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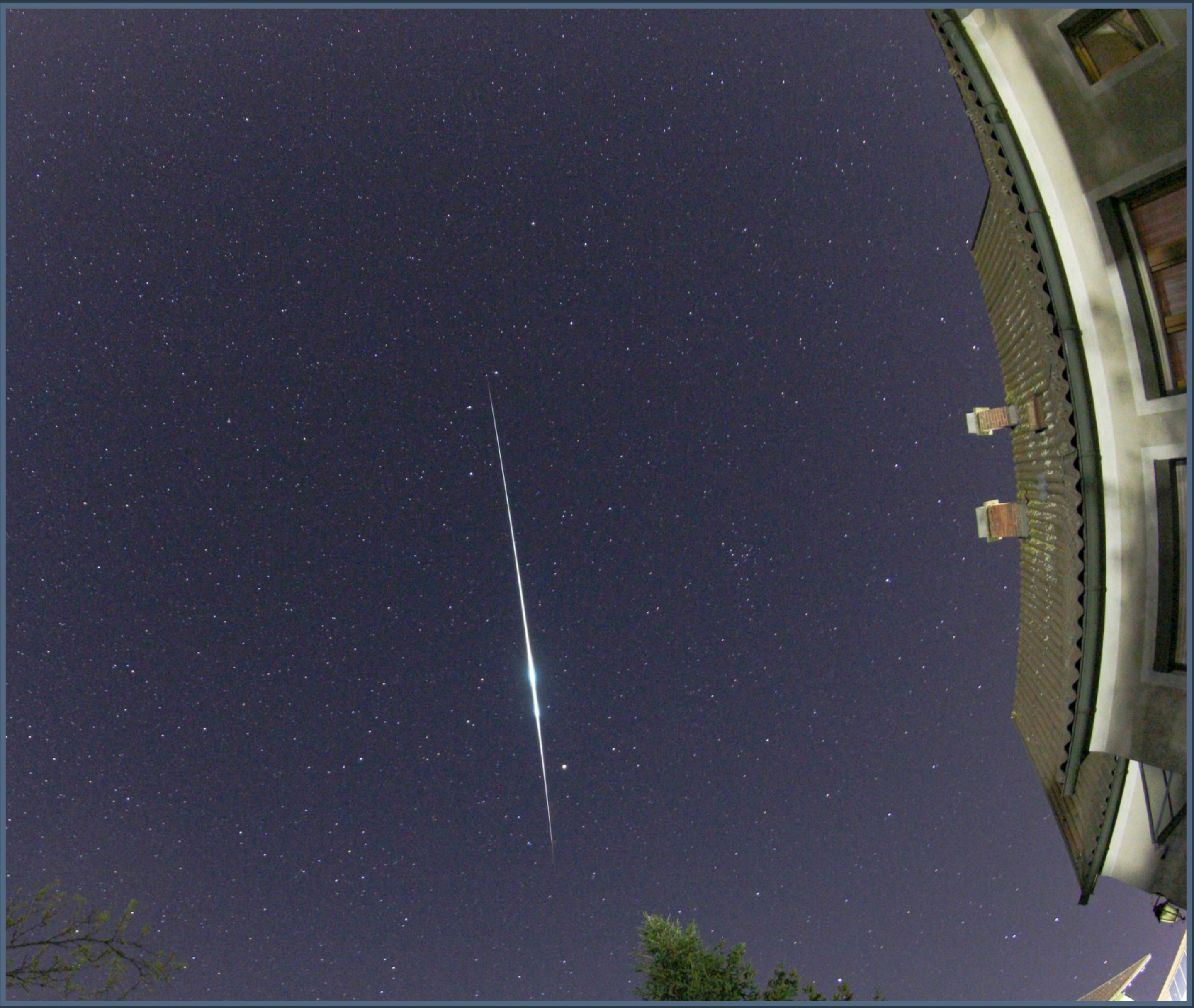

*Antihelion meteor of magnitude –6 (brightest flash)*
*Recorded from Pinkafeld, Austria on 2020 April 22, 23h29m45s ± 5s UT*
*(Photo © and courtesy Christa Plassak)*

- Alexander V. Bagrov
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# Contents

# Obituary Alexander V. Bagrov (1945 – 2020)

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With great sadness we inform you about the passing of the known researcher in the Solar System investigation area.


*Figure 1* – Alexander Bagrov in August 2013 during the International Meteor Conference in Poznan, Poland.

Dr. Alexander Bagrov was born 30 June 1945 in Vladivostok. He graduated from Lomonosov Moscow State University in 1968, in 1987 he defended a PhD thesis, and in 2002 became a full doctor. Since 1972 he was affiliated to the Institute of Astronomy of the Russian Academy of Sciences (INASAN, before 1988 the Astronomical Council of the USSR Academy of Sciences). Since 2000 he had also actively collaborated with the Lavochkin Association.

In 1968–1970 he had been the chief of astroclimate investigations of the Mt. Sanglok, where later telescopes of the Institute of Astrophysics of the Tajikistan Republic were installed, and the Optical Center of Space Control Surveillance (“OKNO”) was built. His main scientific interests were artificial satellites and application to them of astrophysical methods of telescopic observations.

*Figure 2* – A. Bagrov, December 1968, Sanglokh, Tadjikistan (credit Bagrov A. archive ).

From 1980 to 2002 the main field of his scientific interests were artificial satellites and the related application for astrophysical methods of telescopic observation. In collaboration with M. A. Smirnov he invented some devices for specific observations of objects in Near-Earth space (obtained 5 patents), and worked out methods of complex analysis of photometrical and spectral-photometric information from Earth-based observations. As a result of these investigations Dr. Bagrov and his colleagues designed algorithm for reconstruction of satellite's shape and orientation exclusively from telescopic observation data. This method was used for reconstruction of several objects on geostationary orbit in real time view (including secret military ones) and to provide analysis of real condition of space probes after unsuccessful launches.

Later, in 1990th his science interests widened to natural bodies of the Solar System migrating through Near-Earth space and since 2000 Dr. Bagrov reactivated optical meteor observations in Russia in order to confirm his new cosmogony hypothesis. He was principal organizer of television double-station observations in Russia. The meteor observations were obtained from various systems and to cover the magnitude range from +5 to –9. The meteor network in Russia continues to work.

Technical interests of Dr. Bagrov were wide too. He was the principal investigator of the Russian project of space astrometrical interferometer OSIRIS 1995–2006 (project was cancelled in 2014). He was designer of light-beacons technique for global positioning with single satellite (adopted to the "Luna-25" and "Luna-26" Russian missions).

Besides that, he was co-author of a project of an interstellar spaceship with superconductive mirror, lunar space elevator, hyper-velocity penetrators for science payload delivery to the Moon, asteroids and comets, non-rocket launch from Mars, active defense of the Earth against space dangerous bodies, optical light beacons for space probes and others. He published more than 160 papers and 2 monographs.

*Figure 3* – From left to right: Sergey Ipatov, Galina Ryabova, Alexander Bagrov, Boris Klumov, Vyacheslav Emel'yanenko ACM - 2005 conference, Rio de Janejro, Brazil, 07-12 August 2005 (credit Galina Ryabova).

*Figure 4* – August 2013, Poznan, Poland. From left to right Pavel Zigo, Roman Piffl, Stanislav Kaniansky, Anna Kartashova and Alexander Bagrov (credit Axel Haas).

A. V. Bagrov was awarded by medals of the Russian Cosmonautic Federation and Soviet National Achieving Exhibition (1985, 1989). He had the honorary titles of Honor USSR Inventor (in 1990) and Honor Constructor of Space Technique (in 2015). A. Bagrov was the author of 12 inventions (supported by patents).

*Figure 5* – During the 8th Meteoroids Conference excursion in Poznan, Poland. From left to right: Zeljko Andreic, Chris Peterson, Paul Roggemans and Alexander Bagrov. (credit Adriana Roggemans).

*Figure 6* – Alexander Bagrov, Vladislav Leonov and Andrey Murtazov at the Bredikhin conference – 2017, September, 2017, Zavozhsk, Russia (credit Elena Bakanas).

*Figure 7* – Alexander Bagrov at the Bredikhin conference – 2017, September, 2017, Zavozhsk, Russia (credit Elena Bakanas).

Dr. Alexander Bagrov was a popularizer of science and space technology. He gave lectures for students and school children, lectures at the Moscow Planetarium. Alexander Bagrov generously shared his knowledge with young specialists.

*Figure 8* – Alexander Bagrov having a lecture in a school of Zavolzhsk September, 2017 (credit Elena Bakanas).

He was an expert of the Federal register of experts of the Russian Federation, a member of the academic Council of the V. Tereshkova Cultural and educational center, member of the scientific Council and dissertation Council of INASAN. Since 2002, he has been a member of the IAU.

On August 20, 2020 Dr. Alexander Bagrov passed away. He was 75 years old. He has been active astronomer till his last day.

Past affiliation(s) within the IAU:

- Past Member of Division F Planetary Systems and Astrobiology (until 2020).
- Past Member of Commission F1 Meteors, Meteorites and Interplanetary Dust (2016–2020).

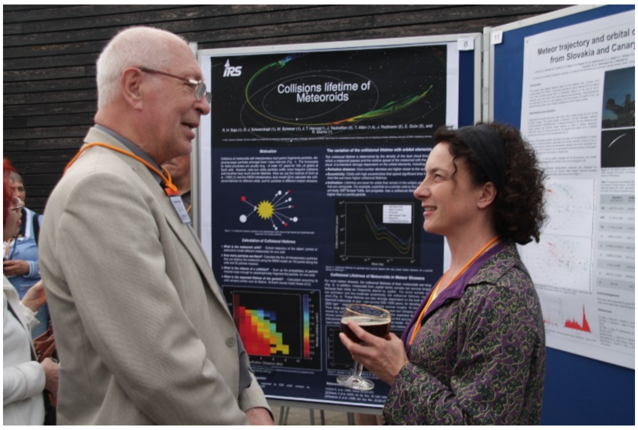


*Figure 9* – Alexander Bagrov in discussion with Maria Hajdukova at the meteor conference in Egmond, the Netherlands, June 2016.

*Figure 10* – Alexander Bagrov during the conference excursion in June 2016.


*Figure 11* – Alexander Bagrov, IMC-2016, at the meteor conference in Egmond, the Netherlands, 5 June 2016. (credit Bagrov A. archive).

# In memoriam Hugo van Woerden (1926 – 2020)

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

## 1 True amateur astronomer

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

*Figure 1* – Hugo van Woerden during the International Meteor Conference in Roden, the Netherlands, September 2006.

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

He started to write letters to Raimond about his observations, including brightness, color and timings, and also visited him in 1942. Raimond was in contact with a dozen active amateurs, with among them Sidney van den Bergh, also very young, who was looking for companions to set up a network of meteor observers. Together with Lammert Huizing they started a small society, the 'Astro Club'. Hugo became Observing Director and treasurer, the other two chair and secretary. Communication was mainly by postal letters these days; they wrote to each other each week. It was WWII, but circumstances were ideal with the Netherlands blacked out, thus no artificial light allowed, being great times for amateur astronomy and one of the few activities considered harmless by the occupants.

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

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

Hugo liked the hunting for meteors: appealing was that they came by surprise, and in the meantime, he could study the constellations. He was himself one of the most active observers in these days.

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

## 2 'De Meteoor'

Many campaigns followed, with as example the ones in March and April 1944 being very successful. Some 200 Lyrids were observed and a few tens of Astro-club members observed later that year reported over 2000 Perseids. The instructions were always written by Hugo in the Astro Club's own periodical, 'De Meteoor'. De first issue appeared in November 1943 and was distributed by post. It was reproduced in small quantities with stencil machines at the University observatories at Leiden and Utrecht, operated by Hugo. The contribution was 1 Dutch Guilder (~40 Euro cent). The Meteor had soon also English content, with the Astro Club becoming in contact with observers in Belgium, France, Spain and Czechoslovakia.

From September 1944 coordination of observations started to hamper, with the war in its final phase. Hugo moved back from Leiden to his native city Arnhem. Communication was difficult with letters and unreliable, no radio, thus no time-signals to calibrate the clocks. In essence, until the liberation in mid-1945, meteor work came to a halt.

As soon as WWII had ended the Astro club resumed its activities, with 5 campaigns focused on Quadrantids, Lyrids, Aquariids, Perseids and Draconids. Results were always published in 'De Meteoor' but analysis nonetheless often lacked behind due to lack of experience, mentorship and leadership, as Hugo commented much later himself, but not strange given the age of the founding members.

Hugo kept creating instructions for the observers, and put already in the beginning emphasis on the importance of accuracy and quality and the need for calibration. He was critical when results remained missing and ambitious. He reported also that the analysis of the results turns out to take much time, and in practice started to conflict with Hugo's study.

## 3 'Werkgroep Meteoren'

Raimond in meantime was elected as chair of the Netherlands Association for Meteorology and Astronomy, NVWS, and thanks to the high level of amateur activity, decided to start - next to the local divisions in each major town- specialized sections, called 'werkgroepen'. He proposed to form a 'Werkgroep Meteoren' based on the Astro Club. Hugo, Sidney and Lammert considered this was a good idea, bringing likely a new momentum, although they reported already in these days the frustrating bureaucratic process of a transition. In August 1946, the Astro Club became part of the NVWS and became named 'Werkgroep Meteoren van de NVWS'. Hugo was again appointed Observing Director and treasurer. 'De Meteoor' became its periodical. Hugo may be considered as the architect of the new section; he wrote an observing manual which was accepted as the program of the werkgroep.

First observing activity of the new Werkgroep Meteoren was the return of the Draconids on October 9–10, 1946. A training session was organized at the planetarium in The Hague. Unfortunately, it was Full Moon, and the weather did not cooperate. Some reports were received but mainly from non-trained witnesses. But astronomers of the Kapteyn Institute in Groningen reported rates up to 60 per minute.

At that time Hugo was also accepted as student astronomy at Leiden University. The following years 1947 and 1948 the momentum in de werkgroep decreased. Sidney moved to Princeton and Hugo had to devote all his time to get his BsC degree, which created pressure and was to be followed by obligatory military service. 'De Meteoor' did not appear for two years.

Kees de Jager (Sonnenborgh Observatory, Utrecht) became president in 1948 so that Hugo could focus on his studies, and Kees could give the werkgroep the additional energy that was needed. Kees together with Hubenet observed already the Perseids the years before (under pseudonyms though, and Hugo discovered that only later). From 1949 'De Meteoor' started to appear again.

End of the forties also the first photographic surveys started to appear, with help of sensitive Schmidt cameras. Also, the Werkgroep Meteoren made plans to build their own (1949), and some prototypes were actually made.

In 1950 Hugo returned to the werkgroep and would never leave anymore (and finally in 2002 he was elected as honorary member). He continued in his role as Observing Director, organized campaigns and observing instructions, made observations and analysis, but also at a somewhat larger distance as others started to take over. On April 7, 1953 a bright fireball appeared during photo-electric observations on variable stars. From the indirect flash he was able to derive the brightness of the fireball.

## 4 Determination of limiting magnitude

Already from the very beginning of the Astro Club Hugo pointed at the importance of accuracy and calibration, and he kept doing so, as well as stressing the importance of the link between observation and theory. In 1949 Hugo instructed, triggered by Whipple's interest in meteor brightness, the observers to use specific stars as reference for their brightness estimations, and this led to –for us as meteor observers- maybe his most important achievement: he tested in 1956 (Sweden), and introduced in 1957 the use of star fields to determine the observer's limiting magnitude (Roggemans, 2010). Today, these are still the standard and worldwide used.

The diversity of topics broadened, and apart from visual observing, also meteorites, photography (first Dutch meteor photograph in 1953), comets, fireballs, physics of streams, statistics were discussed. Analysis of observations went into deeper detail, and focused often on orbit determination. Remarkably, annual analysis of shower activity, not saying ZHR calculations, were largely missing.

End of the fifties, the scope of 'De Meteoor' broadened: it was not only used to report on meteor work anymore, and also other NVWS sections started making use of the magazine to report on their activities. Hugo got less time and soon after he finally gave up his function as Observing Director, he resigned in 1961 as editor. At that time photography was widely used, though difficult, spectroscopy, radar observation and space research started. Members of the werkgroep became routinely involved in satellite observation. There was close collaboration with Belgian observers.

In these years, we heard also for the first time of the uprising of the powerful Super Schmidt cameras (Harvard), so sensitive that they reached almost the sensitivity of the human eye, from then grew the belief that the role of the visual observer would lose importance soon, although visual reporting remained an 'official' research goal.

In the later years, Hugo still every now and then contributed, but it was clear that his focus changed.

## 5 Radio astronomy

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

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

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

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

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

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

## 6 Netherlands Association for Meteorology and Astronomy

In 1991 Hugo retired. As expected, he remained very active. He kept visiting his office, in Groningen, first on a daily basis, later once per week. He was one of the main organizers of the XXII$^{nd}$ General Assembly of the International Astronomical Union held in 1994 in The Hague.

Soon after his retirement, he was asked to join the board of the NVWS as board member, but from 1992 until 2002 as chair. Back to popularizing astronomy and a leader of the amateur society which was what he started 50 years earlier.

It turned out to be a very good choice. Under his guidance the NVWS celebrated its 100$^{th}$ anniversary, which was attended by the Dutch queen Beatrix. NVWS changed its name to Royal Netherlands Association for Meteorology and Astronomy, KNVWS.

This period is the time when most of us have their memories of Hugo. He was interested in everything and everyone. He maintained close contact with all sections, including his beloved Werkgroep Meteoren. He participated in almost all annual meetings, and if he did not contribute himself, he came with a reaction after almost every talk, stimulating and participating in debate and discussion. He valued your work, showed enthusiasm, gratitude and courage, hinted to next steps. If you made a mistake in your presentation, he would let you know, though, but always in a kind way. For many of us he was like a father or coach. He was a strong supporter of amateur work to assist in our scientific understanding of the universe. This put him apart from many others.

It was more than obvious that Hugo had an enormous drive, he was very precise, and had a fantastic memory. He was decorated as 'Ridder in de Orde van de Nederlandse Leeuw' in 1992, and asteroid 10429 van Woerden was named after him. In 2016 a symposium was organized to honor his 90th birthday.

## 7 International Meteor Conference

Hugo gave acte de présence on two International Meteor Conferences, in 1996 and in 2006, both organized in The Netherlands. At both conferences he gave oral presentations, the first on his experience with meteors in three different periods of his life: as amateur meteor hunter, professional astronomer and as president of the KNVWS, for which he used three different hats. At the International Meteor Conference of 2006, he put the observation of meteors in broad perspective, from comets to planetary systems and exoplanets. Indeed, also today, many of us look at meteor science that way, now 17 years later. Again, he stressed the importance of calibration once, identical to what he did in his juvenile years.


*Figure 2* – Hugo van Woerden, in 2009 standing at right during the group photo of the annual Meteorendag at Heesch, the Netherlands.

During his period as KNVWS chair, Hugo handed out three times the Van der Bilt award to meteor observers (Ten Haaf, Koning, Van Leverink), a prestigious national award for extraordinary achievements in their field. In 2011, the KNVWS council also installed a similar award for youngsters, the Hugo van Woerden award.

Dutch astronomers may be proud to have had Hugo van Woerden among them, being a passionate scientist and true ambassador for astronomy, both for amateurs and professionals. He has inspired many of us. Huug will always have a special place in the hearts of many, and he will be missed.

I want to express my gratitude to Urijan Poerink, Kees de Jager, Herman ten Haaf and Niek de Kort, who helped in giving additional insight in Hugo's life and career, providing answers to questions, and/or helped in studying and checking reference material. More information can be found on the websites: KNVWS Werkgroep Meteoren[1], KNVWS[2] and Kapteyn Institute[3].

*Figure 3* – Hugo van Woerden during his talk at the 25th International Meteor Conference in Roden, the Netherlands, September 2006.

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# On the tendency to grouping in the system of minor bodies

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When having studied meteor complexes in the Solar system I. S. Astapovich (1941) found a phenomenon appearing common for various classes of minor bodies ranging from telescopic meteors to giant meteorites. This phenomenon is the tendency of minor bodies to grouping that becomes more prominent among larger objects. The authors describe the idea by I. S. Astapovich and show how it is proved by nowadays studies covering the whole range of objects from faint meteors to asteroids. The study by A. K. Terentjeva (1966) also shows that even sporadic material does not show totally chaotic behavior. The degree of this chaos decreases with increasing masses of the objects. We dedicate this article to the well-known meteor investigator, founder of meteor astronomy in the USSR, Prof. I. S. Astapovich who passed away 45 years ago.

## 1 Introduction

When studying meteor complexes in the Solar system I. S. Astapovich (1941) found a common property of various classes of minor bodies ranging from the smallest one (telescopic meteors) to large meteoroid bodies – giant meteorites. Let us refresh in memory his idea that remains actual so far and keeps developing. According to Astapovich, telescopic observations of meteors showed that approximately 1% of these bodies comprise binary systems. The same results may be derived from the photographic observations as, for instance, one may see in two catalogues of the Harvard observatory. Sometimes one companion follows another in several seconds.

