287	5.4
HUSOP	05/2011	08/2012	487	374	1 765.0	9 594	5.4
JENNI	08/2013	—	2063	1625	10 229.5	54 727	5.3
MARIO	12/2011	—	2661	1937	11 837.0	61 002	5.2
CVETKA	09/2011	—	2766	1298	7 777.7	40 614	5.2
NOWATEC	05/2013	11/2018	2004	750	3 124.6	16 363	5.2
AKM1	07/2001	01/2007	2006	308	1 780.2	9 353	5.2
HUBEC	06/2010	—	3203	2164	12 587.4	63 277	5.0
REMO2	02/2008	—	4068	2826	14 473.1	69 582	4.8
BILBO	10/2011	—	2732	2207	14 222.3	68 519	4.8
HUPIS	04/2017	—	729	478	2 116.7	9 531	4.5
ARCI	08/2017	—	597	485	3 234.8	14 233	4.4
MET38	08/2005	—	4979	2251	14 454.1	62 154	4.3
AKM3	03/2014	—	1828	976	5 448.7	23 487	4.3
BMH2	02/2008	—	4066	2713	16 430.2	68 777	4.2
STEFKA	09/2008	—	3855	1551	8 957.5	37 176	4.2
PAV60	10/2013	—	2002	1298	7 103.7	29 770	4.2
TEMPLAR1	02/2008	—	4064	2980	21 968.3	90 073	4.1
C3P8	08/2008	—	3887	2836	17 235.7	69 448	4.0
PAV36	07/2011	—	2810	1857	9 950.9	39 983	4.0
HINWO1	04/2014	—	1804	1032	6 027.9	24 093	4.0
HUMOB	07/2009	—	3535	2194	12 875.7	49 734	3.9
ORION2	08/2008	—	3889	2392	13 322.7	49 934	3.7
REMO3	10/2012	—	2343	1412	8 201.2	30 215	3.7
HUGOT	07/2014	11/2017	1246	716	2 286.2	8 434	3.7
FINEXCAM	12/2003	—	5595	2128	11 202.7	40 846	3.6
PAV35	07/2011	—	2810	1751	8 454.4	30 653	3.6
ROVER	01/2014	—	1891	1267	4 649.1	16 697	3.6
RF1	12/2003	01/2008	1502	376	2 527.7	9 094	3.6
MINCAM1	07/2002	09/2018	5892	3644	18 782.3	66 587	3.5
MINCAM2	07/2002	—	6091	3696	16 535.9	58 445	3.5
MINCAM5	07/2006	—	4639	2609	12 912.2	45 649	3.5
LIC4	03/2010	04/2016	2243	1115	5 284.3	18 232	3.5
HUVCSE01	10/2010	01/2017	2304	1063	3 648.5	12 616	3.5
TEMPLAR4	08/2012	—	2405	1927	14 118.5	48 135	3.4
TEMPLAR5	12/2013	—	1932	1625	10 844.0	37 358	3.4
SRAKA	01/2006	—	4814	2202	9 325.6	32 118	3.4
CAB1	10/2014	—	1613	1209	9 031.0	30 983	3.4
MOBCAM1	01/2012	09/2015	1360	834	4 796.2	16 332	3.4
CARMEN	07/1999	03/2004	1699	482	2 700.8	9 223	3.4
OMSL1	01/2018	—	446	304	1 446.5	4 960	3.4

Table 3 – (continued) – Distribution of observations over the participating cameras in the IMO Video Meteor Network.