Ellen Dorrit Hoffleit mentioned that the intervals between the falling meteors belonging to a shower differs from those of sporadic meteors, which may indicate that in showers meteors tend to group, at least in pairs. Now we have lists of binary and multiple objects. One may demonstrate observations of various scientists made in different epochs that indicate the continuous transition from single and binary meteors to small streams containing several dozens of objects and simultaneously penetrating the atmosphere. These observations are available for all classes of meteor bodies. For example, on November 28, 1883 Brooks observed a stream with the 9-inch telescope. For ordinary meteors the same phenomenon was, for instance, observed during a short meteor storm that lasted for only 10 minutes on November 24, 1925 in the State of Virginia, USA. The phenomenon is especially spectacular when we observe fireballs. This may be illustrated by the event that took place on the 9th of February, 1913, when the “procession” comprised of several dozens of fireballs spanned the distance of 8000 km from Ontario to the Islands of Bermuda. It is noteworthy that exactly 18 years later, on the 9th of February, 1931, the stream of 30 – 40 fireballs was observed over North-West Europe. On May 27, 1935 a similar stream passed over the Scandinavian peninsula having allowed the observers to obtain approximately 500 registrations. When we consider larger bodies, the same tendency takes place.

Historical data store information on meteorite storms containing tens of thousands of components (for instance, Pułtusk, Poland, January 30, 1868 ~ 100000 components; Holbrook, Arizona, USA, July 19, 1912 ~ 14000 components). Though meteorites usually fragment in the atmosphere, one can show that they can move in a stream prior to their encounter with Earth. For example, along with the event over Pułtusk meteorites of the same chemical composition precipitated in Lerici, Italy and Nosy Be, the island of Madagascar.

As Astapovich mentioned the tendency of grouping may be common for even larger bodies. For example, the meteorite craters recently found all over the world (Saaremaa island, Baltic Sea; Rub' al Khali desert, Arabian Peninsula; Henbury, Australia; Tunguska, Russia; etc.) are formed after the impacts of streams of giant meteorites (thousands of tons each). Due to their enormous masses they would have to lose the cosmic velocity below the Earth surface, which resulted in impacts at extremely high velocities.

According to Astapovich, the observed grouping – more often encountered among more massive bodies – may indicate a relatively young age of these streams. The streams alike should permanently occur in the Solar system. Historical records (for instance in Chinese archives) witness a relatively high frequency of these events in the past, which, in turn, prompts us to suppose that they happen today, too. Astapovich proposed that these streams may occur after collisions of meteoroid bodies (regardless of their origin, interstellar or solar). He also provides a number of suggestions supporting the idea of permanent collisions. Hereafter we will mention only one of these suggestions.

Astapovich (1939) found that the intersection of trajectories of 10 meteorites, more than 20 meteoroid streams (four of them are major showers), 27 large (often detonating) fireballs, and several comets, occurs at the point with coordinates $\lambda = 216°$, $\beta = +2°$ at a distance of approximately 1 AU from the Sun. In our previous works (Terentjeva, 1991; Galibina and Terentjeva, 1987), we paid special attention to this circumstance, and, in particular, considered a possibility for the existence of a comet-meteor-meteorite system.

## 2 Research results

Now let us consider the present-day evidences of the phenomenon discovered by Astapovich for the system of minor bodies. It is known that the fraction of "organized" matter among the fainter meteors (up to the magnitude of +7) is only 28% (Kashcheyev et al., 1967). For ordinary photographic meteors this fraction reaches 56% according to (Terentjeva, 1966) or 43% according to (Lindblad, 1971). Among the larger bodies such as fireballs the "organized" matter fraction reaches 68% (Terentjeva, 1990).

When proceeding with asteroids, we see that 130 of 181 (i.e. 72%) bodies approaching the Earth are related to meteoroid streams (Babadzhanov and Kokhirova, 2009). Therefore, these 72% of bodies comprise the "organized" fraction of the asteroids (of cometary origin, according to P. B. Babadzhanov and G. I Kokhirova).

Thus, a pattern in the system of minor bodies is confirmed in the present time: the larger the bodies the more pronounced their tendency to grouping.

## 3 On the sporadic meteors

Within the period of 1963–1967 A. K. Terentjeva analyzed more than 3700 orbits of individual meteoroid bodies using photographic observations published before 1967 (recording started from 1936) and approximately 2000 visual radiants recorded in the 19th and 20th centuries. This study resulted in the discovery of 359 minor meteoroid streams. A complete bibliography of these streams is given in particular in (Terentjeva and Bolgova, 2020).

It is noteworthy that the rest of the bodies from the above sample, not belonging to any streams, did not show totally chaotic behavior too (Terentjeva, 1966). On the contrary, among these bodies one could find several coinciding characteristics (not all), pick out groups with similar motion (though, this similarity is not accurate enough to convincingly relate these groups to each other), which indicates that the discussed meteoroids may be somehow related. We may then suppose that these are not absolutely sporadic meteoroid bodies, but members of several streams. Their characteristics for some reason differ significantly from the stream's average, which formally prevents us from associating them to a particular stream. The latter statement is exemplified in the paper mentioned above. The author picked out a numerous group of photographic radiants located around the anti-apex point. This group of radiants is spread over the area with the diameter of 56° (!) in the direction perpendicular to the ecliptic. All the six meteors of this group were observed within 11 days, plus 3 meteors on nearby dates. Common criteria do not allow us to unite this group into a stream, though their relation to each other seems possible if we suppose that this group was considerably disturbed by major planets, included the Earth.

One more example shown in the mentioned paper demonstrates three pairs of "photographic" orbits of sporadic meteoroids. The first pair of almost parabolic orbits surprised the author by the strong similarity of the five orbital elements and the body's heliocentric velocity, though the inclinations of the orbits differ by 64° (!) radiant positions are 29° (!) apart, and their pre-atmospheric velocities differ by 11 km/s.

L. G. Jacchia and F. L. Whipple (1961) 20 years later than I. S. Astapovich also noted the tendency of meteoroid bodies grouping and picked out 88 associations. The examination of these associations resulted in the conclusion that most of them are structures, whose nature lie between sporadic material and meteor streams. The possible formation of these associations may indicate the similarity of some groups of sporadic complexes.

When we search an asteroid related to a stream, we always start with a sample of 50 – 60 objects. The authors noted that in this samples the behavior of the members is not absolutely chaotic. Oppositely, one always may find a tendency to grouping at least in clusters of two-three objects. We can exemplify the latter by 8 asteroid streams revealed from the sample of 52 Eccentrid asteroids (Terentjeva and Barabanov 2016). We then can suppose that in the sporadic material the discussed phenomenon is more prominent among the largest bodies, asteroids. It is in a sense natural since the population of asteroids is more compact than meteoroid streams.

This year marks 45 years since the death of Igor Stanislavovich Astapovich (11 January 1908 – 02 January 1976), the founder of meteor astronomy in the USSR. He was a person remarkable in his versatility, encyclopedism, and broad erudition. In our country he was known as a "patriarch" of meteor astronomy. His monograph "Meteor Phenomena in the Earth's Atmosphere" (Astapovich, 1958) was unofficially mentioned as "Meteor Almagest". The monograph "Interesting stories on meteorites" (Astapovich, 2015) recently became a best-seller (in Russian) thanks to the Academy of education in San Francisco, which actively promotes its dissemination. Hundreds of people from all over the world downloaded it from the Internet. The ideas promoted by I. S. Astapovich remain relevant today and keep inspiring the meteor community to solve new pressing problems. For more information about I. S. Astapovich see, e.g., Terentjeva (2001), Husárik et al. (2009).

*Figure 1* – Igor Stanislavovich Astapovich (1908–1976). From the personal archive of A. K. Terentjeva.

## 4 Conclusion

Modern studies prove the idea proposed I. S. Astapovich in 1941 that minor bodies tend to grouping, and this tendency becomes stronger with the growing mass of objects.

As the investigations by A. K. Terentjeva (1966) show, the material we call sporadic actually does not display totally chaotic behavior. And the degree of chaos decreases with increasing masses of considered minor bodies.

## Acknowledgment

The authors thank Paul Roggemans for all efforts with the preparation of this paper.

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# A Carinids (CRN#842) outburst 2020

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Jenniskens (SETI Institute and NASA Ames Research Center), T. Hanke (the H.E.S.S. Collaboration), T. Cooper (Astronomical Society of Southern Africa), S. Heathcote (AURA and Cerro Tololo Interamerican Observatory) and E. Jehin (University of Liege), report an outburst of meteors of the normally weak A-Carinids (CRN#842) near the southern ecliptic pole between 2020 October 12d20h and 14d09h UTC.

## 1 Introduction

The night of October 13 on 14 saw significant meteor activity from an otherwise weak annual shower called the A-Carinids in the southern hemisphere. The radiant is not far from the southern ecliptic pole (latitude 77 degrees South). In a report to the Central Bureau of Astronomical Telegrams, astronomer Peter Jenniskens reports that CAMS networks in Namibia, South Africa and Chile detected the shower between October 12 $20^h$ UTC and October 14 $9^h$ UTC. The peak was at $1^h51^m$ UTC on October. 14 and activity was half that at the peak for about 3 hours. The orbit is that of a steeply inclined (54 degrees) Jupiter Family comet, but the parent body has not yet been found (Jenniskens et al., 2020).

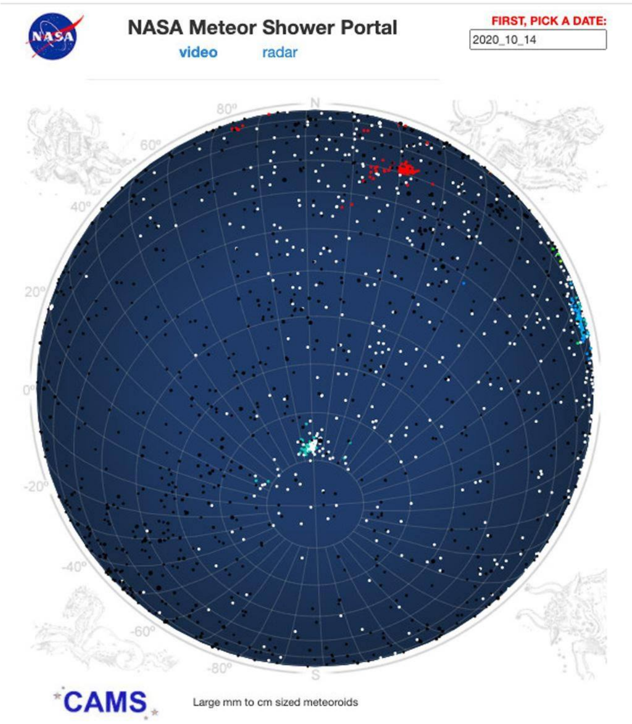


*Figure 1* – The radiant map based on the orbit data.

## 2 A Carinids (CRN#842)

The shower was discovered a few years ago and has been listed with the IAU Meteor Data Center[4]. The 2020 radiants corresponding to the orbits obtained are shown in *Figure 1* and can be consulted in detail on the CAMS website[5] for the dates of 2020 October 13–16. The mean orbit for 2020 has been given in *Table 1*, compared with the past data listed with the IAU MDC working list of meteor showers.

*Table 1* – The A Carinids (CRN#842) outburst compared to its entry in the IAU MDC working list of meteor showers.

| | CRN (#842) | 2020 |
|---|---|---|
| $\lambda_\odot$ | 198° | 200.897 ± 0.005° |
| $\alpha_g$ | 103.2° | 98.7 ± 1.3° |
| $\delta_g$ | –57.0° | –54.3 ± 0.8° |
| $v_g$ | 30.1 km/s | 32.4 ± 1.4 km/s |
| $a$ | 2.87 A.U. | 3.31 A.U. |
| $q$ | 0.989 A.U. | 0.9974 ± 0.0004 A.U. |
| $e$ | 0.655 | 0.696 ± 0.088° |
| $\omega$ | 354.7° | 0.8 ± 1.9° |
| $\Omega$ | 18.0° | 20.90 ± 0.11° |
| $i$ | 50.4° | 54.4 ± 1.7° |
| $T_J$ | – | 2.25 ± 0.47 |
| $N$ | 121 | 130 |

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[4] https://www.ta3.sk/IAUC22DB/MDC2007/Roje/pojedynczy_obiekt.php?kodstrumienia=00842&colecimy=0&kodmin=00001&kodmax=01045&sortowanie=0

[5] http://cams.seti.org/FDL/

# 29 Piscids (PIS#1046) meteor shower 2019

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A new minor shower has been detected in the 2019 orbit data of CAMS. The shower displayed a first outburst during 2019, October 17-18 and a second one in the period 2019 November 11-18. The shower has been added to the IAU working list of meteor showers with the name 29 Piscids.

## 1 Introduction

Some unusual meteor shower activity has been observed in mid-October 2019 from a low-inclination stream. Already in 2014, six meteors from this stream were detected by CAMS California. The shower has been listed in the working list of meteor showers of the IAU Meteor Data Center as the 29 Piscids (PIS#1046)[6].

During 2019 Oct. 17–18 UT, a cluster of 26 meteors was detected with a radiant near 29 Psc by nearly all of the CAMS low-light video networks (Jenniskens et al., 2011). The combined activity period extended from solar longitude 202.3° to 205.0° (equinox J2000.0) with a maximum on $\lambda_{\odot} = 204.0 \pm 0.1°$ (*Figure 1*, see also near the anti-helion source at the website[7] for days of October 17–19). The shower parameters have been listed in *Table 1*.

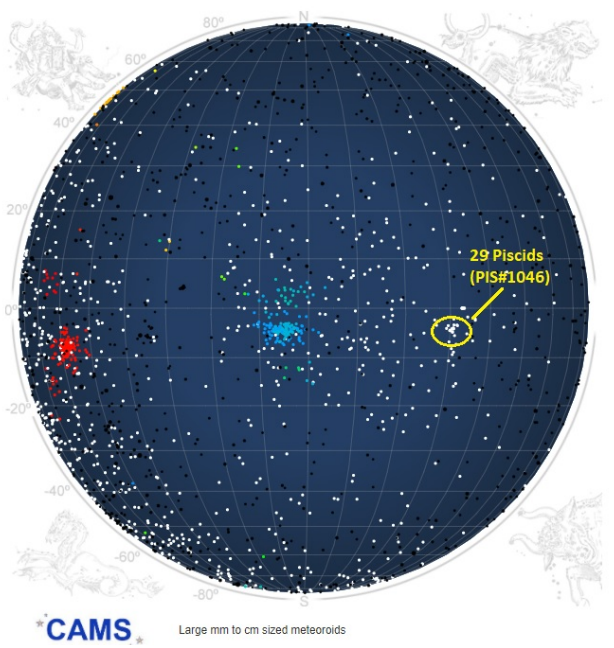


*Figure 1* – The radiant map based on the orbit data with the 29 Piscids during the night of 2019 October 17–18.

## 2 Reappearance one month later

One month later, during 2019 Nov. 11–18 UT, another period of outburst activity has been observed that appears to be associated with the same parent body, given the similar eccentricity and longitude of perihelion of the orbit, when 93 meteors were triangulated. Activity stretched between solar longitude 228.3° and 234.9° and peaked at 231.4° (*Figure 2*, look on the website[2] for the dates of 2019 Nov. 11–18).

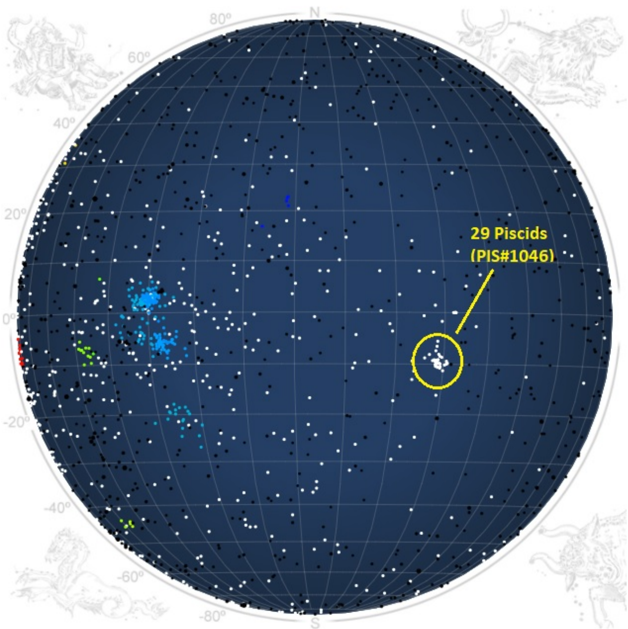


*Figure 2* – The radiant map based on the orbit data with the 29 Piscids during the night of 2019 November 14–15.

There is a distinct trend of $q$ versus Node $\Omega$, and the November observations align with those from October approximately as

$$q = 0.318 + 0.36519 * log(\Omega),$$

for the Node $\Omega$ in the range of 23–54°. So far, the shower has not been detected in 2020.

[6] https://www.ta3.sk/IAUC22DB/MDC2007/Roje/pojedynczy_obiekt.php?kodstrumienia=01046

[7] http://cams.seti.org/FDL/

*Table 1* – The 29 Piscids (PIS#1046). (J2000.0) with the orbits for the October and November outbursts.

| | PIS (#1046) October 2019 | PIS (#1046) November 2019 |
|---|---|---|
| $\lambda_O$ | 204.0° | 231.4° |
| $\alpha_g$ | 4.3 ± 0.6° | 6.8 ± 1.1° |
| $\delta_g$ | –2.7 ± 0.5° | –7.2 ± 1.2° |
| $v_g$ | 15.2 ± 1.3 km/s | 10.8 ± 1.4 km/s |
| $a$ | 2.83 A.U. | 3.10 A.U. |
| $q$ | 0.8166 ± 0.0096 A.U. | 0.943 ± 0.007 A.U. |
| $e$ | 0.709 ± 0.069 | 0.693 ± 0.103 |
| $\omega$ | 55.3 ± 0.9° | 27.5 ± 1.7° |
| $\Omega$ | 24.1 ± 0.6° | 51.3 ± 1.6° |
| $i$ | 1.9° ± 03 | 2.7 ± 0.4° |
| $\Pi$ | 79.1 ± 0.6° | 78.9 ± 0.9° |
| $T_J$ | 2.88 | 2.79 |
| $N$ | 26 | 93 |

## Acknowledgment

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# The 2018 Draconids outburst (DRA#009)

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The CAMS BeNeLux network captured 6773 meteors in the night of 2018 October 8-9 during the Draconid outburst. A total of 1391 meteor orbits could be obtained. A procedure was applied to locate groups of very similar Draconid orbits. Five compact groups of almost identical and three groups with slightly more dispersed Draconid orbits could be distinguished. Using a range of the mean orbits of these groups as reference orbits, 938 orbits were associated with Draconids. The activity profile shows some sub-maxima, the radiant structure, the velocity distribution and the orbital elements indicate the presence of different dust trails.

## 1 Introduction

Weather brought clear sky over the BeNeLux for the night of October 8–9, 2018, ideal to observe a possible outburst predicted by Egal et al. (2018). The predicted outburst took place and the spectacle exceeded the expectations. The CAMS BeNeLux network was ideally situated to cover the event. With 80 of its cameras installed at 20 sites, 6773 meteors were detected, 4071 (60%) of these proved to be good quality multi-station events resulting in 1391 orbits which respected the CAMS quality standards (Jenniskens et al., 2011). Immediately after the event observing reports got published (Johannink, 2018; Martin, 2019; Miskotte, 2019a; Roggemans, 2018; Vida et al., 2018). A detailed analysis of the Draconid activity in 2018, based on visual observations resulted in an activity profile with ZHR values well above 100 with some sub-maxima (Miskotte, 2019b).

## 2 Comparing the 2018 orbits to past data

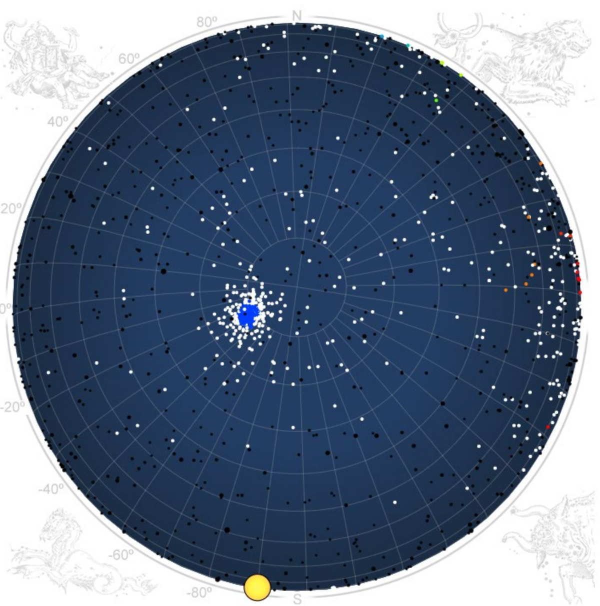


*Figure 1* – The radiant plot for CAMS[8] BeNeLux, 2018 October 8–9. Radiants that fulfilled the similarity criteria with the 2011 Draconid orbit as reference are marked as blue dots. White dots are sporadics.

The radiant map of that night shows a large concentration of radiants that fail to fulfil the similarity criteria around the Draconid radiant area (*Figure 1*). The question is why?

For a first identification of Draconid orbits, the reference orbit obtained by CAMS during the 2011 Draconids outburst (Jenniskens et al., 2016) has been used. The reference orbit is presented in *Table 1*. It should be noted that the 2011 Draconid orbit is only based on a sample of 30 Draconid orbits. This orbit agrees very well with the orbit of the parent comet 21P/Giacobini-Zinner as published by Jenniskens et al. (2016). The Meteor Data Center[9] of the IAU lists a few other reference orbits which can be considered to check the similarity criteria for our 2018 Draconid orbits. The different orbits are listed in *Table 2*. We also consider the 2018 orbit of the parent comet 21P/Giacobini-Zinner. The results are somehow surprising.

*Table 1* – The median values for the reference orbit obtained by CAMS during the Draconid outburst 2011, compared with the orbit of the parent comet.

| | DRA (2011) | 21P/G.-Z. (1900) |
|---|---|---|
| $\lambda_O$ | 195° | 195.0° |
| $\alpha_g$ | 262.9° | 263.2° |
| $\delta_g$ | +55.7° | +55.8° |
| $v_g$ | 20.7 km/s | 20.9 km/s |
| $a$ | 3.15 A.U. | 3.47 A.U. |
| $q$ | 0.996 A.U. | 0.996 A.U. |
| $e$ | 0.706 | 0.707 |
| $\omega$ | 173.2° | 173.5° |
| $\Omega$ | 195.0° | 195.0° |
| $i$ | 31.4° | 31.8° |
| $N$ | 30 | |

The 2011 orbit looks like a valid reference to identify the Draconid orbits among the 1391 orbits registered 8–9 October 2018. A first test shows that 810 of the 1391 orbits fulfil the low threshold similarity criteria with $D_{SH} < 0.25$ and $D_D < 0.105$ to be Draconid orbits. 572 of these orbits fit the high threshold similarity criteria with $D_{SH} < 0.1$ and $D_D < 0.04$. *Figure 2* shows a close up of the Draconid

[8] http://cams.seti.org/FDL/

[9] https://www.ta3.sk/IAUC22DB/MDC2007/Roje/pojedynczy_obiekt.php?kodstrumienia=00009

 

radiant area in equatorial coordinates. However, 159 orbits which have both their radiant and their velocity within the range to be possible Draconids fail in these similarity criteria. Apparently, the 2011 reference is not the ideal reference to identify all our 2018 Draconid orbits.

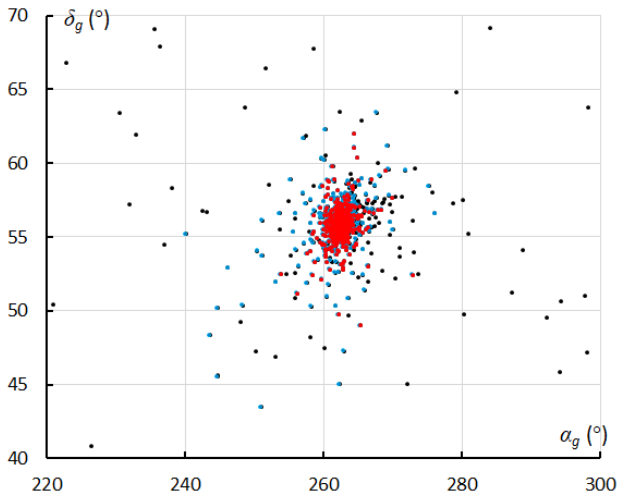


*Figure 2* – All radiants near the Draconid radiant. Black dots are sporadic radiants, blue dots are low threshold ($D_{SH} < 0.25$ and $D_D < 0.105$), red are high threshold ($D_{SH} < 0.1$ and $D_D < 0.04$). 810 orbits fit the low threshold, 572 fit the high threshold.

*Table 2* – Draconid orbits as listed by the IAU Meteor Data Center according to different researchers. The orbit of 21P/Giacobini-Zinner[10] given is valid for 2018.

| | Gavajdova (1994) | Jenniskens (2006) | Brown et al. (2008) | 21P/G.-Z. (2018) |
|---|---|---|---|---|
| $\lambda_O$ | 203.9° | 195.1° | 195.5° | – |
| $\alpha_g$ | 274.7° | 264.1° | 261.7° | – |
| $\delta_g$ | +52.4° | +57.6° | +54.8° | – |
| $v_g$ | 16.7 km/s | 20.4 km/s | 19.7 km/s | – |
| $a$ | 2.392 A.U. | 3.02 A.U. | 2.89 A.U. | 3.498 A.U. |
| $q$ | 0.995 A.U. | 0.996 A.U. | 0.995 A.U. | 1.0128 A.U. |
| $e$ | 0.584 | 0.670 | 0.656 | 0.71046 |
| $\omega$ | 178.2° | 172.9° | 171.9° | 172.86° |
| $\Omega$ | 203.9° | 196.4° | 196.6° | 195.39° |
| $i$ | 25.5° | 31.4° | 30.3° | 31.9977° |
| $N$ | 7 | 5 | 20 | |

### The 1995 reference orbit (Gavajdova, 1994)

Only 329 orbits are detected with the low threshold criterion ($D_{SH} < 0.25$ and $D_D < 0.105$) and not a single one with the high threshold criterion ($D_{SH} < 0.1$ and $D_D < 0.04$)! The main problematic element is the ascending node $\Omega$ which occurs about a week later than what can be expected for the Draconids. Checking out the original paper it becomes clear that this source should not be listed with the DRA#009 shower in the MDC IAU list. The author searched for shower associations among photographic fireball and bright meteor orbits using only the Southworth and Hawkins criterion with an acceptance of $D_{SH} = 0.25$. The "October Draconids" mentioned in this paper have nothing to do with the Draconids (DRA#009).

The "October Draconid" orbit published by Gavajdova (1994) has a better match with the delta Cygnids (DCY#282) with $D_{SH} = 0.15$ and $D_D = 0.05$, a shower discovered by Jenniskens (2006) and believed to be asteroidal in origin. This shower is most likely another instance of the October Cygnids (OCG#083) discovered earlier by Sekanina (1973) which is also similar to the "October Draconids" listed by Gavajdova with $D_{SH} = 0.17$ and $D_D = 0.07$.

Therefore, we suggest removing this entry from the Draconids (DRA#009) table and rather mention it under the delta Cygnids (DCY#282) together with the October Cygnids (OCG#083).

### Jenniskens (2006)

Checking this reference, it is not clear on which data this orbit is based. 780 of our 2018 possible Draconid orbits have a low threshold similarity with this reference, 492 have a high threshold similarity. The 2006 reference orbit fits even less good with our 2018 Draconid orbits than the 2011 reference orbit.

### Brown et al. (2008)

This orbit has been based on radar observations mainly obtained during the 2005 outburst. 764 of our 2018 possible Draconid orbits have a low threshold similarity with this reference, 425 have a high threshold similarity. This reference orbit is also not suitable to properly identify all 2018 likely Draconid orbits.

### 21P/Giacobini-Zinner orbit of 2018

When using the actual parent comet orbit of 2018, we obtain a slightly better fit than with the few older reference orbits we tried so far. 817 of our 2018 possible Draconid orbits have a low threshold similarity with this reference, 566 have a high threshold similarity. But still too many possible Draconid orbits have no similarity with this reference orbit.

## 3 Different groups of similar orbits?

All attempts failed to derive a single mean orbit which has good similarity to identify all likely 2018 Draconid orbits. All past reference orbits leave a suspect large number of likely Draconids unidentified. Therefore, the question arises if the Draconid stream may consist of a structure with at least two or more groups of similar orbits, different dust trails, which all encounter the Earth at the same descending node, but with slightly different velocities?

The presence of two or more groups of Draconid orbits with a significant difference in eccentricity $e$, length of perihelion $\Pi$ or inclination $i$ could explain why a substantial number of the 2018 Draconid orbits fails to fulfill the similarity criteria with a single mean orbit as reference. In this study, we'll try if we can detect different groups with

[10] https://minorplanetcenter.net//iau/mpec/K18/K18Q24.html

concentrations of very similar Draconid orbits to explain the failure to fit the similarity criteria for a single mean orbit.

Meteor streams get dispersed along the parent object orbit and gravitational perturbations will result in a considerable spread on orbits. At some point the spread on the orbits will become too large and the D-criteria will fail to confirm any similarity because the orbital elements for differently perturbated segments of the stream differ too much. This complex dynamic evolution of meteor streams is at the basis of different meteor shower complexes. Such complexes cannot be represented with a single reference orbit. In some cases, the planetary perturbations on the orbits must be integrated back in time in order to find a common origin. In our case with the 2018 Draconid orbits all meteors were recorded within a relative short time interval of about 10 hours from the same radiant area at the sky, any differences in some of the orbital elements should be detectable in slightly different radiant positions and slightly faster or slower velocities.

## 4 A pre-selection of possible Draconids

The idea of this analysis is to search for mean orbits that allow to identify the 2018 Draconids CAMS BeNeLux dataset of Draconid orbits, independently from any previously determined Draconid orbit. For this study we use a slightly adapted version of our iterative method to detect concentrations of similar orbits. This method has been successfully applied in case studies of meteor showers and has been explained in a previous paper (Roggemans et al., 2019).

To calculate a reference orbit for a collection of similar orbits we do not use the median or average values of the orbital elements, but we compute the mean orbit according to the method described by Jopek et al. (2006). To compare orbits on similarity researchers established different discrimination criteria, often abbreviated as D-criteria. The D-criteria that we use are these of Southworth and Hawkins (1963), Drummond (1981) and Jopek (1993) combined. The oldest and most popular D-criterion, the one established by Southworth and Hawkins or $D_{SH}$ proved often too tolerant and unsuitable for short period orbits near the ecliptic. It is not unusual that orbits which are very similar according to $D_{SH}$, fail for another D-criteria such as that of Drummond or $D_D$.

In order to apply a stricter discrimination, we use three different D-criteria combined to consider five different threshold levels of similarity. The different classes for the threshold are defined as follows:

- Low: $D_{SH} < 0.25$ & $D_D < 0.105$ & $D_H < 0.25$;
- Medium low: $D_{SH} < 0.2$ & $D_D < 0.08$ & $D_H < 0.2$;
- Medium high: $D_{SH} < 0.15$ & $D_D < 0.06$ & $D_H < 0.15$;
- High: $D_{SH} < 0.1$ & $D_D < 0.04$ & $D_H < 0.1$;
- Very high: $D_{SH} < 0.05$ & $D_D < 0.02$ & $D_H < 0.05$.

While the low threshold class may contain pure chance similar orbits, the risk for contamination with sporadic orbits is very unlikely for the high and the very high threshold level.

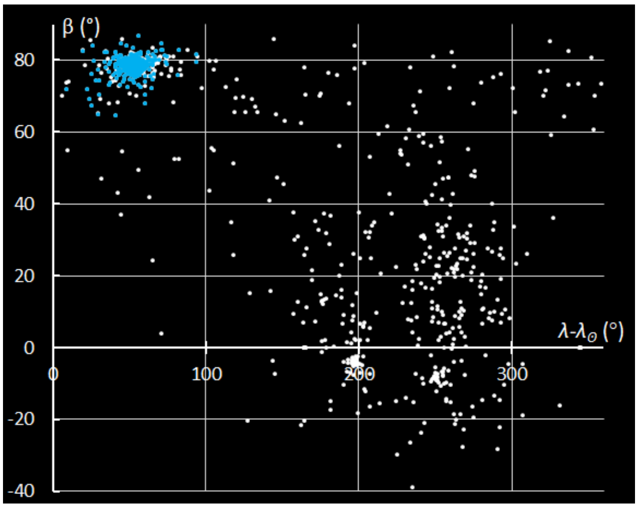


*Figure 3* – All the radiants of the 1391 orbits plotted in geocentric Sun-centered ecliptic coordinates as registered by CAMS BeNeLux during the night 2018 October 8–9.

To reduce the number of iterations in our procedure, we remove all orbits which are a priori excluded from being related to the Draconids meteor shower. This pre-selection is normally defined by limiting the activity interval, the radiant and the velocity range. In this particular case the activity interval is just one night. Because the Draconids have their geocentric radiant in Sun centered ecliptic coordinates close to the ecliptic pole (*Figure 3*) and radiant drift can be neglected in an interval of 10 hours, we will exceptionally use the geocentric equatorial coordinates to select the radiant positions.

To estimate the actual ranges, we use 810 orbits that fit the low threshold class using the 2011 Draconid orbit listed in *Table 1* as reference. These 810 orbits occur within the following range in time, radiant and velocity:

- Time interval: $195.176° < \lambda_\odot < 195.586°$;
- Radiant area: $240° < \alpha_g < 276°$ & $+43.5° < \delta_g < +63.4°$;
- Velocity: 17 km/s $< v_g <$ 24.2 km/s.

For the actual search we set the margins slightly wider in order not to miss any possible Draconids. This way we have a more workable dataset which requires less iterations to detect concentrations of orbits:

- Time interval: $195.14° < \lambda_\odot < 195.61°$;
- Radiant area: $220° < \alpha_g < 360°$ & $+40° < \delta_g < +75°$;
- Velocity: 15 km/s $< v_g <$ 30 km/s.

The resulting selection includes 969 orbits of the 1391 collected orbits that night. At least 432 orbits were collected that cannot be related to Draconids which is a realistic number of orbits in a single night early October without Draconid activity. Most of the 969 selected orbits must be related to the Draconids, but only 810 at best fit the similarity with the 2011 reference orbit. The 159 other orbits with a radiant and velocity within the above-mentioned ranges are far too many to be all sporadics.

## 5 Search for orbit concentrations

To locate a first concentration of orbits we calculate the mean orbit for all 969 orbits in our selection, then we compute the D-criteria for each orbit of the selection using this mean orbit as reference orbit. Next, we start the iterative procedure that calculates the average orbit for all orbits that fulfil the low threshold criteria. At each step the D-criteria are recalculated with the new mean orbit as reference until the procedure converges for the low threshold class with a set of orbits that does not change anymore. Then, a new loop of iterations is started using the mean orbit of the very high threshold criterion until convergence is reached. The resulting collection of orbits represents a group of almost identical orbits.

Applying this procedure, we identify several groups of almost identical orbits within our dataset of orbits. The iterative procedure will identify the most dominant group of orbits within the dataset. Once the iteration converges at a selection of almost identical orbits, a mean orbit can be calculated. The orbits that belong to this group are removed from the sample and a new loop of iterations is started to identify the next dominant collection of almost identical orbits. This procedure is repeated until no distinct groupings of orbits can be detected. The procedure confirmed the presence of concentrations or groups of orbits, all sharing the Draconid radiant area but with a wider range in geocentric velocities $v_g$ than known before.

**Group A: 331 almost identical orbits**

After four iterations we have a dataset of orbits with 818 orbits in the low threshold class and 331 orbits in the very high threshold class. We take these 331 orbits apart as these identify a first distinct group of almost identical orbits. Using these 331 orbits for another loop of iterations remains with the same 331 orbits, so it must be a very distinct group of orbits, the crème of our 2018 Draconid orbits. *Table 3* lists the mean orbit for these 331 orbits, the standard deviation and the median value of the uncertainties on the individual orbits. The minimum uncertainties on the individual orbits are close to zero and the maximum uncertainties concern only few outliers. These 331 orbits have a median value of $D_{SH}$ = 0.019 and $D_D$ = 0.010 which is a very compact concentration, further referred as "Group A". These orbits have a geocentric velocity $v_g$ = 20.8 km/s (median value) with all its geocentric velocities within the range of 19.7 km/s and 22.1 km/s.

**Group B: 121 almost identical orbits**

In order to locate a possible next group of very similar orbits, we remove the first 331 orbits of group A and repeat our iterative procedure on the remaining dataset with 638 candidate Draconid orbits. After five iterations the procedure converges with a stable number of 491 orbits that fulfil the low threshold level, 31 of which fulfil the very high threshold level. Using the mean orbit for these 31 very similar orbits as reference ($D_D$ < 0.02), after few iterations we find 121 orbits which fit the very high threshold D-criteria which determine a second group of very similar orbits (*Table 4*). These 121 orbits have a median value of $D_{SH}$ = 0.020 and $D_D$ = 0.010 which is also a very compact concentration. The Draconids in group B have a geocentric velocity $v_g$ = 21.7 km/s (median value) with all its geocentric velocities within the range of 21.7 km/s and 22.8 km/s. Group B may be regarded as a slightly faster component than Group A.

**Group C: 170 almost identical orbits**

We remove the 121 very similar orbits of group B and repeat the iterative procedure on the remaining 517 orbits until the iteration converges for the low threshold similarity class. The procedure ends with 355 low threshold orbits of which 84 orbits fulfil the very high threshold criteria. Using the mean orbit for these 84 very similar orbits as reference, few more iterations result in a third group with 170 almost identical orbits (*Table 5*). These 170 orbits have a median value of $D_{SH}$ = 0.016 and $D_D$ = 0.008 another very compact concentration. The Draconids in group C have a geocentric velocity $v_g$ = 20.2 km/s (median value) with all its geocentric velocities within the range of 18.8 km/s and 21.1 km/s, a slightly slower component than group A.

**Group D: 45 almost identical orbits**

Removing the 170 orbits of the group C leaves 347 possible Draconid orbits to search. The same procedure is applied as for previous groups. The result is a small but very distinct group of 45 orbits of orbits with higher eccentricity and higher inclination (*Table 6*). This group of orbits appears remarkably compact with very small values for $D_D$ and $D_{SH}$. Because of the eccentricity *e*, these orbits are missing among the first 810 Draconid orbits identified with the 2011 reference orbit given by Jenniskens et al. (2016). These 45 orbits have a median value of $D_{SH}$ = 0.023 and $D_D$ = 0.010, a very compact concentration situated well beyond the main Draconid stream. The Draconids in group D have a geocentric velocity $v_g$ = 24.2 km/s (median value) with all its geocentric velocities within the range of 23.4 km/s and 25.4 km/s which well above the past reference values.

**Group E: 58 almost identical orbits**

The next loop through the 302 remaining orbits required six iterations on the low threshold class and eight on the very high threshold class to detect another group with 58 very similar orbits (*Table 7*). These 58 orbits have a median value of $D_{SH}$ = 0.024 and $D_D$ = 0.011. The Draconids in group E have a geocentric velocity $v_g$ = 22.7 km/s (median value) with all its geocentric velocities within the range of 21.5 km/s and 23.9 km/s. Group E is the fifth and last distinct group of very high threshold orbits that we can locate in our dataset.

For the remaining 244 orbits we make the iteration loop converge in the high threshold class with $D_{SH}$ < 0.1 and $D_D$ = 0.04 instead of the very high threshold class in order to locate groups with significant numbers of orbits with a slightly less compact concentration than previous five groups.