Camera	First Action	Last Action	Possible Obs. Nights	Obs. Nights	Eff. Obs. Time [h]	Meteors	Meteors per Hour
TEMPLAR2	08/2008	—	3889	2865	20 622.8	69 054	3.3
BMH1	12/2005	—	4850	3096	19 438.5	64 425	3.3
HERMINE	11/2006	—	4519	2965	14 293.2	47 193	3.3
DORAEMON	08/2009	—	3529	2503	11 869.6	39 163	3.3
KLEMOI	01/2011	01/2019	2922	1983	10 075.8	33 023	3.3
HUBAJ	11/2009	12/2014	1872	1120	5 165.1	17 002	3.3
SSO1—WAT	03/2001	11/2003	975	344	3 062.3	10 116	3.3
MINCAM3	06/2003	—	5772	2833	13 724.5	44 267	3.2
HULUD2	08/2010	11/2013	1204	679	3 835.5	12 249	3.2
TIMES4	07/2000	09/2012	4452	748	3 618.0	11 554	3.2
RO3	01/2014	—	1877	1445	10 508.5	32 571	3.1
ORION1	05/2007	11/2017	3831	2227	10 605.2	32 526	3.1
LOOMECON	09/2011	10/2016	1880	1031	6 541.2	20 087	3.1
RAN1	08/2014	—	1694	1271	9 163.9	27 898	3.0
PAV57	11/2013	10/2018	1796	583	3 410.9	10 352	3.0
SALSA2	06/2009	08/2010	416	319	1 430.1	4 313	3.0
ORIE1	01/2010	02/2019	3343	2154	11 172.6	32 393	2.9
MINCAM6	01/2014	—	1889	1338	6 746.8	19 432	2.9
ALBIANO	08/2008	11/2018	3751	1260	5 951.0	17 527	2.9
PAV78	09/2016	—	936	596	2 721.5	7 865	2.9
KAYAK1	06/2002	—	6138	2502	12 130.7	33 386	2.8
HUHOD	04/2009	—	3645	1907	9 811.7	27 166	2.8
HUVCSE02	05/2011	11/2015	1650	451	1 876.1	5 266	2.8
HUDEB	08/2011	12/2015	1602	1024	6 246.8	17 076	2.7
RO2	06/2011	—	2843	2108	15 160.4	39 122	2.6
METKA	12/2003	—	5592	1901	11 636.1	30 195	2.6
HUAGO	11/2011	—	2680	1846	11 170.8	28 602	2.6
ARMEFA	08/2007	—	4249	1982	10 094.8	26 254	2.6
LEO	08/2011	—	2785	1573	8 845.0	23 009	2.6
PAV43	07/2011	—	2811	1603	8 287.8	21 486	2.6
SALSA3	08/2010	12/2018	3072	1977	15 836.9	39 768	2.5
MBB3	05/2011	02/2019	2856	1639	8 924.8	21 760	2.4
ORION4	12/2011	—	2665	1607	8 221.6	19 820	2.4
HUSOR	12/2010	10/2018	2888	1901	11 068.5	24 979	2.3
HULUD3	04/2011	09/2015	1596	752	4 382.6	10 013	2.3
MBB4	08/2011	12/2014	1233	663	3 538.5	8 160	2.3
TACKA	04/2011	—	2909	453	2 851.9	6 645	2.3
ORION3	12/2011	—	2657	1145	5 949.5	13 366	2.2
ESCIMO2	01/2015	—	1538	968	5 791.0	12 941	2.2
SALSA	02/2008	02/2010	716	551	3 467.6	7 511	2.2
RO1	06/2011	—	2841	2071	14 108.5	29 868	2.1
TEMPLAR3	07/2011	—	2803	2246	16 352.5	32 913	2.0
SOFIA	11/2011	—	2684	1995	13 646.3	27 445	2.0
HUFUL	02/2010	—	3345	2098	12 568.8	25 531	2.0
MINCAM4	08/2004	—	5345	1500	6 820.8	13 690	2.0
HUSOR2	03/2015	—	1489	1005	6 186.2	12 496	2.0
NASO1	03/2015	10/2017	952	570	2 912.2	5 022	1.7
RO4	11/2016	—	849	623	4 126.8	5 597	1.4
TIMES5	07/2004	12/2010	2349	501	1 683.6	2 405	1.4
HUPOL	04/2010	—	3280	1539	7 661.0	9 726	1.3
FARELHO1	07/2016	—	968	439	2 339.7	2 949	1.3
SAPHIRA	07/2011	05/2013	699	303	1 395.6	1 819	1.3
KAYAK2	11/2014	—	1611	877	5 542.2	6 713	1.2
HUSUL	11/2011	08/2015	1395	903	4 921.2	5 461	1.1

Table 4 – Longest uninterrupted series of observing nights in the 20-year history of the IMO Network.