**Group F: 28 orbits with high eccentricity**

The next loop on 244 remaining orbits ends after nineteen iterations with 28 orbits with all a remarkable high value for the eccentricity *e* (*Table 8*). These 28 orbits have a median value of $D_{SH}$ = 0.039 and $D_D$ = 0.016. This group is likely connected to group D with its high eccentricity orbits. Although the error margin on the velocities measured by CAMS are reasonably small, the presence of 11 slightly hyperbolic cases among these 28 orbits indicates measurement inaccuracies. However, the number of so many high eccentricity orbits cannot entirely be explained

*Table 3* – Group A. The mean orbit for the first group of 331 almost identical Draconid orbits which fulfil the very high threshold class with $D_D$ < 0.02 for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_O$ | 195.38° | ±0.08° | – | – |
| $\alpha_g$ | 262.5° | ±1.0° | ±0.5° | ±5.6° |
| $\delta_g$ | +55.9° | ±0.8° | ±0.2° | ±2.5° |
| $v_g$ | 20.8 km/s | ±0.4 | ±0.07 | ±0.8 |
| $\lambda-\lambda_O$ | 52.7° | ±2.7° | ±1.2° | ±10.5° |
| $\beta$ | +78.7° | ±0.8° | ±0.3° | ±2.5° |
| $a$ | 3.42 AU | ±0.18 | – | – |
| $q$ | 0.9958 AU | ±0.0007 | ±0.0003 | ±0.008 |
| $e$ | 0.7088 | ±0.01 | ±0.007 | ±0.06 |
| $\omega$ | 172.98° | ±0.8° | ±0.3° | ±4.7° |
| $\Omega$ | 195.37° | ±0.08° | – | – |
| $i$ | 31.7° | ±0.6° | ±0.1° | ±1.0° |
| $\Pi$ | 8.4° | ±0.8° | ±0.3° | ±4.7° |
| $Q$ | 5.75 AU | ±0.35 | – | – |
| $T_j$ | 2.52 | ±0.08 | – | – |
| $P$ | 6.2 y | ±0.5 | – | – |
| $N$ | 331 | | | |

*Table 4* – Group B. The mean orbit for the second group with 121 almost identical Draconid orbits which fulfil the very high threshold class with $D_D$ < 0.02 for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_O$ | 195.38° | ±0.08° | – | – |
| $\alpha_g$ | 262.9° | ±1.2° | ±0.6° | ±5.4° |
| $\delta_g$ | +56.1° | ±0.9° | ±0.3° | ±2.0° |
| $v_g$ | 21.7 km/s | ±0.4 | ±0.09 | ±0.9 |
| $\lambda-\lambda_O$ | 53.3° | ±3.6° | ±1.4° | ±15.6° |
| $\beta$ | +79.0° | ±0.9° | ±0.3° | ±2.0° |
| $a$ | 4.10 AU | ±0.24 | – | – |
| $q$ | 0.9961 AU | ±0.0008 | ±0.0003 | ±0.004 |
| $e$ | 0.7568 | ±0.01 | ±0.008 | ±0.07 |
| $\omega$ | 173.47° | ±0.9° | ±0.4° | ±4.0° |
| $\Omega$ | 195.37° | ±0.08° | – | – |
| $i$ | 32.8° | ±0.7° | ±0.1° | ±1.1° |
| $\Pi$ | 8.8° | ±0.9° | ±0.4° | ±4.0° |
| $Q$ | 7.18 AU | ±0.49 | – | – |
| $T_j$ | 2.25 | ±0.07 | – | – |
| $P$ | 8.3 y | ±0.7 | – | – |
| $N$ | 121 | | | |

*Table 5* – Group C. The mean orbit for the third group with 170 almost identical Draconid orbits which fulfil the very high threshold class with $D_D$ < 0.02 for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_O$ | 195.37° | ±0.07° | – | – |
| $\alpha_g$ | 262.1° | ±1.3° | ±0.7° | ±6.1° |
| $\delta_g$ | +55.8° | ±0.9° | ±0.4° | ±2.5° |
| $v_g$ | 20.2 km/s | ±0.4 | ±0.08 | ±0.8 |
| $\lambda-\lambda_O$ | 51.6° | ±3.5° | ±1.8° | ±12.1° |
| $\beta$ | +78.6° | ±0.9° | ±0.4° | ±2.4° |
| $a$ | 2.98 AU | ±0.10 | – | – |
| $q$ | 0.9956 AU | ±0.0010 | ±0.0005 | ±0.009 |
| $e$ | 0.6664 | ±0.01 | ±0.010 | ±0.06 |
| $\omega$ | 172.57° | ±1.0° | ±0.5° | ±5.3° |
| $\Omega$ | 195.37° | ±0.07° | – | – |
| $i$ | 31.0° | ±0.7° | ±0.2° | ±1.0° |
| $\Pi$ | 7.9° | ±1.1 | ±0.5° | ±5.3° |
| $Q$ | 5.00 AU | ±0.19 | – | – |
| $T_j$ | 2.70 | ±0.06 | – | – |
| $P$ | 5.2 y | ±0.3 | – | – |
| $N$ | 170 | | | |

*Table 6* – Group D. The mean orbit for the fourth group with 45 almost identical Draconid orbits which fulfil the very high threshold class with $D_D$ < 0.02 for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_O$ | 195.36° | ±0.08° | – | – |
| $\alpha_g$ | 263.8° | ±1.0° | ±0.6° | ±5.5° |
| $\delta_g$ | +56.5° | ±0.8° | ±0.3° | ±1.5° |
| $v_g$ | 24.2 km/s | ±0.4 | ±0.11 | ±0.8 |
| $\lambda-\lambda_O$ | 55.5° | ±3.2° | ±1.8° | ±16.1° |
| $\beta$ | +79.4° | ±0.8° | ±0.3° | ±1.6° |
| $a$ | 10.3 AU | ±2.2 | – | – |
| $q$ | 0.9965 AU | ±0.0006 | ±0.0004 | ±0.004 |
| $e$ | 0.9034 | ±0.02 | ±0.012 | ±0.08 |
| $\omega$ | 174.20° | ±0.7° | ±0.4° | ±3.7° |
| $\Omega$ | 195.35° | ±0.08° | – | – |
| $i$ | 35.4° | ±0.7° | ±0.2° | ±1.2° |
| $\Pi$ | 9.4° | ±0.8° | ±0.4° | ±3.7° |
| $Q$ | 19.6 AU | ±4.5 | – | – |
| $T_j$ | 1.48 | ±0.10 | – | – |
| $P$ | 33.1 y | ±11.2 | – | – |
| $N$ | 45 | | | |

*Table 7* – Group E. The mean orbit for the fifth group with 58 almost identical Draconid orbits which fulfil the very high threshold class with $D_D < 0.02$ for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_\odot$ | 195.36° | ±0.07° | – | – |
| $\alpha_g$ | 263.2° | ±1.3° | ±1.0° | ±7.2° |
| $\delta_g$ | +56.3° | ±1.0° | ±0.4° | ±2.0° |
| $v_g$ | 22.7 km/s | ±0.5 | ±0.15 | ±1.1 |
| $\lambda-\lambda_\odot$ | 54.2° | ±4.0° | ±3.0° | ±18.3° |
| $\beta$ | +79.2° | ±1.0° | ±0.4° | ±3.0° |
| $a$ | 5.4 AU | ±0.5 | – | – |
| $q$ | 0.9962 AU | ±0.0008 | ±0.0006 | ±0.01 |
| $e$ | 0.8143 | ±0.02 | ±0.015 | ±0.09 |
| $\omega$ | 173.76° | ±1.0° | ±0.7° | ±5.2° |
| $\Omega$ | 195.36° | ±0.07° | – | – |
| $i$ | 33.9° | ±0.8° | ±0.2° | ±1.4° |
| $\Pi$ | 9.0° | ±1.0° | ±0.7° | ±5.2° |
| $Q$ | 9.62 AU | ±1.03 | – | – |
| $T_j$ | 1.96 | ±0.09 | – | – |
| $P$ | 12.2 y | ±1.8 | – | – |
| $N$ | 58 | | | |

*Table 8* – Group F. The mean orbit for the sixth group with 28 almost identical Draconid orbits which fulfil the high threshold class with $D_D < 0.04$ for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_\odot$ | 195.36° | ±0.08° | – | – |
| $\alpha g$ | 263.9° | ±1.8° | ±0.7° | ±4.5° |
| $\delta g$ | +56.6° | ±1.2° | ±0.4° | ±1.4° |
| $v_g$ | 25.4 km/s | ±0.6 | ±0.14 | ±0.65 |
| $\lambda-\lambda_\odot$ | 55.5° | ±5.2° | ±2.2° | ±13.9° |
| $\beta$ | +79.6° | ±1.2° | ±0.4° | ±1.5° |
| $a$ | 80 AU | ±94 | – | – |
| $q$ | 0.9965 AU | ±0.001 | ±0.0004 | ±0.003 |
| $e$ | 0.9876 | ±0.03 | ±0.015 | ±0.07 |
| $\omega$ | 174.43° | ±1.3° | ±0.4° | ±2.8° |
| $\Omega$ | 195.34° | ±0.08° | – | – |
| $i$ | 36.6° | ±0.9° | ±0.2° | ±0.9° |
| $\Pi$ | 9.6° | ±1.3° | ±0.4° | ±2.8° |
| $Q$ | 129 AU | – | – | – |
| $T_j$ | 1.10 | – | – | – |
| $P$ | 527 y | – | – | – |
| N | 28 | | | |

by just measuring errors. The Draconids in group F have a geocentric velocity $v_g = 25.4$ km/s (median value) with all its geocentric velocities within the range of 24.3 km/s and 26.5 km/s. Group F can be considered as a component related to group D with slightly faster Draconids and more dispersed orbits.

*Table 9* – Group G. The mean orbit for the seventh group with 69 almost identical Draconid orbits which fulfil the high threshold class with $D_D < 0.04$ for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_\odot$ | 195.37° | ±0.06° | – | – |
| $\alpha_g$ | 261.5° | ±3.6° | ±0.9° | ±8.5° |
| $\delta_g$ | +56.3° | ±2.2° | ±0.6° | ±3.2° |
| $v_g$ | 19.6 km/s | ±0.9 | ±0.13 | ±0.88 |
| $\lambda-\lambda_\odot$ | 49.7° | ±10.7° | ±2.4° | ±18.4° |
| $\beta$ | +78.9° | ±2.3° | ±0.7° | ±3.3° |
| $a$ | 2.64 AU | ±0.12 | – | – |
| $q$ | 0.9946 AU | ±0.003 | ±0.0008 | ±0.01 |
| $e$ | 0.6226 | ±0.02 | ±0.016 | ±0.08 |
| $\omega$ | 172.29° | ±2.9° | ±0.8° | ±7.5° |
| $\Omega$ | 195.36° | ±0.06° | – | – |
| $i$ | 30.8° | ±1.8° | ±0.3° | ±1.3° |
| $\Pi$ | 7.9° | ±2.9 | ±0.8° | ±7.5° |
| $Q$ | 4.33 AU | ±0.23 | – | – |
| $T_j$ | 2.91 | ±0.09 | – | – |
| $P$ | 4.4 y | ±0.3 | – | – |
| $N$ | 69 | | | |

*Table 10* – Group H. The mean orbit for the eighth group with 24 almost identical Draconid orbits which fulfil the high threshold class with $D_D < 0.04$ for the orbit mentioned.

| | Mean orbit | S.D. | Median uncertainty | Max. uncertainty |
|---|---|---|---|---|
| $\lambda_\odot$ | 195.37° | ±0.07° | – | – |
| $\alpha_g$ | 263.3° | ±3.8° | ±1.1° | ±4.4° |
| $\delta_g$ | +54.2° | ±1.9° | ±0.5° | ±2.0° |
| $v_g$ | 22.6 km/s | ±1.0 | ±0.17 | ±0.69 |
| $\lambda-\lambda_\odot$ | 55.1° | ±9.8° | ±0.2° | ±0.7° |
| $\beta$ | +77.0° | ±2.0° | ±0.5° | ±2.0° |
| $a$ | 6.00 AU | ±1.12 | – | – |
| $q$ | 0.9944 AU | ±0.003 | ±0.0008 | ±0.003 |
| $e$ | 0.8341 | ±0.03 | ±0.015 | ±0.07 |
| $\omega$ | 172.73° | ±2.8° | ±0.8° | ±2.9° |
| $\Omega$ | 195.37° | ±0.07° | – | – |
| $i$ | 32.9° | ±1.7° | ±0.3° | ±1.0° |
| $\Pi$ | 8.9° | ±2.8° | ±0.8° | ±2.9° |
| $Q$ | 11.94 AU | ±2.23 | – | – |
| $T_j$ | 1.81 | ±0.16 | – | – |
| $P$ | 16.4 y | ±4.2 | – | – |
| $N$ | 24 | | | |

## Group G: 69 orbits with low eccentricity

At this point the dataset has 216 orbits left. After fourteen iterations on the low threshold class and four more iterations on the high threshold class the procedure converges on a group of 69 orbits that fit the high threshold similarity, 45 orbits of these even fit the very high threshold class. This group is close to group C and has the smallest eccentricity of all groups (*Table 9*). These 69 orbits have a median value of $D_{SH}$ = 0.031 and $D_D$ = 0.015. The Draconids in group G have a geocentric velocity $v_g$ = 19.6 km/s (median value) with all its geocentric velocities within the range of 17.1 km/s and 22.4 km/s. Group G looks related to group C, containing more dispersed and slower Draconids.

## Group H: 24 very similar orbits

The 147 orbits left in this procedure allowed a last iteration loop to converge at a group of 24 orbits fitting the high threshold similarity. This group resembles much to group E except for a difference of 1° in both inclination *i* and length of perihelion *Π*. These 24 orbits have a median value of $D_{SH}$ = 0.047 and $D_D$ = 0.021. The Draconids in group H have a geocentric velocity $v_g$ = 22.6 km/s (median value) with all its geocentric velocities within the range of 20.3 km/s and 24.2 km/s.

The final remaining 123 orbits include 40 hyperbolic cases which were most likely affected by measuring inaccuracies. Most of the remaining orbits are dispersed Draconids with medium or low threshold similarity with one or more of the above listed groups. Some orbits differ too much in length of perihelion and are likely sporadics. No further groupings of orbits can be detected in this remaining dataset.

## Using these groups as reference orbit

The eight compact concentrations of Draconid orbits were used as a range of reference orbits to check all 1391 orbits obtained during this night on possible similarity with the mean orbits of each of the eight groups. In total 938 orbits fulfill the similarity criteria with at least one of the mean orbits of the eight groups. *Table 11* lists the number of orbits counted for each group for each class of similarity threshold. Note that the groups with the highest velocities (D and F) have the smallest numbers of positive matches.

*Table 11* – Number of orbits that match with the mean orbit of a group counted for each similarity threshold class (Lo = low; Ml = medium low; Mh = medium high, H = high and Vh = very high).

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Lo | 814 | 839 | 775 | 324 | 762 | 172 | 697 | 684 |
| Ml | 764 | 739 | 716 | 199 | 525 | 118 | 570 | 411 |
| Mh | 693 | 613 | 635 | 131 | 312 | 84 | 402 | 245 |
| H | 568 | 378 | 491 | 81 | 160 | 51 | 183 | 126 |
| Vh | 331 | 155 | 243 | 45 | 60 | 18 | 55 | 43 |

Most orbits fulfill the similarity criteria for more than one group. In fact, only four orbits match with a single mean orbit. All four have low values for the eccentricity *e*, 0.516 to 0.540 with low and medium low similarity with the mean orbit of group G (with the slowest geocentric velocity). Ten orbits match with two different groups, 27 with three of the groups, 122 with four different groups, 137 with five different groups, 490 with six different groups and 111 with seven different groups but not any single orbit satisfies similarity with all eight groups. *Table 12* lists the number of orbits that each group has in common with another group with the groups ordered from slow to fast.

*Table 12* – The number of orbits that a group has in common with each of the eight groups. The cross sections of each group marked in yellow is the total number of orbits associated with this group.

| | G | C | A | B | E | H | D | F |
|---|---|---|---|---|---|---|---|---|
| G | 697 | 693 | 686 | 660 | 562 | 476 | 97 | 0 |
| C | 693 | 775 | 768 | 742 | 642 | 557 | 177 | 14 |
| A | 686 | 768 | 814 | 788 | 688 | 603 | 222 | 59 |
| B | 660 | 742 | 788 | 839 | 739 | 654 | 273 | 110 |
| E | 562 | 642 | 688 | 739 | 762 | 676 | 296 | 133 |
| H | 476 | 557 | 603 | 654 | 676 | 684 | 303 | 140 |
| D | 97 | 177 | 222 | 273 | 296 | 303 | 324 | 161 |
| F | 0 | 14 | 59 | 110 | 133 | 140 | 161 | 172 |

*Table 13* – Number of orbits that match with the reference orbit from different literature sources, counted for each similarity threshold class (Lo = low; Ml = medium low; Mh = medium high, H = high and Vh = very high).

| Reference orbit | Lo | Ml | Mh | H | Vh |
|---|---|---|---|---|---|
| Gavajdova (1994) | 325 | 70 | 2 | 0 | 0 |
| Jenniskens (2006) | 780 | 721 | 639 | 492 | 257 |
| Brown et al. (2008) | 764 | 687 | 598 | 425 | 179 |
| Jenniskens et al. (2016) | 810 | 763 | 694 | 572 | 340 |
| 21P/Giacobini-Zinner | 817 | 765 | 692 | 566 | 297 |

*Table 14* – Mean orbit for 938 Draconid orbits identified according to the range of the mean orbits of the 8 groups of Draconid orbits.

| | Mean orbit | S.D. | Minimum value | Maximum value |
|---|---|---|---|---|
| $\lambda_{\odot}$ | 195.37° | ±0.07° | 195.146° | 195.586° |
| $\alpha_g$ | 262.7° | ±3.1° | 240.1° | 281.0° |
| $\delta_g$ | +56.0° | ±1.8° | +43.5° | +67.7° |
| $v_g$ | 20.9 km/s | ±1.8 | 15.8 km/s | 31.1 km/s |
| $\lambda$-$\lambda_{\odot}$ | 53.0° | ±15.4° | 8.6° | 351.8° |
| $\beta$ | +78.8° | ±1.9° | +64.7° | +86.7° |
| $a$ | 3.82 AU | – | – | – |
| $q$ | 0.9937 AU | ±0.003 | 0.96196 | 0.9991 |
| $e$ | 0.73988 | ±0.105 | 0.5163 | 1.18 |
| $\omega$ | 173.165° | ±2.46° | 155.181° | 185.155° |
| $\Omega$ | 195.349° | ±0.07° | 195.147° | 195.588° |
| $i$ | 32.37° | ±2.14° | 23.77° | 47.53° |
| $\Pi$ | 8.514° | ±2.46° | 350.605° | 20.578° |
| $Q$ | 6.65 AU | – | – | – |
| $T_j$ | 2.34 | – | – | – |
| $P$ | 7.47 y | – | – | – |
| $N$ | 938 | | | |

Checking our 938 Draconid orbits with past reference orbits (see *Table 1* and *Table 2*), using any of these reference orbits misses a significant number of our 938 Draconid orbits. *Table 13* lists the number of orbits in each threshold class of similarity that fits the criteria for each of the reference orbits listed. The reference given by Jenniskens et al. (2016), based on the 2011 Draconid return, as well as the 2018 orbit of the parent comet 21P/Giacobini-Zinner are the best matching references, but both still fail to identify about 15% of all the candidate Draconid orbits.

The mean orbit for all 938 Draconids is listed in *Table 14* together with the standard deviation, for completeness we also mention the outliers with the highest and lowest value for each parameter where applicable.

The more than 120 obvious Draconid orbits that fail to be identified as Draconids when using just a single valid reference orbit to check similarity, mostly concern orbits with a remarkable fast heliocentric velocity $v_h$, including 37 with a hyperbolic orbit which must be due to velocity measuring inaccuracies. The problem concerns mainly group F and to a less extent group D.

Velocity measurement uncertainties are a typical problem for high velocity meteors such as Leonids, Orionids and Perseids. It is a bit a mystery how this could affect slow meteors like the Draconids with geocentric velocities typically within the range of 19 to 22 km/s. 24% of our 938 Draconids have geocentric velocities faster than 22 km/s which is a strong indication that the shower may include a component which encounters the Earth at a slightly higher velocity than the main Draconid stream, assuming that the velocity measurements in the CAMS system are correct. The error margins calculated by the CAMS software are rather small and cannot explain the excess in remarkable fast Draconids. The remarkable high velocities found from the CAMS BeNeLux data remains without confirmation from other studies. Question is how Draconids were identified in other studies? The most common approach for known meteor showers is to use a past orbit as reference or to simply select meteors based on the known radiant position and velocity, ignoring all outliers. However, this is a rather biased way to identify shower members as the reference values of the past are assumed to be representative for any future returns. Any changes in the stream structure will remain unnoticed this way.

The remarkable number of "too fast" Draconids requires further investigations which we discuss in Section 9.

## 6 Activity profile

The number of Draconid orbits counted in time bins of 15 minutes offers a reasonably good possibility to reconstruct an activity profile. To temper statistical fluctuations, we count the number of orbits in time bins of 0.02° in solar longitude, shifted 0.01° at each step. The radiant elevation varies greatly during the night. When observations started the Draconid radiant was at about 80° elevation for the center of the CAMS BeNeLux network. When the shower display was in full progress at 22$^h$ UT, the radiant was at 45° getting at 17° by the end of the display. Since the radiant elevation within the network was about the same for all cameras, a zenith distance correction can be applied similar to ZHR calculations. We apply this correction to the number of orbits counted in each time bin for the zenith distance *Z* with a factor sec(*Z*).

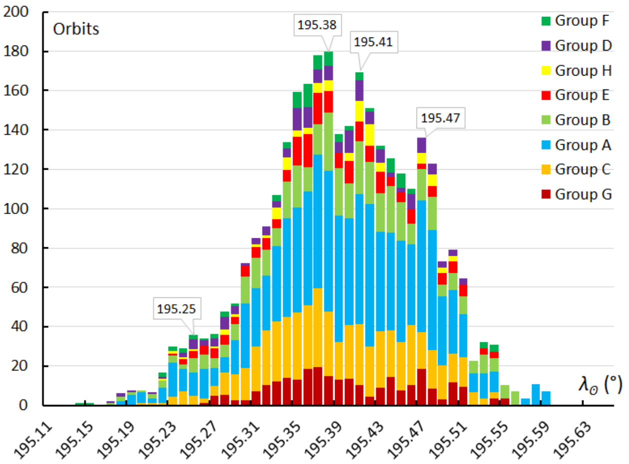


*Figure 4* – The number of orbits counted in bins of 0.02° duration shifted per 0.01° solar longitude for each group of similar orbits as described in Section 5, corrected for zenith distance.

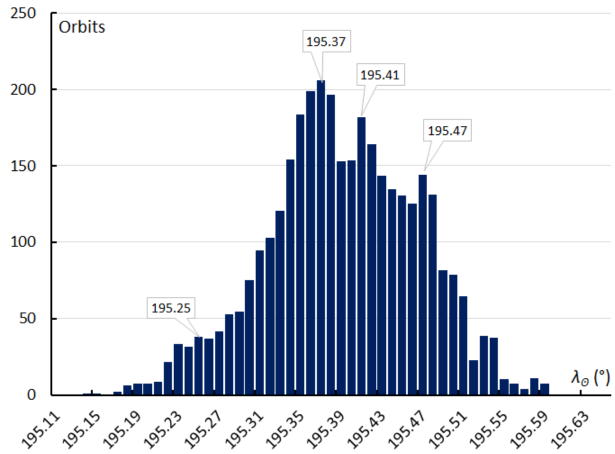


*Figure 5* – The number of orbits counted in bins of 0.02° duration shifted per 0.01° solar longitude for all 938 Draconid orbits, corrected for zenith distance.

*Figure 4* shows the activity profile with different colors for the different concentrations of orbits. The groups are ordered from slow at the bottom to fast at the top layers. The two groups, D and F, with the somehow problematic high velocities represent rather small numbers. The profile shows a "shoulder" around $\lambda_{\odot} = 195.25°$ (20$^h$27$^m$ UTC), the main peak occurred at $195.35° < \lambda_{\odot} < 195.38°$ (22$^h$53$^m$ to 23$^h$36$^m$ UTC) followed by another peak at $\lambda_{\odot} = 195.41°$ (0$^h$20$^m$ UTC). The activity profile is skew with a steeper ascending branch and a slower descending branch. Another sub-maximum appeared at $\lambda_{\odot} = 195.47°$ (1$^h$48$^m$ UTC). The time of the best activity agrees well with the prediction of Maslov (2011), who predicted 23$^h$ to 0$^h$ UTC, but the actual activity was much higher than expected. Ye et al. (2013) predicted the peak at $\lambda_{\odot} = 195.4°$ (0$^h$06$^m$ UTC). The results can be compared with the visual observations analyzed by Miskotte (2019). Nothing unusual was detected at $\lambda_{\odot} = 195.25°$ in the visual data, but too few visual data was available at this time. The visual data had a fairly flat maximum during $195.34° < \lambda_{\odot} < 195.40°$, no sub-maximum at $\lambda_{\odot} = 195.41°$ but at $\lambda_{\odot} = 195.44°$, although all this varies within the error margins. The visual data has also a sub-maximum at $\lambda_{\odot} = 195.48°$ (Miskotte, 2019).

Using all our 938 Draconid orbits does not change much to the shape of the activity profile (*Figure 5*). Although we corrected the number of Draconid orbits for the zenith distance, these profiles are no ZHR profiles. The sky conditions are not taken into account. For a relatively small camera network in a single night we can assume that the number of non-shower orbits has the same sky condition influence as the number of shower orbits. If we express the shower activity as a percentage relative to the non-shower activity, we can eliminate the effect of sky conditions. However, for network data from a limited geographical area, the random statistical fluctuations of non-shower activity for each time interval and the effect of the diurnal variation will seriously distort the shower activity profile. The effect of the diurnal variation on the proportion Draconids/sporadics will result in an overestimation in the evening hours and an underestimation in the morning hours. This is what we see in *Figure 6*. Here the peak at $\lambda_{\odot} = 195.25°$ stands out while the maximum interval during $195.34° < \lambda_{\odot} < 195.40°$ gets a bit deformed because of a sudden increase in sporadics at $\lambda_{\odot}$ [195.36°–195.37°]. The sub-maximum at $\lambda_{\odot} = 195.48°$ remains well visible although the level will be underestimated due to the diurnal variation effect.

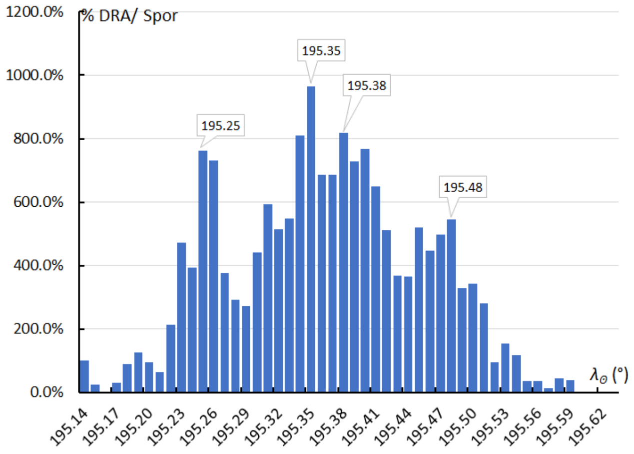


*Figure 6* – Number of Draconid orbits expressed as a percentage relative to the number of non-Draconid orbits in the same time bin.

These activity profiles show the main features but should be regarded with caution because these are based on raw counts. Both Vida et al. (2020) and Koten et al. (2014) reported a very rapid change in the population index which was observed in the Draconid returns of 2011 and 2018. Miskotte (2019) found a variable population index for the 2018 Draconids, but not the sudden and strong variation found by Vida et al. (2020). The most likely explanation is that not enough visual magnitude data were available for short observing intervals. Unfortunately, the magnitude data were not available for analyzing.

If we consider Draconids identified on a single reference orbit, instead of our range of orbits the activity profile and its features remain unchanged (*Figure 7*).

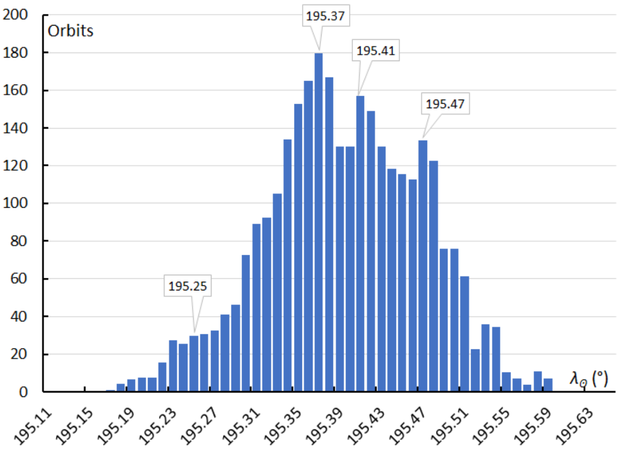


*Figure 7* – The number of orbits counted in bins of 0.02° duration shifted per 0.01° solar longitude for all 817 Draconid orbits identified with the 2018 21P/Giacobini-Zinner orbit, with the number of orbits corrected for zenith distance.

## 7 The Draconid radiant

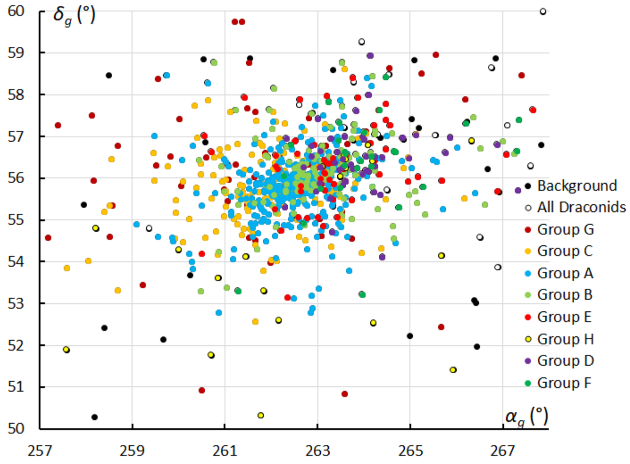


*Figure 8* – Radiants plotted in geocentric equatorial coordinates. The Draconid groups are plotted in layers with the slow velocity radiants (G) in the background and the fast in front (F).

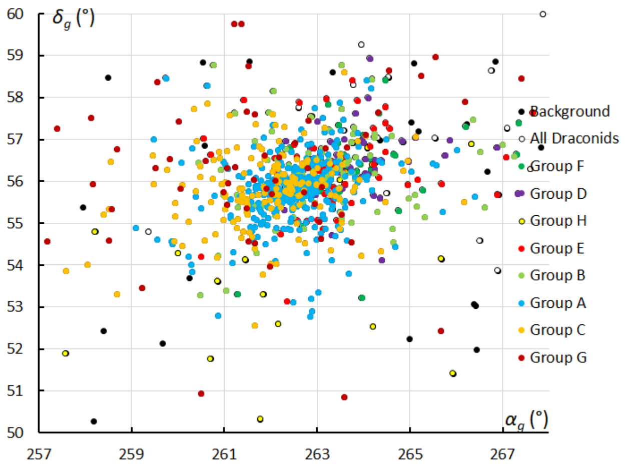


*Figure 9* – Radiants plotted in geocentric equatorial coordinates. The Draconid groups are plotted in layers with the fast velocity radiants (F) in the background and the slow in front (G).

Would the concentrations of orbits be visible in the radiant of the Draconids? Apart from some outliers, the Draconids radiate from a rather compact radiant area. Plotting the radiants in geocentric equatorial coordinates the large number of radiants results in a crowded picture with overlapping radiant points between the different groups. Therefore, we plot two versions with all radiants plotted in layers, once with the fast velocity radiants in front (*Figure 8*) and once with the slow velocity radiants in front (*Figure 9*). The slower velocity radiants appear mainly towards the bottom-left quarter and the faster velocity radiants in the upper right quarter of the radiant area.

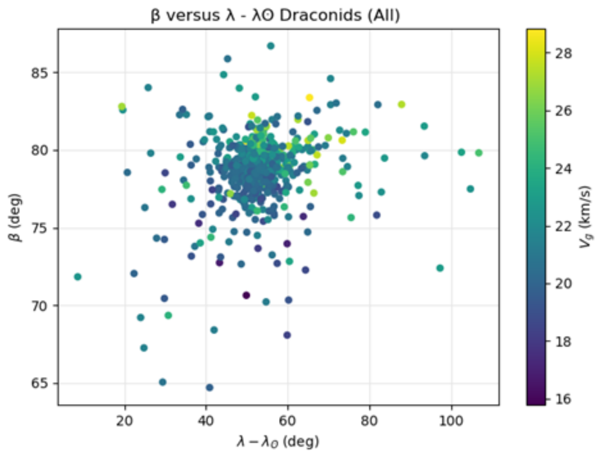


*Figure 10* – The radiant positions for the 938 Draconid orbits in Sun centered geocentric ecliptic coordinates with the geocentric velocity marked color coded.

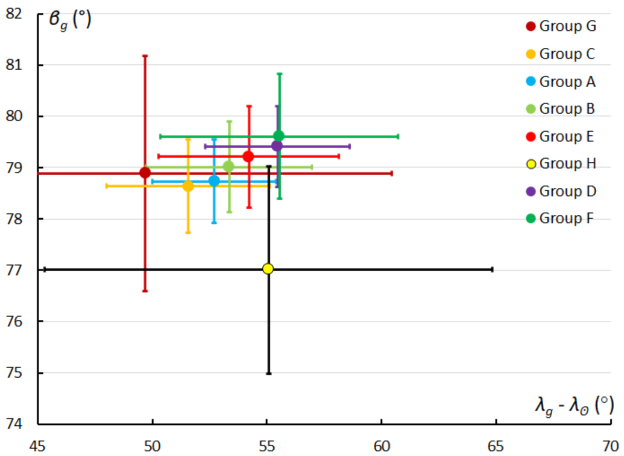


*Figure 11* – The radiant positions in Sun centered geocentric ecliptic coordinates for the median value of each group of Draconid orbits with the s.d. as error bars.

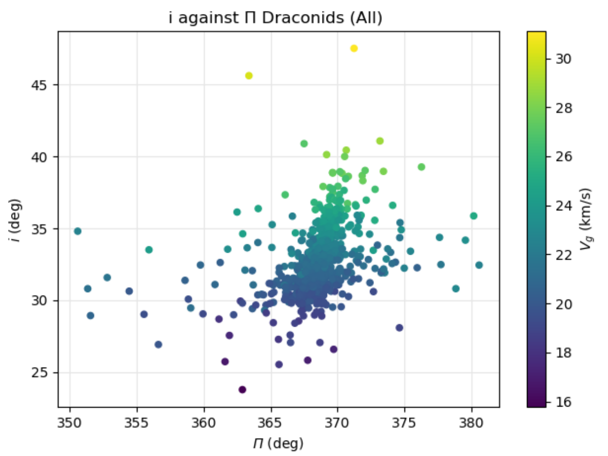


*Figure 12* – The inclination *i* in function of the length of perihelion *Π* with the geocentric velocity $v_g$ color coded.

Looking at the radiant plot in Sun-centered geocentric ecliptic coordinates does not really help to see the general picture because of the scatter of the radiant points being close to the ecliptic pole (*Figure 10*). Plotting the median values for the Sun centered geocentric ecliptic coordinates for each group reveals a trend for the groups C, A, B, Z, D and F as the values of $\lambda_g - \lambda_\odot$ and $\beta_g$ increase with higher geocentric velocities $v_g$. Groups G and H have a much larger spread than the other groups (*Figure 11*).

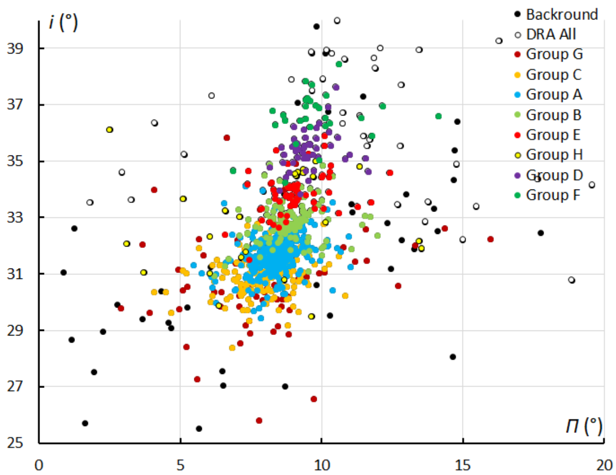


*Figure 13* – The inclination *i* in function of the length of perihelion *Π* for the different groups of high threshold similarity orbits, plotted in layers with the slow velocity orbits in the background and the fast in front.

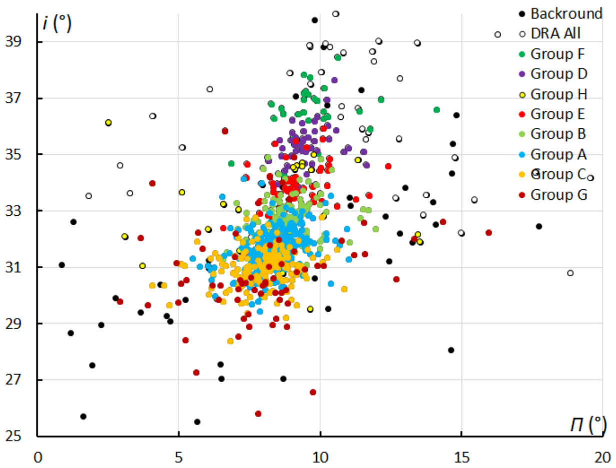


*Figure 14* – The inclination *i* in function of the length of perihelion *Π* for the different groups of high threshold similarity orbits, plotted in layers with the fast velocity orbits in the background and the slow in front.

Plotting the inclination *i* against the length of perihelion *Π* with the geocentric velocity $v_g$ color coded displays a clear trend with the higher inclination orbits having a higher velocity (*Figure 12*). The same plot of *i* against *Π*, but for the groups with concentrations of similar orbits shows the same pattern. The 'slow' orbits appear in the bottom left part, the 'fast' orbits in the upper right part. The groups were plotted in layers, once with the 'fast' orbits in front (*Figure 13*) and once with the 'slow' orbits in front (*Figure 14*).

In *Figures 15 to 28* we compare the plots for seven different time intervals. For each time bin we show the plot based on all Draconids, including the outliers with a color code for the geocentric velocity, compared with the plot of the orbits that fulfill the very high threshold similarity criteria for each of the groups with a concentration of orbits. Groups A to E appear very compact while F, G and H appear more dispersed. The strength of each group in each time bin changes but these changes can be explained as statistical fluctuations. It seems that all the groups and the entire velocity range was registered during the entire activity period, but some groups appear absent in some intervals.

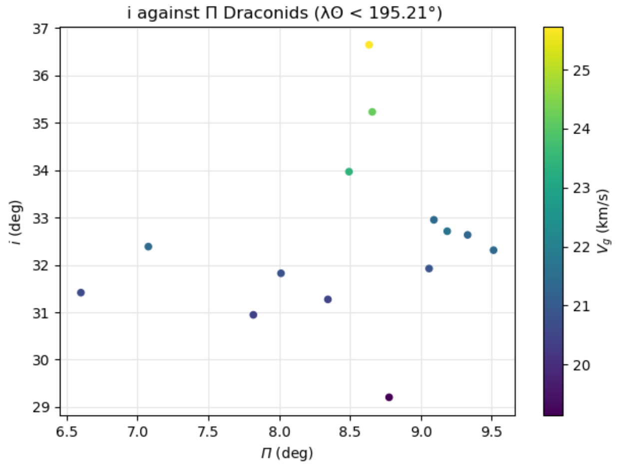


*Figure 15* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval $\lambda_{\odot} < 192.21°$.

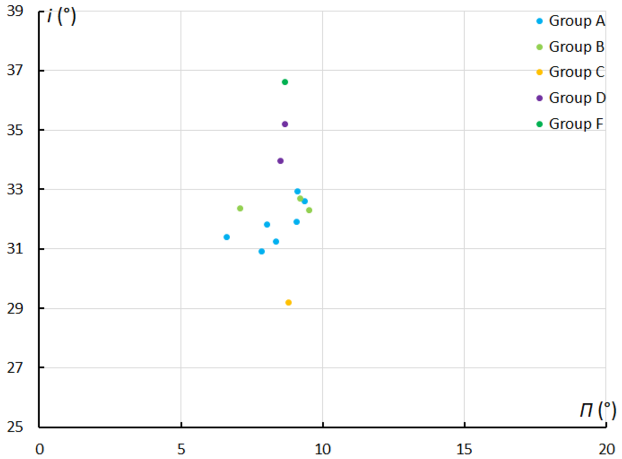


*Figure 16* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval $\lambda_{\odot} < 192.21°$.

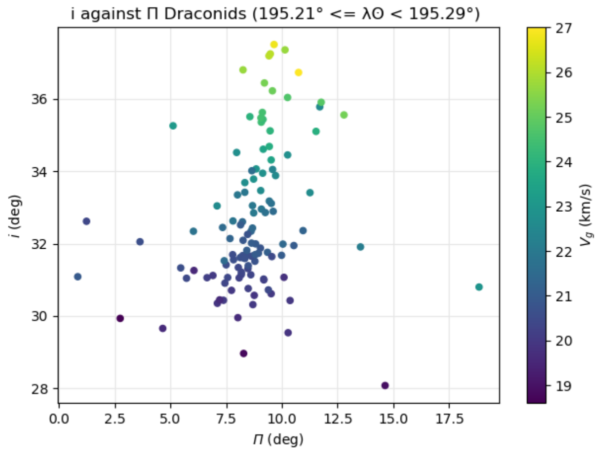


*Figure 17* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval $195.21° < \lambda_{\odot} < 192.29°$.

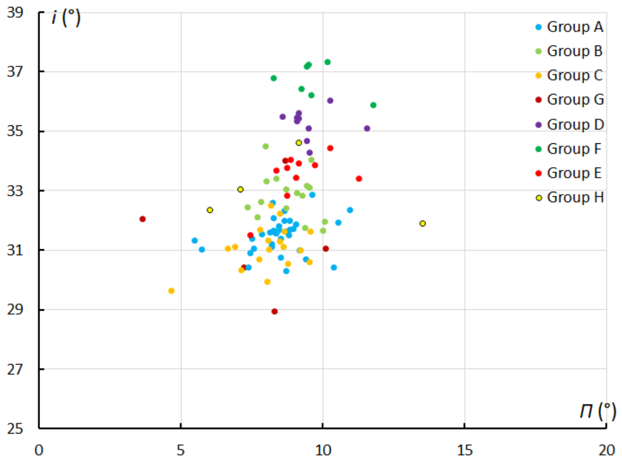


*Figure 18* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval $195.21° < \lambda_{\odot} < 192.29°$.

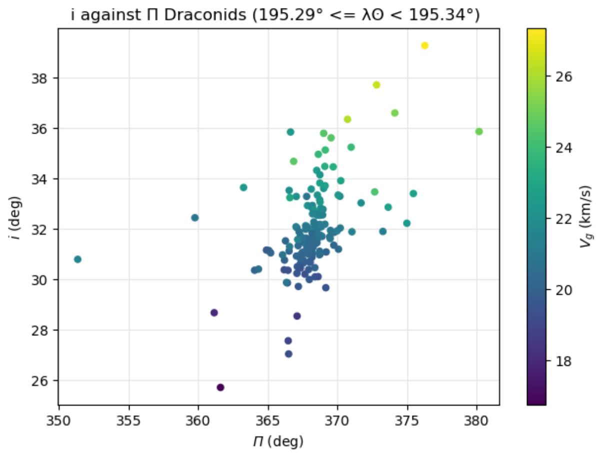


*Figure 19* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval $195.29° < \lambda_{\odot} < 192.34°$.

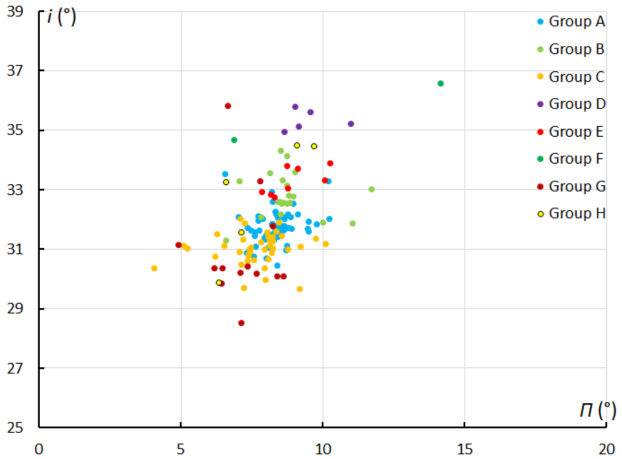


*Figure 20* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval $195.29° < \lambda_{\odot} < 192.34°$.

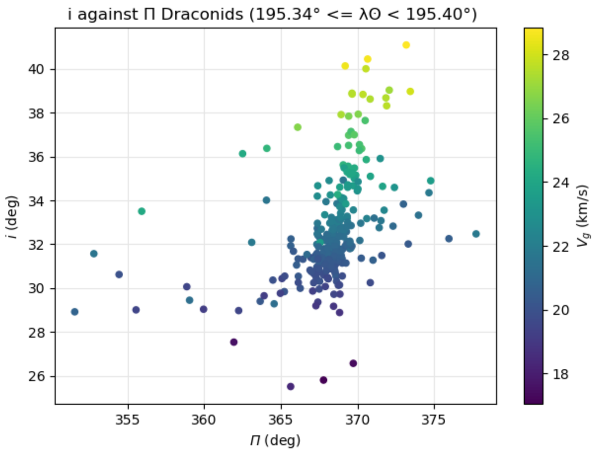


*Figure 21* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval 195.34° < $\lambda_O$ < 192.40°.