Camera	Country	Start Date	End Date	Duration [days]
SCO38	IT	18.05.2017	17.09.2017	123
STG38	IT	26.06.2016	11.10.2016	108
BILBO	IT	28.06.2018	09.10.2018	104
ARCI	IT	28.06.2018	09.10.2018	104
TEMPLAR1	PT	01.07.2016	10.10.2016	102
TEMPLAR4	PT	01.07.2016	10.10.2016	102
TEMPLAR2	PT	01.07.2016	10.10.2016	102
STG38	IT	14.06.2018	21.09.2018	100
CAB1	PT	05.07.2016	10.10.2016	98
SALSA3	US	26.09.2010	29.12.2010	95
MARIO	IT	15.06.2017	15.09.2017	93
JENNI	IT	15.06.2017	14.09.2017	92
TEMPLAR1	PT	19.07.2017	16.10.2017	90
TEMPLAR1	PT	14.06.2015	10.09.2015	89
NOA38	IT	15.06.2017	08.09.2017	86
TEMPLAR2	PT	14.06.2015	06.09.2015	85
BILBO	IT	07.06.2012	29.08.2012	84
BILBO	IT	23.07.2016	11.10.2016	81
CAB1	PT	09.07.2017	26.09.2017	80
TEMPLAR2	PT	26.07.2018	12.10.2018	79
STG38	IT	20.07.2011	06.10.2011	79
TEMPLAR1	PT	26.07.2018	12.10.2018	79
TEMPLAR4	PT	19.07.2017	03.10.2017	77
TEMPLAR2	PT	19.07.2017	03.10.2017	77
TEMPLAR3	PT	19.07.2017	03.10.2017	77
SALSA3	US	07.01.2016	19.03.2016	73
MET38	IT	22.06.2017	01.09.2017	72
TEMPLAR5	PT	31.07.2016	10.10.2016	72
BILBO	IT	30.05.2015	08.08.2015	71
BILBO	IT	19.07.2013	26.09.2013	70
STG38	IT	25.06.2017	02.09.2017	70
STG38	IT	19.07.2013	24.09.2013	68
JENNI	IT	23.05.2015	29.07.2015	68
MIN38	IT	27.06.2017	01.09.2017	67
JENNI	IT	19.06.2016	20.08.2016	63
STG38	IT	23.05.2015	23.07.2015	62
JENNI	IT	02.07.2018	31.08.2018	61
SALSA3	US	21.09.2016	20.11.2016	61
BILBO	IT	11.07.2017	08.09.2017	60
HUDEB	HU	26.06.2013	24.08.2013	60
JENNI	IT	30.07.2014	27.09.2014	60
TEMPLAR5	PT	09.07.2017	03.09.2017	57
SALSA3	US	25.04.2016	20.06.2016	57
TEMPLAR4	PT	16.07.2015	10.09.2015	57
LIC1	ES	25.05.2016	19.07.2016	56
HUDEB	HU	12.08.2011	06.10.2011	56
HUHOD	HU	25.06.2013	19.08.2013	56
HUFUL	HU	25.06.2013	19.08.2013	56
STG38	IT	26.07.2014	18.09.2014	55
TEMPLAR3	PT	13.07.2013	04.09.2013	54
RO3	PT	23.06.2015	15.08.2015	54
MARIO	IT	10.07.2018	31.08.2018	53
REMO2	DE	28.08.2018	19.10.2018	53
C3P8	IT	25.07.2009	14.09.2009	52
SCO38	IT	02.08.2015	22.09.2015	52
PAV35	PL	13.07.2015	01.09.2015	51

Table 5 – Cameras with most observing nights per year in the 20-year history of the IMO Network.

Camera	Year	Obs. Nights	Eff. Obs. Time [h]	Meteors
SALSA3	2014	330	2818.4	6 266
SALSA3	2015	330	2568.9	6 570
SALSA3	2017	326	2707.6	6 591
CAB1	2017	326	2612.8	9 234
TEMPLAR1	2017	325	2544.3	10 463
TEMPLAR5	2016	320	2100.4	7 927
TEMPLAR2	2017	320	2525.6	8 541
MARIO	2017	319	2131.3	10 833
TEMPLAR4	2017	319	2409.5	8 843
SCO38	2017	318	1865.4	11 193
SALSA3	2016	318	2711.1	6 932
TEMPLAR5	2017	317	2213.1	7 896
TEMPLAR1	2016	317	2369.8	9 615
BILBO	2017	316	2096.0	10 180
TEMPLAR1	2015	315	2306.4	9 055
NOA38	2017	315	1848.5	9 877
TEMPLAR2	2016	314	2369.7	7 922
STG38	2017	313	2144.1	13 640
MIN38	2017	312	1772.4	11 177
TEMPLAR4	2016	312	2234.0	7 846
TEMPLAR3	2012	311	2295.2	5 878
TEMPLAR2	2015	311	2303.5	7 384
TEMPLAR4	2015	310	2200.3	7 815
TEMPLAR5	2015	309	2078.4	7 596
JENNI	2017	307	1777.4	7 851
STG38	2016	307	2002.1	14 100
TEMPLAR5	2014	306	1915.4	6 777
MARIO	2018	305	1874.5	9 169
RO3	2017	304	2236.1	7 728
STG38	2015	303	2033.1	12 675
BILBO	2015	301	1913.8	8 296
RO2	2017	301	2291.8	6 424
SCO38	2016	300	1707.3	11 288

Table 6 – Observers with most observing nights per year in the 20-year history of the IMO Network.

Observer	First Name	Last Name	Year	Obs. Nights	Eff. Obs. Time [h]	Meteors
KOSDE	Detlef	Koschny	2015	351	5 495.0	46 642
GONRU	Rui	Goncalves	2017	348	13 073.2	40 966
MOLSI	Sirko	Molau	2016	347	9 309.0	50 677
IGAAN	Antal	Igaz	2012	346	6 355.9	19 508
MOLSI	Sirko	Molau	2018	344	10 616.2	62 822
MOLSI	Sirko	Molau	2015	342	10 059.2	57 765
KOSDE	Detlef	Koschny	2013	341	4 949.9	41 536
MARRU	Rui	Marques	2017	341	4 725.3	16 111
KOSDE	Detlef	Koschny	2016	340	7 802.4	75 865
GONRU	Rui	Goncalves	2016	339	11 669.6	37 588
GONRU	Rui	Goncalves	2015	339	11 010.4	35 553
MOLSI	Sirko	Molau	2017	339	9 851.3	49 563
SARAN	Carlos	Saraiva	2017	336	10 643.7	26 049
MOLSI	Sirko	Molau	2008	336	4 108.1	20 882
GONRU	Rui	Goncalves	2018	334	10 930.5	30 362
STOEN	Enrico	Stomeo	2017	334	5 486.3	32 247
CRIST	Stefano	Crivello	2017	330	6 925.9	34 880
HERCA	Carl	Hergenrother	2014	330	2 818.4	6 266
HERCA	Carl	Hergenrother	2015	330	2 568.9	6 570
MOLSI	Sirko	Molau	2014	329	8 169.6	43 032
GONRU	Rui	Goncalves	2014	328	9 556.4	30 344
GONRU	Rui	Goncalves	2012	328	7 206.0	23 394
KOSDE	Detlef	Koschny	2014	328	4 488.6	32 567
MARRU	Rui	Marques	2018	327	3 429.6	10 790
HERCA	Carl	Hergenrother	2010	327	1 580.2	5 567
MOLSI	Sirko	Molau	2007	326	3 296.6	18 322
HERCA	Carl	Hergenrother	2017	326	2 707.6	6 591
MOLSI	Sirko	Molau	2011	324	5 430.8	27 831
MOLSI	Sirko	Molau	2012	323	5 041.9	28 941
MOLSI	Sirko	Molau	2009	323	3 968.3	20 453
MARRU	Rui	Marques	2015	322	3 923.1	12 166
SARAN	Carlos	Saraiva	2018	321	8 526.8	16 938
IGAAN	Antal	Igaz	2011	320	4 481.5	19 470
IGAAN	Antal	Igaz	2013	319	4 543.7	10 660
BOMMA	Mario	Bombardini	2017	319	2 131.3	10 833
MOLSI	Sirko	Molau	2013	318	6 950.8	35 596
MARRU	Rui	Marques	2016	318	4 082.5	14 101
HERCA	Carl	Hergenrother	2016	318	2 711.1	6 932
CRIST	Stefano	Crivello	2012	317	5 324.1	26 484
STOEN	Enrico	Stomeo	2016	316	4 939.0	30 025
CRIST	Stefano	Crivello	2016	315	5 405.0	29 811
CRIST	Stefano	Crivello	2011	315	4 411.8	23 887
GONRU	Rui	Goncalves	2013	312	8 129.3	27 003
SARAN	Carlos	Saraiva	2016	312	7 867.5	19 732
CRIST	Stefano	Crivello	2015	311	5 549.8	26 387
CRIST	Stefano	Crivello	2013	309	5 304.1	24 126
IGAAN	Antal	Igaz	2014	309	4 010.6	7 213
CASFL	Flavio	Castellani	2015	308	4 341.2	15 590
STOEN	Enrico	Stomeo	2015	307	5 206.9	31 820
CINFR	Francesca	Cineglosso	2017	307	1 777.4	7 851
SARAN	Carlos	Saraiva	2015	306	8 119.3	19 882
STOEN	Enrico	Stomeo	2018	306	4 398.9	30 805
BOMMA	Mario	Bombardini	2018	305	1 874.5	9 169
SARAN	Carlos	Saraiva	2012	304	6 110.5	12 579
CRIST	Stefano	Crivello	2014	304	4 648.5	20 291
CRIST	Stefano	Crivello	2018	302	6 522.4	33 935