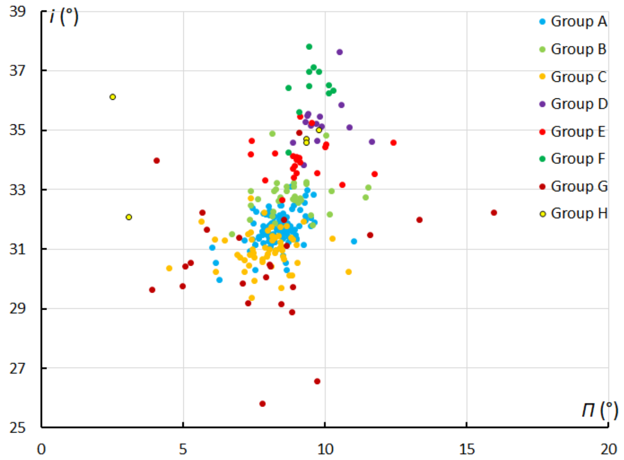


*Figure 22* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval 195.34° < $\lambda_O$ < 192.40°.

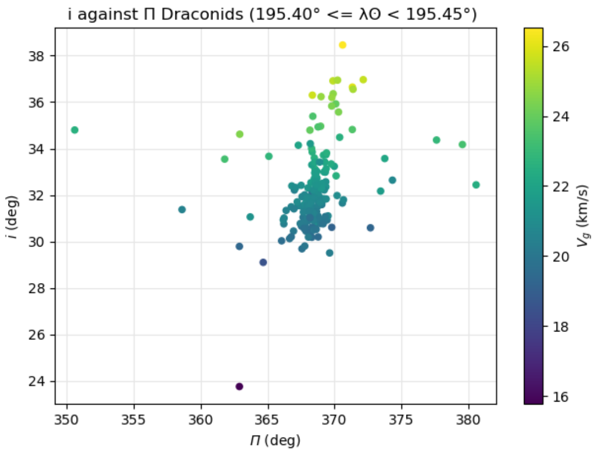


*Figure 23* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval 195.40° < $\lambda_O$ < 192.45°.

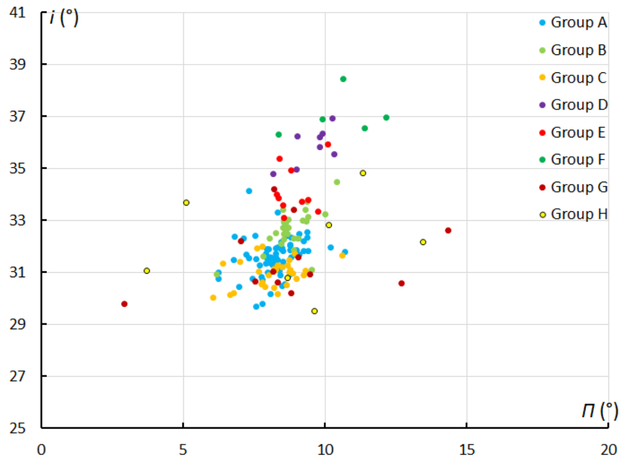


*Figure 24* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval 195.40° < $\lambda_O$ < 192.45°.

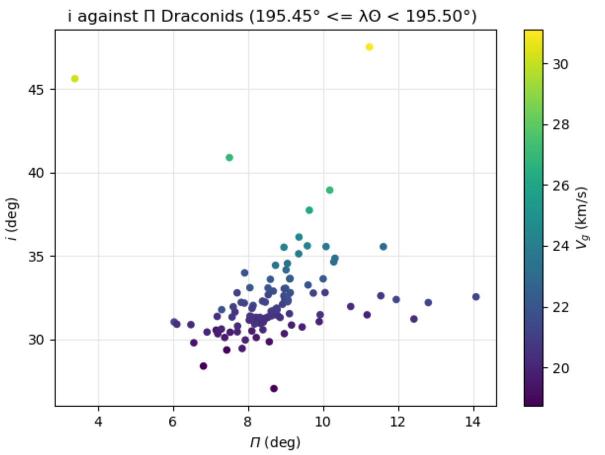


*Figure 25* – The inclination $i$ in function of the length of perihelion $\Pi$ with the geocentric velocity $v_g$ color coded for the interval 195.45° < $\lambda_O$ < 192.50°.

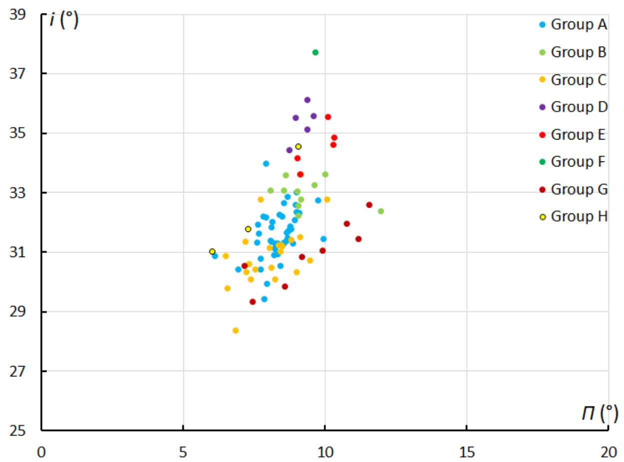


*Figure 26* – The inclination $i$ in function of the length of perihelion $\Pi$ for the different groups of high threshold similarity orbits for the interval 195.45° < $\lambda_O$ < 192.50°.

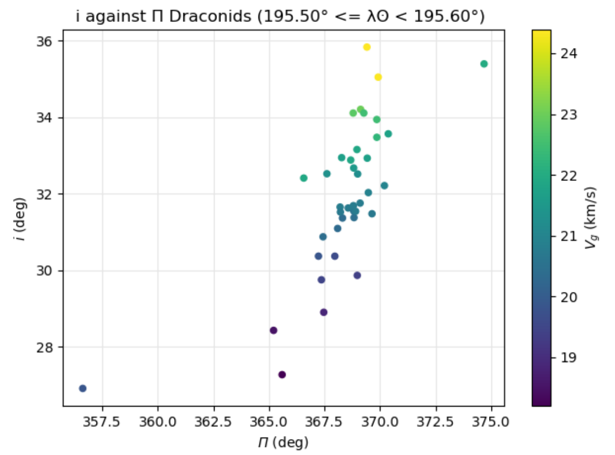


*Figure 27* – The inclination *i* in function of the length of perihelion *Π* with the geocentric velocity $v_g$ color coded for the interval 195.50° < $\lambda_{\odot}$ < 192.60°.

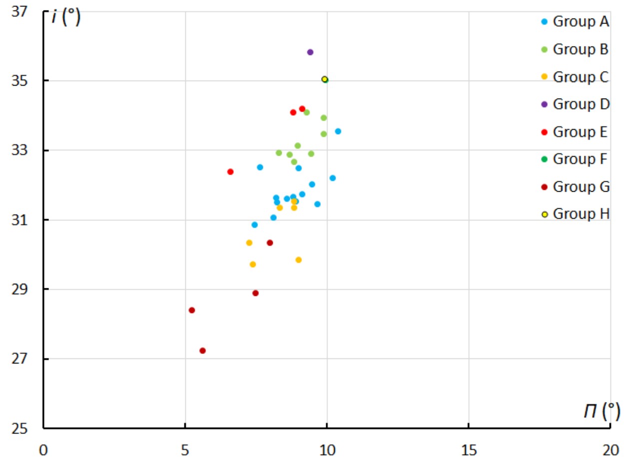


*Figure 28* – The inclination *i* in function of the length of perihelion *Π* for the different groups of high threshold similarity orbits for the interval 195.50° < $\lambda_{\odot}$ < 192.60°.

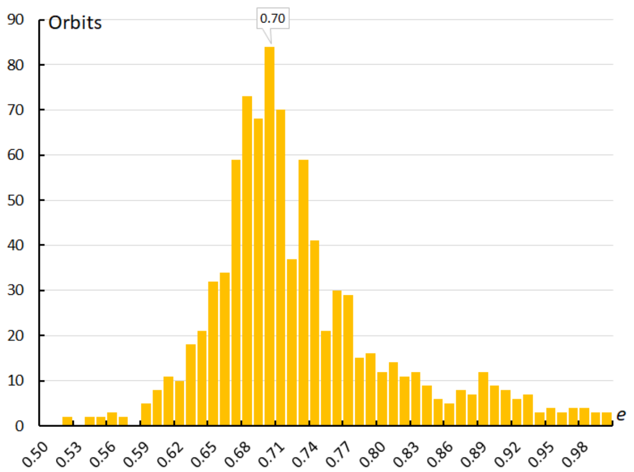


*Figure 29* – Histogram showing the eccentricity distribution for all 938 Draconid orbits identified by the groups, counted in 0.01 bins.

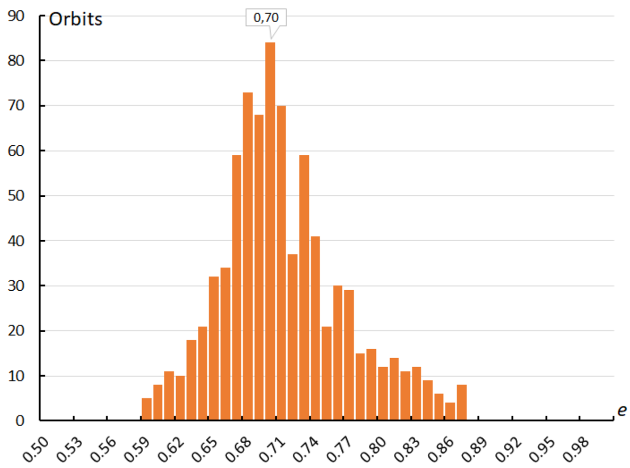


*Figure 30* – Histogram showing the eccentricity distribution for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit, counted in 0.01 bins.

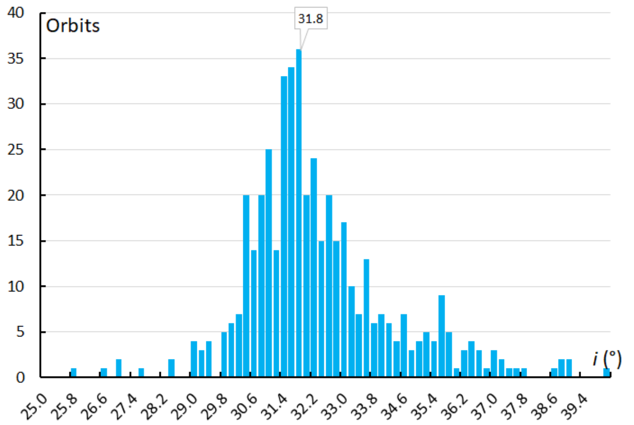


*Figure 31* – Histogram showing the inclination distribution for all 938 Draconid orbits identified by the groups, counted in 0.2° bins.

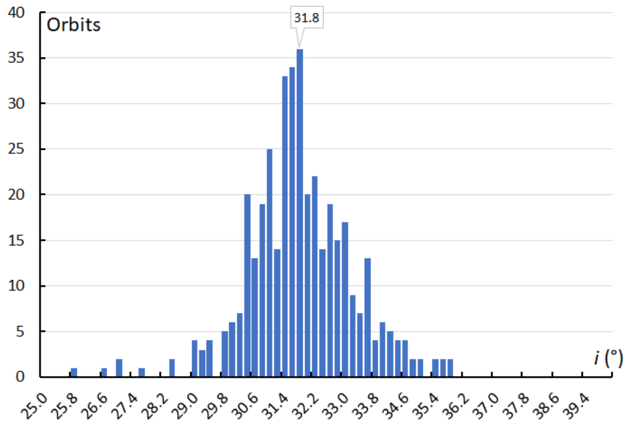


*Figure 32* – Histogram showing the inclination distribution for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit, counted in 0.2° bins.

## 8 The heliocentric orbits

In Section 5 we screened our dataset of orbits to locate concentrations of Draconid orbits. Using the range of mean orbits for the detected groups of very similar orbits we could identify 938 Draconid orbits. However, this approach includes orbits with suspicious fast Draconids with velocities well above the common values in literature. If we use a more conventional way to identify Draconid orbits, a significant number of radiant points is left that fail to fit the similarity criteria, mainly because of the velocity.

If we use the 21P/Giacobini-Zinner orbit for the comet's 2018 return as a reference orbit, 817 orbits fulfill the low threshold similarity criteria. 121 of our 938 orbits fail, mainly because of too high velocities. We can compare both results for some of the orbital parameters. Looking at some parameters:

Eccentricity $e$: The mean orbit has $e = 0.7399 \pm 0.105$ (median value $e = 0.7102 \pm 0.105$) for the 938 orbits and $e = 0.7112 \pm 0.056$ (median value $e = 0.7033 \pm 0.056$) for the 817 orbits. The histogram of the different eccentricity values is identical for the common part. The only difference between *Figure 29* and *Figure 30* are the outliers with higher eccentricities which don't fit the similarity criteria for the 21P/Giacobini-Zinner orbit as reference. Gajdoš et al. (2020) found $e = 0.7026 \pm 0.0367$. Koten et al. (2020) has $e = 0.712$.

Inclination $i$: The mean orbit has $i = 32.37° \pm 2.14°$ (median value $i = 31.84° \pm 2.14°$) for the 938 orbits and $i = 31.85° \pm 1.38°$ ° (median value $i = 31.69° \pm 1.38°$) for the 817 orbits. The main part of the histograms in *Figure 31* and *Figure 32* is identical. Gajdoš et al. (2020) found $i = 31.55° \pm 0.77°$. Koten et al. (2020) has $i = 31.88°$.

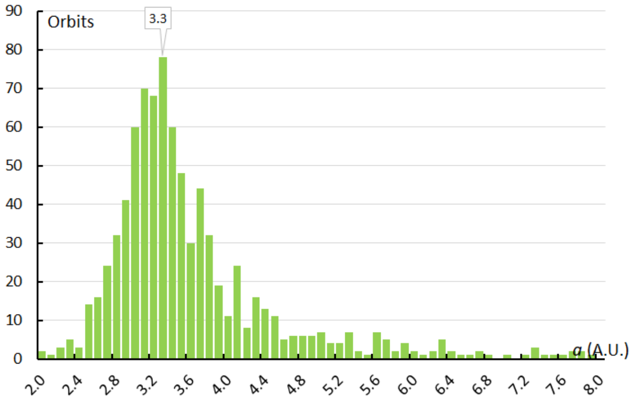


*Figure 33* – Histogram showing the semi major axis distribution for all 938 Draconid orbits identified by the groups, counted in 0.1 A.U. bins.

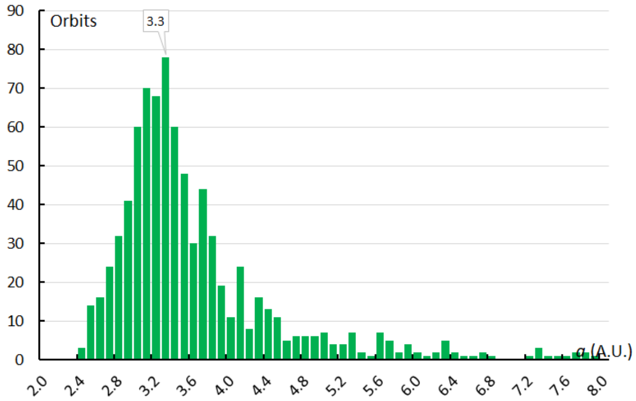


*Figure 34* – Histogram showing the semi major axis distribution for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit, counted in 0.1 A.U. bins.

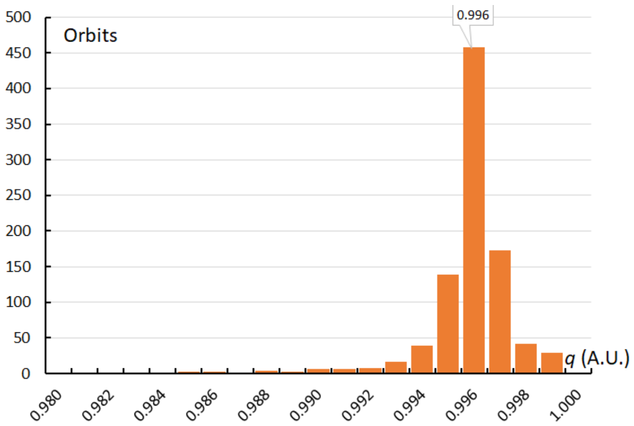


*Figure 35* – Histogram showing the perihelion distance distribution for all 938 Draconid orbits identified by the groups, counted in 0.001 A.U. bins.

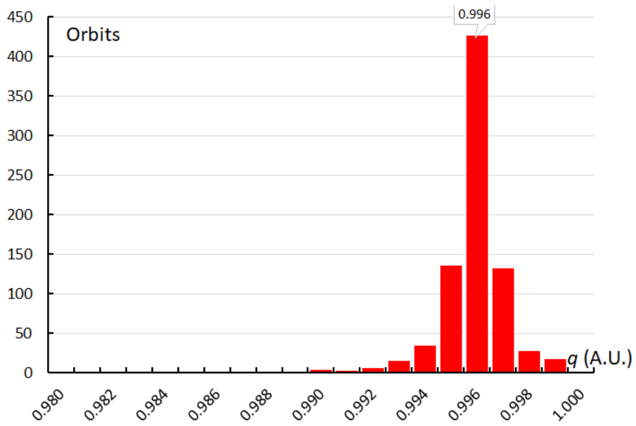


*Figure 36* – Histogram showing the perihelion distance distribution for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit, counted in 0.001 A.U. bins.

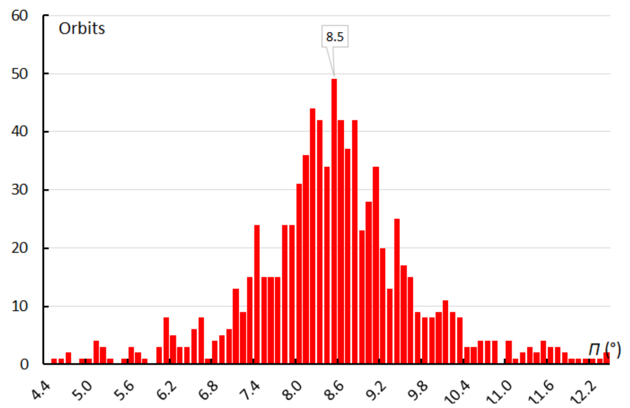


*Figure 37* – Histogram showing the length of perihelion distribution for all 938 Draconid orbits identified by the groups, counted in 0.1° bins.

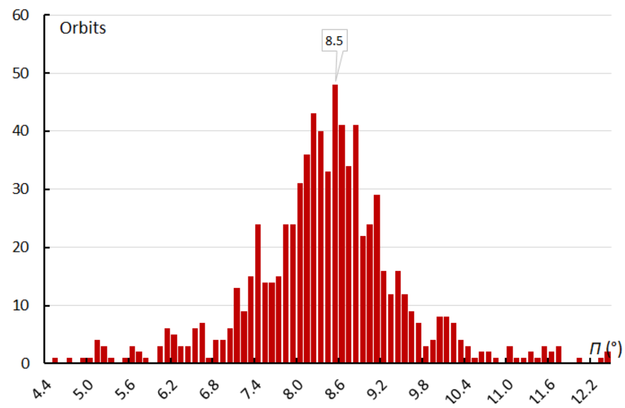


*Figure 38* – Histogram showing the length of perihelion distribution for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit, counted in 0.1° bins.

Semi major axis $a$: The mean orbit has $a = 3.82$ A.U. and the median value for all 938 orbits is $a = 3.44$ A.U. (*Figure 33*). For the 817 orbits identified with the 2018 orbit for 21P/Giacobini-Zinner, we find $a = 3.45$ A.U. for the mean orbit and the median value for these orbits is $a = 3.36$ A.U. (*Figure 34*). Gajdoš et al. (2020) found $a = 3.40 \pm 0.41$ A.U. Koten et al. (2020) has $a = 3.46$ A.U.

Perihelion distance $q$: The mean orbit has $q = 0.9937$ A.U. while the median value for all 938 orbits is $q = 0.9961 \pm 0.003$ A.U. (*Figure 35*). Looking at the 817 orbits identified with the 2018 orbit for 21P/Giacobini-Zinner, $q = 0.9951$ A.U. for the mean orbit and the median value for these orbits is $q = 0.9960 \pm 0.003$ A.U. (*Figure 36)*. Gajdoš et al. (2020) found $q = 0.9963 \pm 0.0007$ A.U. Koten et al. (2020) has $q = 0.9960$ A.U.

Length of perihelion $\Pi$: The mean orbit has $\Pi = 8.51° \pm 2.46°$ for the 938 orbits and a median value of $\Pi = 8.49° \pm 2.46°$. The mean orbit for the 817 orbits has $\Pi = 8.28° \pm 2.19°$, the median value is $\Pi = 8.41° \pm 2.19°$, Also, here, the main part of the histograms in *Figure 37* and *Figure 38* is identical. Gajdoš et al. (2020) found $\Pi = 8.75° \pm 0.85°$. Koten et al. (2020) has $\Pi = 8.41°$.

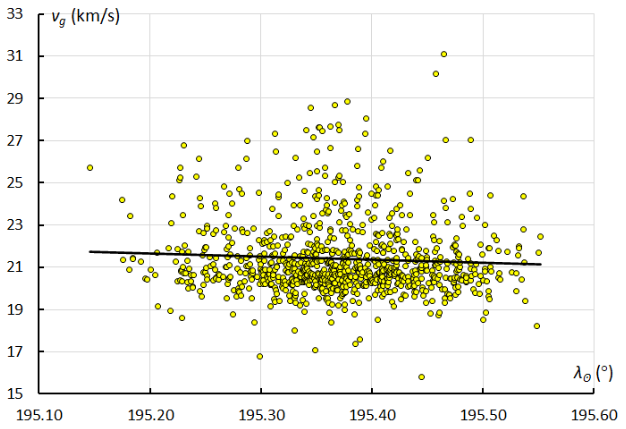

*Figure 39* – Distribution of the geocentric velocities for all 938 Draconid orbits identified by the groups. The black line is the linear regression fit.

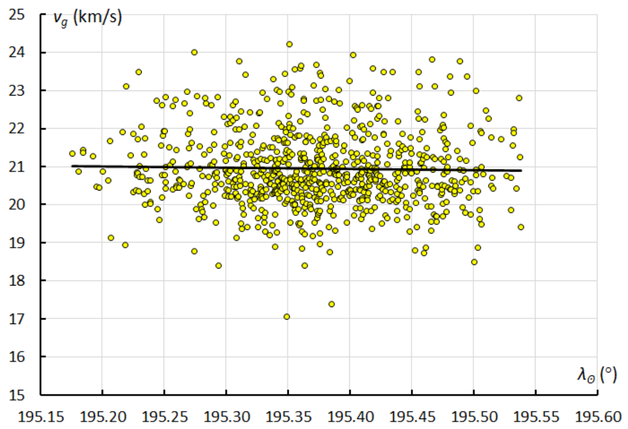

*Figure 40* – Distribution of the geocentric velocities for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit. The black line is the linear regression fit.

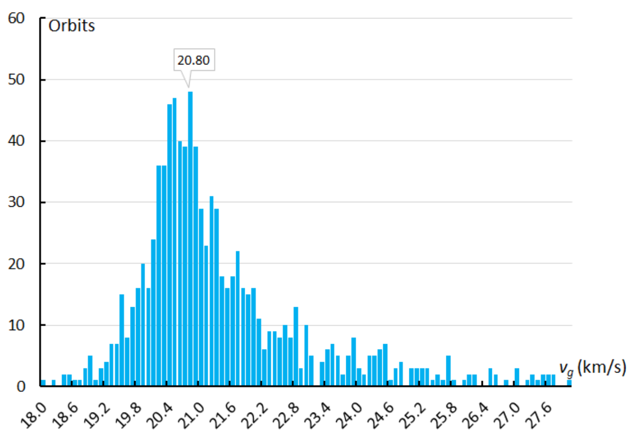

*Figure 41* – Histogram of the geocentric velocities for all 938 Draconid orbits identified by the groups (0.1 km/s bins).

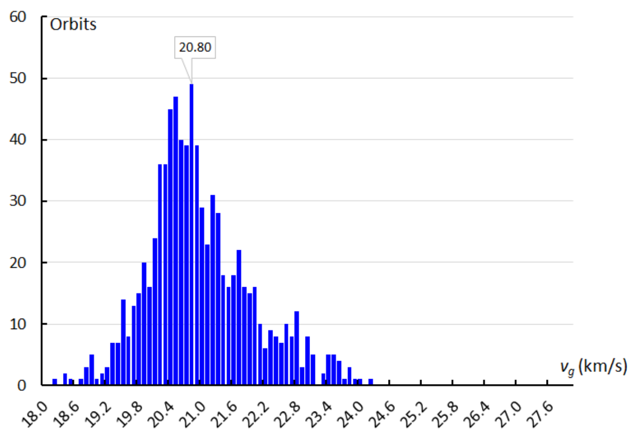

*Figure 42* – Histogram of the geocentric velocities for all 817 Draconid orbits identified by using the 2018 orbit of 21P/Giacobini-Zinner as reference orbit (0.1 km/s bins).

## 9 Geocentric velocities

The initial challenge of this analysis was to explain why we had so many, more than 100, multi-station events with a concentration at the Draconid radiant that failed to be confirmed as a Draconid meteor when using a classic single reference orbit to verify the similarity. Most researchers identify shower meteors using known radiant position, velocity and orbit from previous research, as did we in section 2. Our alternative approach was to search for concentrations of orbits without considering past established Draconid orbits. This has been done with an algorithm based on an iterative loop to locate narrow concentrations of orbits. The Draconid meteor shower is obviously a complex mixture of dust trails left by different perihelion passages of the parent comet. The different concentrations we found cannot be linked to any perihelion passage related dust trail. The groups of almost identical orbits defined by our iterative loop mainly split the Draconids up in bins with similar radiant-velocity combinations. Most remarkably, some concentrations are well above the literature values for the geocentric velocity known for the Draconids. The first most evident explanation is that some measurement artifact affected the velocities, however the error margins on the measured velocities by the CAMS software exclude that any systematic artifact could cause erroneous velocity measurements.

Not all multiple station events produce a favorable triangulation. Such cases are rejected on the basis of a rigid quality assessment. Unfortunately, the author had no access to the trajectory data. A separate investigation focused on the remarkable fast Draconids may shed some light on this phenomenon, looking at the trajectory lengths, duration measurements etc. In 2019 a number of CAMS operators reported so-called "Zebrids", meteor trails on which a number of frames were skipped during the detection. This artifact did not affect all cameras, only those working with a problematic configuration. For instance, when 20 fps occurred on a meteor trail while the system assumes 25 fps such 20% discrepancy can explain why the duration is underestimated and the velocity overestimated. A meteor with an actual velocity of 20 km/s ends up with an erroneous velocity of 25 km/s. According to the personal comments by the CAMS BeNeLux network coordinator, Carl Johannink, such cases are rejected and as far as the author knows, such cases did not occur during the Draconids.

Draconids are very slow meteors, slow meteors are not very sensitive to instrumental measurement errors. Assuming that the CAMS velocity derivation is reliable, there should be another explanation for the groups of similar Draconids with higher velocities than expected. The existence of one or more dust trails with faster particles could be an explanation. Other studies may have simply ignored these orbits if they had these too, assuming these weren't Draconids because of the speed. The velocity mainly determines the semi major axis *a*, the eccentricity *e* and to less extent the inclination *i.* For this reason, the orbits of these faster 'Draconids' with higher eccentricity and higher inclination will fail in the similarity criteria. If we simply assume that these 'too' fast Draconids must be ignored, we risk to bias the picture.

Comparing the geocentric velocity distribution in function of the solar longitude (*Figure 39*) and the histogram (*Figure 41*) for the 938 Draconids with the 817 Draconids identified with the 2018 orbit of 21P/Giacobini-Zinner as reference orbit (*Figures 40 and 42*), the only difference between both are the outliers. The median value for all 938 orbits is $v_g = 20.91 \pm 1.78$ km/s. Looking at the 817 orbits identified with the 2018 orbit for 21P/Giacobini-Zinner, the median value for these orbits is $v_g = 20.79 \pm 1.01$ km/s. Vida et al. (2020) found a mean geocentric velocity of 20.05 ± 0.93 km/s, Gajdoš et al. (2020) found 20.71 ± 0.66 km/s, Koten et al. (2020) found 20.96 km/s.

Both the histograms with the geocentric velocity and the histograms for the orbital elements aren't smooth profiles but show some sub-peaks that correspond with the median values for some of the different groups of Draconid orbits obtained in Section 5. This could be an indication for the presence of dust trails each with slightly different orbital elements.

## 10 Conclusion

Applying the method to detect orbit concentrations on the dataset with possible Draconid orbits of 2018 allowed to resolve five distinct groups of very similar Draconid orbits and three slightly more dispersed groups. The velocity range covered by these groups include orbits with geocentric velocities higher than the traditional values published in literature. The range in velocities is displayed in the radiant structure, in the plots of the inclination versus length of perihelion as well as in the histograms of the orbital elements. The activity profile based on the number of orbits counted within bins of 0.02° in solar longitude shows the main peak activity as well as some sub-maxima. None of these maxima can be related to any specific group of orbits. The different groups can be seen at slightly different positions within the radiant structure, as well as in the distributions of the geocentric velocities and the orbital elements. This could be an indication for the presence of different dust trails with slightly different velocity and orbits.

The method used to identify the Draconid meteors, using a range of mean orbits or using a single reference orbit, only influences the total number of Draconids but has no influence on the activity profile, radiant structure or any other aspect of the results.

## Acknowledgment

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# The interesting case of a slow meteor Aten's orbit type

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During the night of 2020 May 28, precisely beginning at $02^h03^m27^s$ UTC, Exoss project cameras registered the path of a very slow meteor, the object entered the atmosphere at an initial velocity of 15.06 km/sec, brightening at 84 km height and disappearing approximately at 49 km height. Its average low height track totally disagreed with an Earth grazing type and even a space junk reentry was disregarded. After further analysis we concluded that the meteor orbit was similar to a NEO Aten's class with a perihelion distance $q$ = 0.579 A.U. and semi-major axis $a$ = 0.796 A.U. Despite no close encounters were found to Mercury, Venus and the Earth-Moon barycenter after orbital integration for 10 years backwards in time, we suggest, besides planetary gravitational influences, that the Yarkovsky effect dynamically acting upon the meteoroid could have contributed to transform an originally Atira's type orbit into an Aten's type orbit, supposing a meteoroid with an initial estimated mass of 0.2 – 0.3 kilograms.

## 1 Introduction

The Exoss project has as a main goal to survey and to monitor regularly the night sky for the registration of meteors and bolides (De Cicco et al., 2018), producing data for scientific studies. In 2020, May $28^{th}$ at $02^h03^m27.5^s$ UTC Exoss stations SJU1, SJU2 and ROC1 located in the Northern part of Rio de Janeiro state registered a bright and very slow meteor, that initially was thought to be an Earth grazing meteoroid or even a piece of space junk. However, further analysis demonstrated that it was a very peculiar meteor, its trajectory duration was about 13 seconds, with a 174 km long path in the atmosphere, the low height and its path indicated it was a meteor. No space junk reentry over the area had been forecasted[11].

The event is analyzed in this paper, the trajectory and orbit are calculated in addition to mass and size estimate. Its peculiar material strength as no notable flare was detected, and its orbital elements show a reasonable possibility to be from a NEO parental origin, as Aten's or even from Atira's type orbit family.

## 2 Meteor trajectory

The calculations to obtain key parameters concerning velocity, atmospheric trajectory and orbital elements of the meteoroid were possible thanks to 3 Exoss station detections, using analog videos, two cameras with a 1/3" and one with a 1/2" sensor, respectively, black and white system mode, suited for meteor video monitoring. The astrometry data were reduced by CAMS software, the trajectory and orbit were evaluated using the orbit tool (Jenniskens et al., 2016), applying high quality processing and exponential velocity parameters which are considered more suitable for deceleration values, during the objects transit through the atmosphere, as modeled by the following equation:

$$X(t) = |\underline{V_b}|\, t - |a_1|\, exp(|a_2|\, t),$$

where $X(t)$ is the position, $V_b$ is the constant velocity, $a_1$ and $a_2$ are parameters (Gural, 2012).

### 2.1 Observations from Rio de Janeiro state


*Figure 1* – The long path trajectory registered by station SJU2, the image has been converted to CAMS standards.

Marcelo Mozer operates the SJU1 and SJU2 cameras. Both have a 1/3" sensor and a Fujinon F0.95 lens, adapted to

[11] https://www.satview.org/

meteor video registration, SJU1 facing SO direction with a fov of 48.9° × 64.3°and resolution of 5.9'/pixel, and SJU2 facing NE with a fov of 45.7° × 61.3° and resolution of 5.1'/pixel, both from the same place at São João de Uba city. Carlos Henrique operates the ROC1 camera remotely. This camera is a Watec 902 Ultimate, the lens a Computar 1:0.8, facing SE with a fov 67.2° × 89.2° and a resolution of 7.8'/pixel, located at Campos dos Goytacazes city. The stations SJU1 and SJU2 are at a low light pollution zone suitable for video meteor detections, despite ROC1 being located in a medium city.

The stations SJU1 and SJU2 are adapted to UFO suite detection mode, while the station ROC1 has been operating CAMS software since 2020, which is part of a collaboration between our project Exoss and CAMS-SETI/NASA. These stations constitute a node for triangulation, called ES - node (Espirito Santo node). All cameras are always running. So, those stations at the night of 2020, May 27th, local time, detected a very slow meteor, with SJU2 registering the most part of its path, just like ROC1, while SJU1 had been detecting only the initial part.

The three stations baseline, SJU1, SJU2 and ROC1 has a linear distance of 83.1 km forming a nice triangulation, as that distance ensures a good set of intersections to be evaluated using CAMS allowing trajectory and orbits to be done using reasonable quality calculations, whereas a good number of stars for calibration is possible.

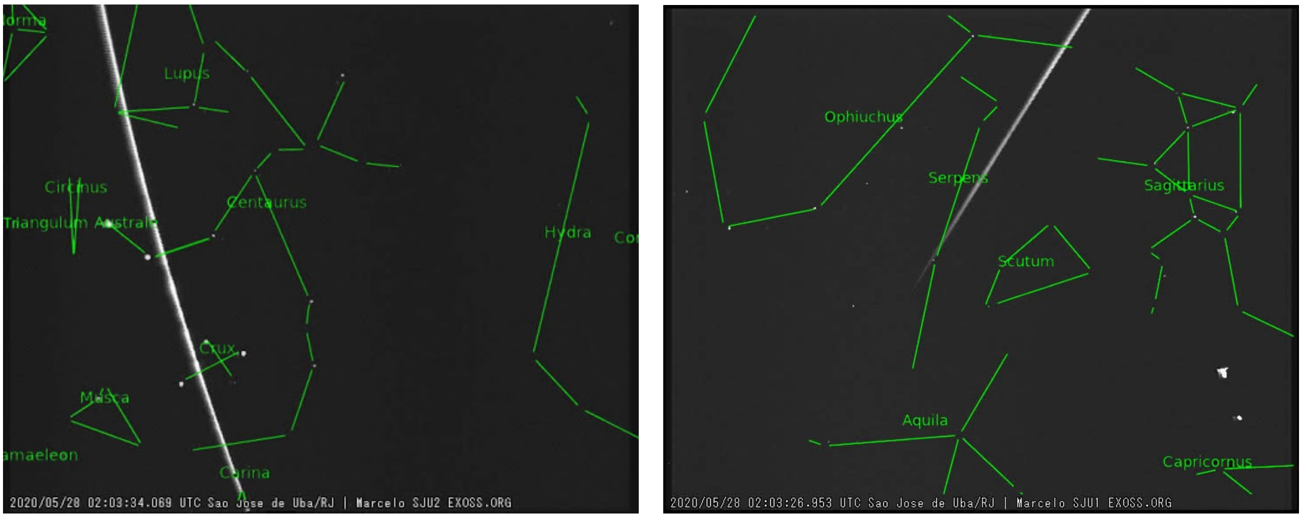


*Figure 2* – Constellation maps upon stacked images, detected and plotted using astrometry.net. Left: The SJU2 station image shows the meteor crossing by Rigil Centaurus and Hadar stars. Right: The initial luminous path begins inside the Serpens constellation, as seen by the SJU1 station fov. (Author: Marcelo Mozer).

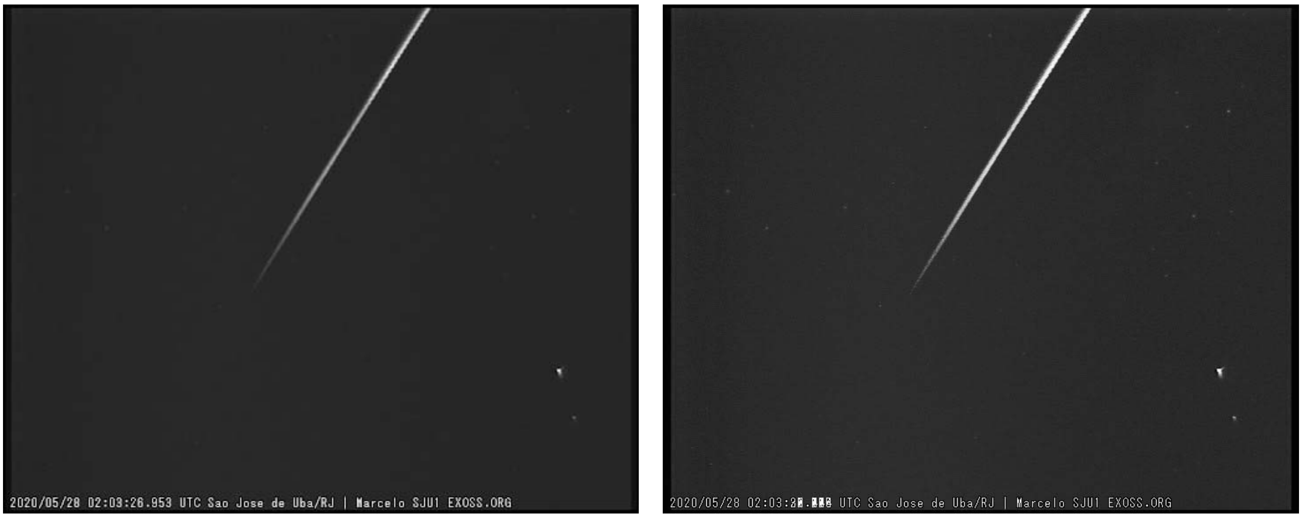


*Figure 3* – Camera Exoss SJU1. Left: UFO stacked image. Right: The same image converted to CAMS. (Author Marcelo Mozer).

## 3 Data reduction

The first part of the analysis was dedicated to the reduction of images and star calibration. Two cameras using UFO (SJU1, SJU2) and one camera running CAMS (ROC1) software. So, we decided to unify the data, under the same standards, previously converting SJU avi type videos to cams bin file type, allowing data to be calibrated under the same CAMS applications, star calibrations, trajectory and orbit analyses. *Figures 2 and 3* are presented as stacked images of the meteor captured by ROC1 and SJU1 and 2.

Applying the highest quality trajectory and orbital evaluation, it was possible to get a final result, so the authors analyzed all data using CAMS software tools, further details relating to CAMS can be found on the website[12].


*Figure 4* – Image of the ROC1 station, CAMS id 1220. It is easy to notice the beginning of the path of the meteor, still image mode from CAMS software. (Author Carlos Henrique).

## 4 Results

Related to the initial trajectory, the meteor had an initial velocity of 15.06 km/sec, and an entry altitude of 84.3 km, estimated at 21.0143° S and 41.2714° W, near Mimoso do Sul – ES , at a shallow angle of 20° to the horizon and exiting at 22.0441° S 42.4349° W, near Duas Barras – RJ, by the time the altitude dropped to 49.25 km, and the full atmosphere path length extended over 174 km, corresponding to an observed ground track of 155 km. The trajectory parameters are shown in *Table 1*.

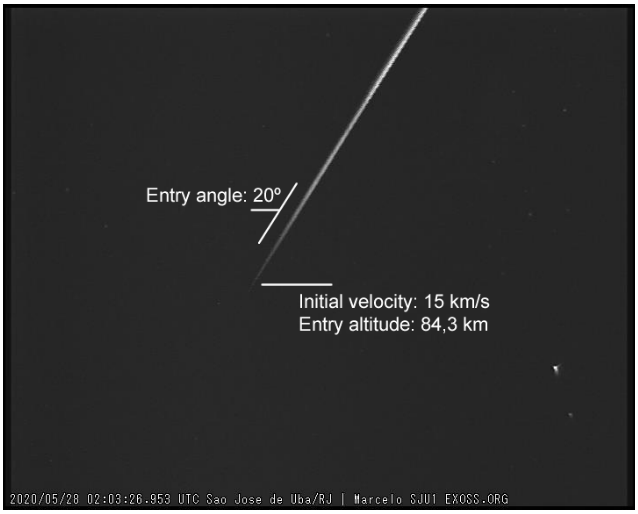


*Figure 5* – Image taken from Exoss camera SJU1, showing the begin part of the trajectory.

The complete videos processing by CAMS in order to estimate the geocentric velocities, beginning and end heights, the radiants, the size and the initial mass, as well as the orbital elements, enabled the authors to analyze the trajectory dynamics. The event had a total duration of about 13 seconds, reaching a maximum visual magnitude of −2.1. No radiant association could be found, using the CAMS shower-look-up-table listed in the paper by Jenniskens et al. (2018), considering a maximum radiant distance radius of 5.0° and a maximum velocity difference of 10.0% (Vida et al., 2018). In the *Table 2* the observed and geocentric coordinates of the radiant parameters are shown.

The time spent during on its ablation path shows an unusual material resistance for a cometary type origin, besides no significant flare or very bright peak was noted. This made the authors believe that a gradual and fairly stable fragmentation was probably maintained during all the flight. This may point in the direction of a denser material like a stony, stony-iron or iron material.