Table 7 – The Top-10 observing sites where most meteors were recorded in the 20-year history of the IMO Network.

Site Code	Site	Country	Obs. Nights	Eff. Obs. Time [h]	Meteors	Meteors per Hour
14083	Spinea	Italy	3335	51 234.9	312 654	6.1
40110	Linhaceira Tomar	Portugal	3373	83 905.8	277 530	3.3
14024	Valbrevenna	Italy	3255	51 861.0	257 426	5.0
11181	Ketzür	Germany	3720	49 101.2	253 885	5.2
16070	Seysdorf	Germany	4164	42 480.3	246 932	5.8
40105	Lisbon	Portugal	2415	69 590.1	167 434	2.4
23129	Rezman Observatory	Slovenia	2143	28 979.1	157 402	5.4
14260	Osserv. Monte Baldo	Italy	3547	37 981.9	139 725	3.7
15600	Roque Los Muchachos	Spain	1447	13 720.5	136 919	10.0
34012	Chelm	Poland	2055	33 814.1	121 975	3.6

Table 8 – The Top-10 observing nights with respect to the number of recorded meteors in the 20-year history of the IMO Network.

Date	Cameras	Eff. Obs. Time [h]	Meteors	Meteors per Hour
11.08.2016	61	406.9	13 035	32.0
12.08.2015	77	518.2	12 915	24.9
12.08.2018	77	483.5	12 820	26.5
12.08.2016	71	424.6	9 779	23.0
12.08.2013	67	391.5	9 669	24.7
13.12.2015	54	402.8	9 059	22.5
13.08.2015	77	521.2	9 032	17.3
12.08.2012	67	421.8	8 881	21.1
13.12.2010	36	292.2	8 332	28.5
13.12.2018	48	355.1	8 288	23.3

Table 9 – The Top-10 observing nights with respect to the number of observing hours in the 20-year history of the IMO Network.

Date	Cameras	Eff. Obs. Time [h]	Meteors	Meteors per Hour
30.12.2016	75	854.8	2756	3.2
29.12.2016	69	789.8	2977	3.8
12.10.2018	75	757.2	3826	5.1
04.12.2018	73	732.1	3473	4.7
27.02.2019	74	724.1	1749	2.4
02.11.2015	69	709.1	4399	6.2
04.10.2018	78	706.2	3442	4.9
16.11.2018	74	702.3	3922	5.6
23.02.2019	73	702.2	1513	2.2
09.10.2018	76	699.2	2729	3.9

Table 10 – The Top-10 observing months with most meteor records in the 20-year history of the IMO Network.

Month	Eff. Obs. Time [h]	Meteors	Meteors per Hour
08/2016	12 322.5	98 979	8.0
08/2015	12 386.7	91 442	7.4
08/2018	13 140.5	88 080	6.7
08/2017	13 077.4	80 622	6.2
08/2013	9 878.2	75 405	7.6
08/2012	10 631.2	75 375	7.1
10/2018	13 725.6	74 787	5.4
08/2014	9 857.0	71 210	7.2
10/2017	13 426.0	68 824	5.1
12/2016	13 823.8	64 991	4.7

Table 11 – The Top-10 observations with most meteors recorded by a single camera in a single night in the 20-year history of the IMO Network.

Date	Site	Country	Camera	Eff. Obs. Time [h]	Meteors	Meteors per Hour
18.11.2001	Taegu	Korea	AVIS	8.2	2085	254.3
18.11.2001	Taegu	Korea	CAPCAM	6.1	1521	249.3
17.11.1999	Al-Azraq	Jordan	CAPCAM	4.0	872	218.0
17.11.1999	Tavira	Portugal	ELLI	6.7	734	109.6
18.11.2001	Lindian	China	AKM2	7.1	715	100.7
14.12.2007	Field Ca	Usa	BOCAM	7.7	709	92.1
12.12.2012	Endrefalva	Hungary	HULUD1	13.6	691	50.8
13.12.2013	Faenza	Italy	JENNI	13.5	657	48.7
18.11.2002	Lucianena De Las Tor	Spain	ELLI	5.4	647	119.8
13.12.2010	Spinea	Italy	SCO38	11.2	620	55.4

Table 12 – Percentage of meteor showers in the IMO Video Meteor Database.

Meteor Shower	Name	Meteors	Percentage	Avg. Brightness [mag]
SPO	Sporadics	2 581 257	63.69%	0.96
PER	Perseids	348 298	8.59%	0.33
ANT	Anthelion	258 565	6.38%	1.06
ORI	Orionids	147 127	3.63%	0.67
GEM	Geminids	135 278	3.34%	0.61
STA	S-Taurids	91 733	2.26%	1.08
NTA	N-Taurids	86 900	2.14%	0.98
SDA	S-delta-Aquarids	50 551	1.25%	0.81
CAP	alpha-Capricornids	35 799	0.88%	1.02
LEO	Leonids	31 603	0.78%	0.56
QUA	Quadrantids	27 087	0.67%	0.59
COM	Coma-Berenicids	25 412	0.63%	0.62
DAU	delta-Aurigids	24 115	0.59%	0.75
KCG	kappa-Cygnids	21 752	0.54%	0.81
LYR	Lyrids	20 219	0.50%	0.64
SPE	September-Perseids	17 475	0.43%	0.56
HYD	sigma-Hydrids	17 407	0.43%	0.43
ETA	eta-Aquarids	16 179	0.40%	0.74
EGE	epsilon-Geminids	16 166	0.40%	0.65
MON	Monocerotids	15 514	0.38%	0.66
NOO	November-Orionids	11 338	0.28%	0.61
AUR	alpha-Aurigids	10 476	0.26%	0.66
GIA	Draconids	8 468	0.21%	1.22
URS	Ursids	6 991	0.17%	0.61
PAU	Piscis-Austrinids	6 715	0.17%	0.98
LMI	Leo-Minorids	5 824	0.14%	0.39
DLE	delta-Leonids	5 298	0.13%	1.23
OCU	Oct-Ursa-Majorids	5 283	0.13%	0.75
ELY	eta-Lyrids	5 106	0.13%	0.89

Observing report

Iron Meteor Spectrum 2019 11 07 : $23^h27^m43^s$ UT

Bill Ward[1]

A bright spectrum, of what appears to be primarily an iron composition, was captured on evening of the 7th November 2019.

Received 2020 November 29

A bright spectrum, of what appears to be primarily an iron composition, was captured on evening of the 2019 November 7.

The meteor was captured using a ZWO 174MM monochrome HD video camera with a 25 mm $f/1.3$ lens running at 17.1 fps. A 50 mm × 50 mm grating with 600 lines/mm was used as the diffracting element. The grating was secured inside a lens hood via a 72 mm rotating adapter ring.

This system is one of three ZWO HD cameras, in addition to eight Watec cameras, used by the author as part of the Kilwinning Spectroscopic Survey for Meteors. This programme has been ongoing since August 2008.

The crop from the image used to produce the spectrum is shown in Figure 1. The zero image of the meteor was not captured.

The spectrum was processed using VisualSpec[a]. The calibration is based on the assumption that the strongest lines were identifiable from previous meteor spectra with the additional lines being identified subsequently.

The NIST Atomic Spectra Lines online database was used to identify the additional lines.[b]

Having worked with the NEMETODE group[c] on previous combined spectro-orbital observing campaigns (Ward, 2017) the group was contacted to find out if any members had caught this particular meteor. Unfortunately this was not the case and an orbit was not determined.

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IMO bibcode WGN-491-ward-spectrum
NASA-ADS bibcode 2021JIMO...49...29W

[a]VisualSpec spectroscopy software. http://astrosurf.com/vdesnoux/

[b]NIST Online database. https://physics.nist.gov/PhysRefData/ASD/lines_form.html

[c]Network for Meteor Triangulation and Orbit Determination (NEMETODE). http://www.nemetode.org/

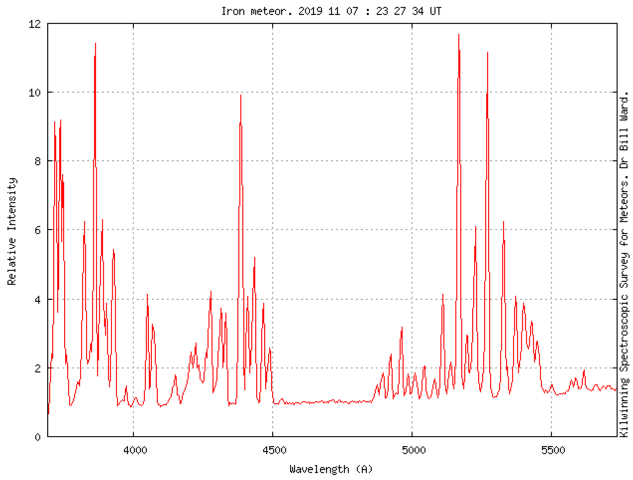

Figure 2 – Complete spectrum reduced from the image.

The complete spectrum is shown in Figure 2. The two main lines zones are shown in Figures 3 and 4 respectively with the identified lines numbered.

Tables 1 and 2 list the identified lines.

Figure 5 shows a synthetic colourised version of the spectrum.

This example illustrates that moderate resolution meteor spectra can be captured with relatively modest equipment. With routine spectroscopy comes a much deeper understanding of the meteor environment in which the Earth moves as it provides information beyond integrated light flux rate counts.

References

Ward W. (2017). "Video meteor spectroscopic and orbit determination observations, April 2015 to April 2016.". *J. Br. Astron Assoc*, **127:4**, 217–222.

Handling Editor: Javor Kac

Figure 1 – Crop from the image of meteor spectrum.

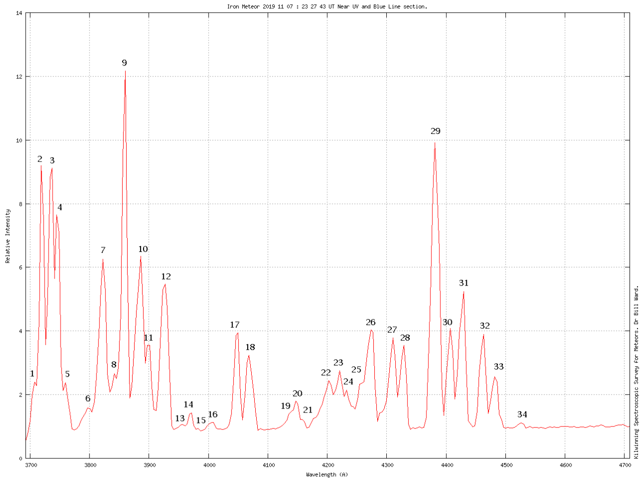

Figure 3 – The blue line section of meteor spectrum.

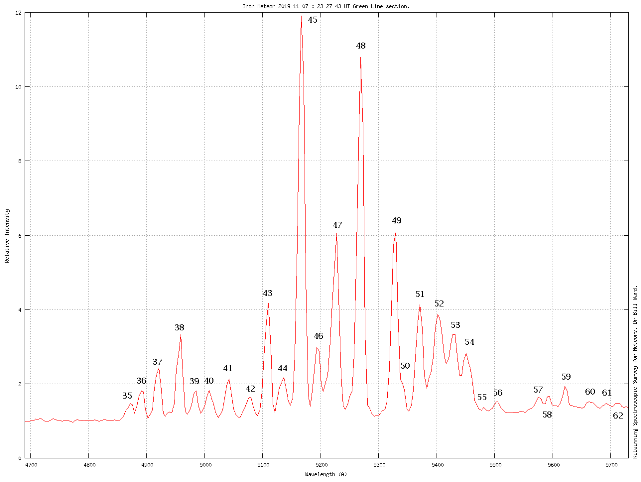

Figure 4 – The green line section of meteor spectrum.

Figure 5 – Synthetic colourised version of the spectrum.

Table 1 – Iron Meteor Spectrum 2019 11 07 : $23^{h}27^{m}43^{s}$ UT. Near Uv/Blue line identification.

#	Wavelength (nm)	Element
1	370.704	Fe
2	371.993	Fe
3	373.486/373.713	Fe
4	374.556/374.590	Fe
5	375.823	Fe
6	375.955	Fe
7	382.043	Fe
8	384.128	Fe
9	385.991	Fe
10	388.628	Fe
11	390.115	V
12	392.026/392.291/392.792	Fe
13	395.645	Fe
14	396.944	Fe II
15	398.177	Fe
16	400.524	Fe
17	404.581	Fe
18	406.339/407.174	Fe
19	413.936	Fe II
20	414.387	Fe
21	415.680	Fe
22	420.202	Fe
23	421.936	Fe
24	423.246	V
25	425.854	Fe
26	427.176/428.240	Fe
27	432.926	Fe
28	433.002	V
29	438.354	Fe
30	440.475	Fe
31	442.730	Fe
32	446.165	Fe
33	448.217	Fe
34	452.422	V

Table 2 – Iron Meteor 2019 11 07 : $23^{h}27^{m}43^{s}$ UT. Green line identifications.

#	Wavelength (nm)	Element
35	487.126	V
36	489.075	Fe
37	492.050	Fe
38	595.760	Fe
39	498.413	Ni
40	501.207	Fe
41	504.176	Fe
42	507.479	Mn
43	511.021	Fe
44	513.708	Ni
45	516.745/517.160	Fe
46	519.362	V
47	522.715	Fe
48	526.954/527.036	Fe
49	532.804	Fe
50	534.106	Mn
51	537.149	Fe
52	540.193	Fe
53	542.970/542.999	Fe
54	544.726	Si II
55	547.691	Ni
56	550.344	W
57	557.873	Ni
58	559.242	V
59	562.620	V
60	566.215	Fe
61	569.473	Cr
62	591.190	Ni

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Fireballs over Missouri skies

This impressive fireball was captured on 2020 September 6 at $04^{\mathrm{h}}11^{\mathrm{m}}$ UT, from Albany, Missouri, USA. For more details on this particular event visit: `https://fireball.imo.net/members/imo_view/event/2020/5020`. Image courtesy: Daniel Bush.

This brilliant fireball was captured on 2020 December 2, at $10^{\mathrm{h}}54^{\mathrm{m}}$ UT, from Albany, Missouri, USA. For more on this event, visit `https://fireball.imo.net/members/imo_view/event/2020/7309`. Image courtesy: Daniel Bush.