*Table 1* – Atmospheric trajectory parameters for the meteor of 2020 May 28, 02$^h$03$^m$27.5$^s$ UTC.

| | Parameter | σ |
|---|---|---|
| Infinity Velocity observed (km/sec) | 15.06 | 0.07 |
| Beginning height (km) | 84.37 | 0.40 |
| End height (km) | 49.25 | 1.23 |
| Zenithal angle (°) | 79.20 | n.a. |
| Max-$m_v$ magnitude | –2.10 | n.a. |
| Int-$M_v$ magnitude | –6.20 | n.a. |

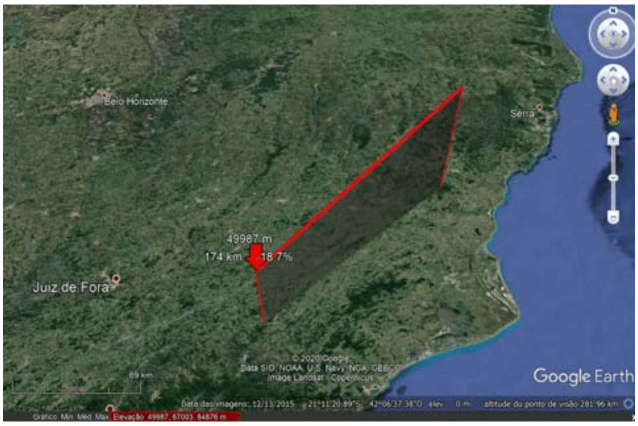


*Figure 6* – Ground track based on the CAMS analysis of Exoss stations data. The red arrow shows altitude and path, both in meters. The entry point on 2020 May 28 at 02$^h$03$^m$27.5$^s$ UTC.

*Table 2* – Radiant data (J2000.0).

| Sporadic | Observed | Geocentric |
|---|---|---|
| R.A. (°) | 293.72 ± 0.42 | 313.248 ± 0.904 |
| Decl. (°) | +33.54 ± 0.25 | +42.405 ± 1.151 |
| Vel. (km/sec) | 15.06 ± 0.07 | 10.175 ± 0.101 |

### 4.1 Meteoroid mass and size

The absolute magnitude at each stage in the trajectory was calculated using the formula:

$$m_{abs} = m_{obs} - 2.512 \cdot \log(L_{inc})$$

where $m_{abs}$ is the magnitude at a distance of 100 km from

[12] http://cams.seti.org/

the station, $m_{obs}$ is the observed magnitude and $L_{inc}$ is the increase in luminosity given by the formula:

$$L_{inc} = \left(\frac{d}{100}\right)^2$$

where $d$ is the distance (in km) between the observer and the meteoroid. In order to estimate the mass, we are able to apply Jacchia's formula (Jacchia et al., 1967) for the maximum absolute magnitude:

$$m_v = 55.34 - 2.25 \cdot log(M) - 8.75 \cdot log(v_g) - 1.5 \cdot log(\cos\ z)$$

where $m_v$ is the maximum absolute magnitude, $M$ is the original meteoroid mass, $v_g$ is the geocentric velocity and $z$ is the zenith angle.

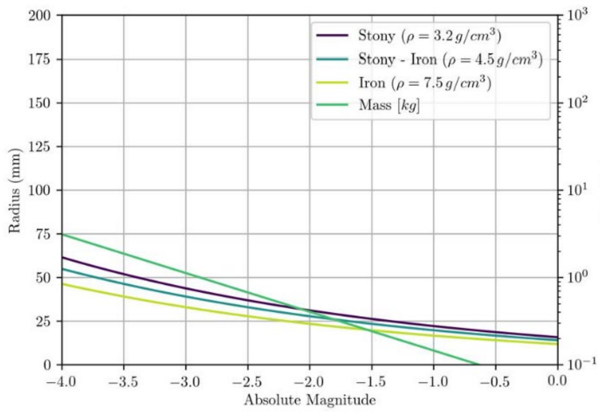


*Figure 7* – Assuming an asteroidal origin, the typical meteoroid densities for iron, stony-iron and stony are 3.2, 4.5 and 7.5 g/cm$^3$, respectively. The plot of the radius and mass is derived from Jacchia's formula, with respect to $v_g$ and $z$ values.

At *Figure 7* a plot of radius and mass against absolute magnitude for $v_g = 10.175$ km/s and $z = 79.2°$ is demonstrated (Stewart and Pratt, 2013). So, assuming a maximum absolute magnitude of −2.10, the geocentric velocity and zenithal angle can be used in order to estimate the mass and size.

As already cited in the *Section 4*, our perspectives pointed towards a denser material, so the authors estimate its original mass in the order of 0.2 to 0.3 kg, with approximately a radius of 30 mm, if a stony material is considered, also taking in account its probable parental family type, an Aten's or less likely Atira class.

### 4.2 Orbital parameters

After the image and data reduction, a good fit for the meteoroid orbit estimation was possible, and according to the results, the orbit indicated to be an Atena type object, with a semi- major axis $a$ of 0.796 A.U., perihelion distance $q$ of about 0.578 A.U. and an aphelion $Q$ of 1.014 A.U. *Figure 8 and 9* show a perspective and 3-D view of the final orbit (Vida et al., 2019). Its perihelion passage was estimated at 2020–01–22 05$^h$44$^m$05$^s$ UTC. In *Table 3* we show the orbital parameters.

Despite the orbital features are pointing at an Aten type orbit, we run an integration of the orbit 10 years back in time, using the IAS15 integrator (Rein and Liu, 2012) in order to obtain the close encounters with the planets Mercury, Venus and the Earth-Moon barycenter prior to its final encounter, in fact the meteor crossed the orbit of Venus and the minimum distance obtained was 0.034 A.U. at 2011–10–24, but beyond the SOI (Sphere of Influence) of this planet, as the minimum distance for the influence by Venus is less than 0.004 A.U. *Table 4* shows the SOI distance from each interior planet. As can be seen for the last 10 years the closest approach (Venus) was beyond the gravitational planetary influence.

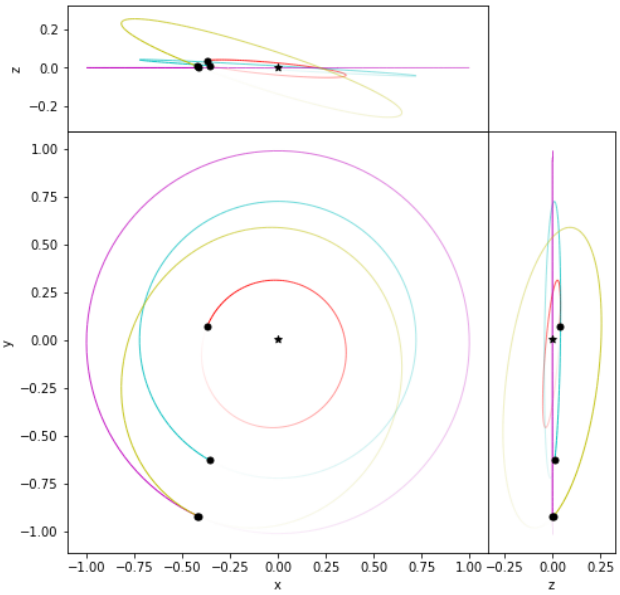

*Figure 8* – The orbital diagrams at 2020–05–28 UTC, these show the view perspectives of the osculated orbits from the interior planets and the meteor path. Top: lateral view, Ecliptic's North Pole is up. Left: front view, the red circle is Mercury orbit, the blue circle representing Venus path and purple one is the Earth orbit. The meteor trajectory, filled by the light green line, cross the Venus orbit. Right: a lateral view, Ecliptic's North Pole is to the right.

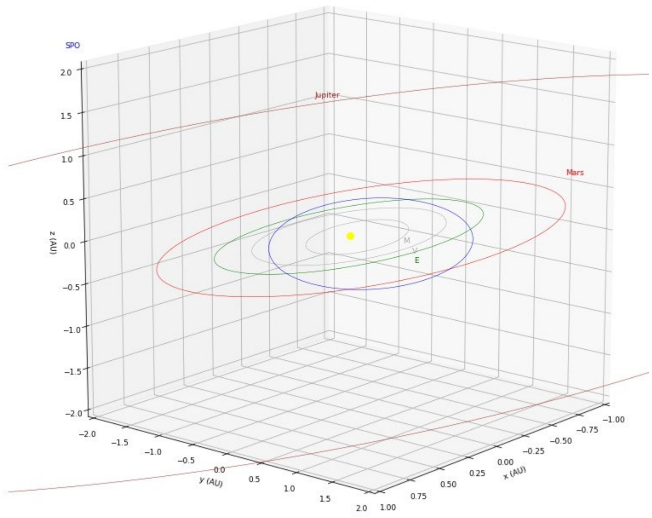


*Figure 9* – 3-D view of the meteoroid final orbit.

*Table 3* – Orbital elements (J2000.0). Observed date: 2020–05–28 $02^h03^m26.5^s$ UTC.

| | Orbital element | $\sigma$ |
|---|---|---|
| $P$ (years) | 0.710 | |
| $v_h$ (km/s) | 25.223 | 0.143 |
| $q$ (A.U.) | 0.57851 | 0.01017 |
| $Q$ (A.U.) | 1.01349 | 0.01017 |
| $a$ (A.U.) | 0.796 | |
| $e$ | 0.2733 | 0.0081 |
| $i$ (°) | 19.629 | 0.23 |
| $\Omega$ (°) | 66.9949 | 0.0004 |
| $\omega$ (°) | 1.136 | 1.167 |

### 4.3 An analyses of meteoroid orbit classification

NEOS can be classified considering its $a$, $q$ and $Q$ orbital parameters, so the 5 classes can be distributed as follows:

- *Amors* – orbits do not cross the Earth path, and $1.017 < q < 1.3$ A.U. and $a > 1.017$ A.U., they belong between Mars and Earth.
- *Apollo* – these cross the Earth orbit, $a > 1.0$ A.U. and $q < 1.017$ A.U., their orbits are larger than our planet's orbit.
- *Atens* – these cross the Earth orbit, $a < 1.0$ A.U., $Q > 0.983$ A.U. They remain during their lifetime.
- *Atira* or *Apohele* – they have orbits completely inside the Earth orbit, $Q < 0.983$ A.U. their aphelion is less than the Earth perihelion ($q = 0.983$ A.U.). This class Atira was considered for theoretical purposes until the asteroid 163693 Atira was discovered on 2003 February 11 and confirmed as an Apohele type.

So, our calculations showed a low score possibility for a close encounter perturbation, in a short period of 10 years but even other non-gravitational forces could be in action, such as the Yarkovsky effect (Brož et al., 2005), if this is taking into account on the mass calculation errors and size estimations, then its dimensions could be larger, greater than 10 cm. In that case, a hypothetic effect with a counter-clockwise spin (right-hand) on a prograde orbit could be in play. Then the irradiation dissipation of momentum could increase its semi-major axis, going from an Atira type orbit to an Aten's one.

*Table 4* – Planetary sphere of Influence (*LD is Lunar Distance).

| Planet | Distance (LD)* | Distance A.U. |
|---|---|---|
| Mercury | 0.76 | 0.00075 |
| Venus | 2.21 | 0.00400 |
| Earth-Moon Barycenter | 2.41 | 0.00620 |

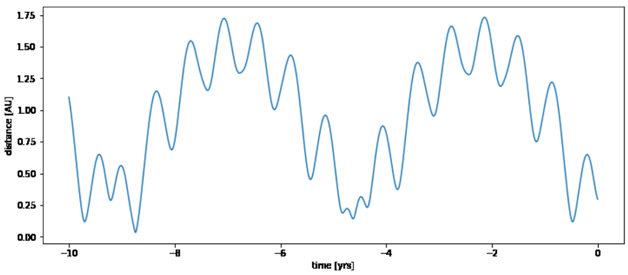


*Figure 10* – Close encounters with Venus, the minimum distance was approximately 0.034 A.U., 9 years before the meteoroid hit Earth atmosphere.

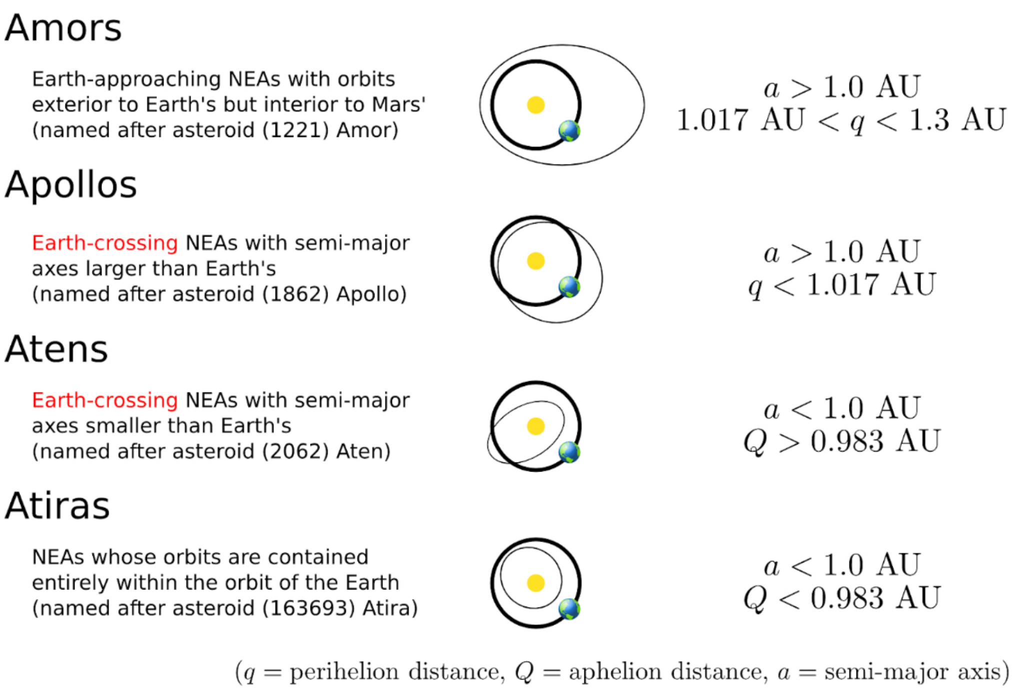


*Figure 11* – Diagram from the Center for Near Earth Object Studies[13].

[13] https://cneos.jpl.nasa.gov/about/neo_groups.html

## 5 Conclusions

The meteoroid 2020-05-28 $02^h03^m27^s$ UTC was registered by three stations, under good weather conditions, with a satisfactory baseline distance, a number of reference stars of more than 20 for ROC1 and SJU2, although for SJU1 only 13 stars. First guess indicated a reentry of space junk, but after examining each data station in detail, we concluded that the meteor had a slow velocity and an orbit classified as an Aten's type.

Even though an Aten's type object and after applying integrations back in time for a 10 years period, supposing close encounters with the Earth-Moon barycenter, Venus and Mercury (however only closest encounter was found around 0.034 U.A. distance from Venus at 2011–10–24, it stayed away from the planet's sphere of influence), the authors propose an Atira type orbit as a possibility. If taking in account the non-gravitational forces such as the Yarkovsky effect, and a detailed analysis for planetary close encounters, for a longer period backwards in time, there is room for a further investigation relating the meteoroid to an Atira type orbit.

## Acknowledgments

The authors wish to thank to Exoss team.

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# Perseids 2020: again, enhanced Perseid activity around solar longitude 141?

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In 2018 and 2019, a peak in Perseid activity was observed around solar longitude 141.0°, about ~30 hours after the traditional Perseid maximum. In 2018 this was only observed visually, in 2019 almost only with radio observations. Only the onset to the peak in 2019 has been observed visually in Europe. With two consecutive years of extra Perseid activity around sun longitude 141.0°, 2020 was eagerly anticipated.

## 1 Introduction

In August 2018, a number of DMS observers were located in the south of France in the town of Aubenas Les Alps. The aim was to observe the Perseids (Vandeputte, 2018). During the night of 13–14 August, the group noticed that there was a lot of Perseid activity, more than what you would normally expect around that time. Other European observers also reported this. An analysis of the author showed that there had been a nice peak in activity with a maximum ZHR of 85, more than 24 hours after the annual traditional maximum (Miskotte, 2019), just before $\lambda_{\odot} = 141°$. The observations also showed that the population index *r* barely changed that night. From old data from 1986, 1994, 2002 and 2010, (weaker) peaks in activity were also found around solar longitude 141°.

In 2019, Michel Vandeputte, among others, was able to observe during the night of 13–14 August. He was not disappointed, especially at dawn there was an impressive increase in bright Perseids (Vandeputte, 2020; Miskotte and Vandeputte, 2019). Radio observer Felix Verbelen also noticed that the Perseids (especially the long-lasting reflections) were active well above normal level. Finally, it was also found that Hirofumi Sugimoto's radio analysis of the Perseids[14] showed a nice peak in activity, which occurred shortly after solar longitude 141°.

Unfortunately, an analysis by the author showed that, besides Michel's observation (perhaps the first increase to the peak), hardly any other observations were available (Miskotte, 2019b). The data for 2020 was eagerly awaited. Would something happen again around solar longitude 141°?

## 2 The situation in 2020

On August 13, 2020 around noon, the Belgian radio observer Felix Verbelen posted the following message on the VVS mailing list: "*A bit against expectations, the maximum of the Perseids (so far) only came this morning, with numerous reflections, of which a number of fireballs. Attached are a few SpecLab images on 49.99 MHz here in Kampenhout, as well as a graph showing the development of the number of reflections longer than 10 seconds since the beginning of the month. The counts continued until $08^h00^m$ UT this morning (more later)*".

Immediately after this the author took a look at the graph of the Perseids on the website of Hirofumi Sugimoto[15]: indeed, another distinct peak!

It should be noted, however, that the peak of 2020 was 6 hours earlier than in 2019!

## 3 Analysis of the available data

The author searched on the IMO site for data during a period on 13 August 2020 around $09^h00^m$ UT. Only an observation of Michael Linnolt was found in that period. He observed from the Volcano National Park in Hawaii. Only 4 Perseids (magnitudes +1, +2, +4 and +5) are seen. That doesn't look spectacular, but if we look at the radiant height, it makes sense: it was only 4 degrees high. So, unfortunately, this observation cannot be used because the author only uses data with radiant elevations of 25 degrees or higher.

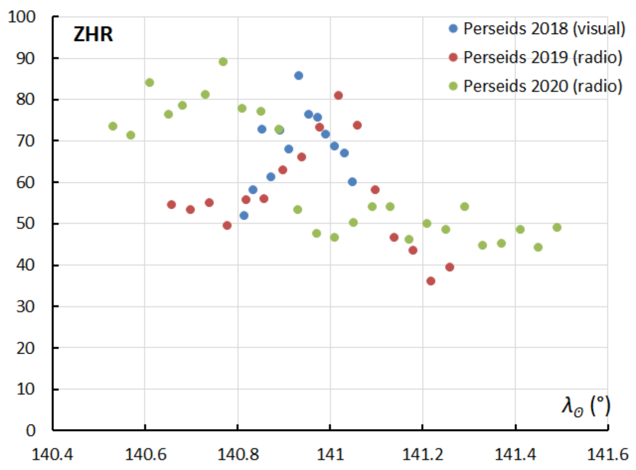


*Figure 1* – Activity profiles of the Perseids for 2018, 2019 and 2020 around solar longitude 141°.

Via Hirofumi Sugimoto I got the data used to create the graph on his website. *Figure 1* shows the result of three graphs from 2018 (based on visual observations), 2019

[14] http://www5f.biglobe.ne.jp/~hro/Flash/2019/PER/index.html

[15] http://www5f.biglobe.ne.jp/~hro/Flash/2020/PER/index.html

(based on radio observations) and 2020 (based on radio observations). The following can be concluded from *Figure 1*:

- Compared to the peak of 2018, the 2019 peak was 2 hours later.
- Compared to the peak of 2018, the 2020 peak was just 4 hours earlier.
- If this is a new structure in the Perseid meteor shower then the maximum time seems to be swabbing between solar longitude 140.75° and 141.10°.
- The eruption in 2020 appears to be slightly stronger than that of 2019. How this is calculated by Hirofumi Sugimoto is described in Sugimoto (2017).
- The activity before the 2020 peak is higher than the other peaks, this makes perfect sense as this peak is closer to the traditional maximum.

The peaks of 2019 and 2020 were accompanied by many bright meteors. The radio observations of Felix Verbelen from 2019 and 2020 regarding the long-term reflections clearly show this. The run-up to the peak in 2019 was visually observed by Michel Vandeputte, among others there was an increase in bright Perseids.

But also in 2020, a group of observers seems to have seen something spectacular. Via Facebook, the author came across the following message from Paul Jones, a meteor observer who has been active for more than 40 years. He wrote: "*WOW!!!! We had a very good Perseid display for an hour and a half for the ages this morning (8/13/20) from the Fairgrounds despite the clouds!! We had at least SIX Perseid fireballs and over twenty in all brighter than zero magnitude! We were speechless!! They were doing about 70 per hour as dawn broke, stunning bright and colorful ones popping in every direction, we were blown away!! It was slow going up until about 3:30 a.m., when the bottom fell out as only the Perseids can do! We had one –6, two –5, and three –4 Perseid fireballs this morning, plus at least 20 others in negative magnitudes! The –6 Perseid was a bolide that split the Great Square of Pegasus in half and left a smoke train that hung on the sky for almost three minutes!! We were going bonkers! One of the best displays I've seen in my 45 years of meteor watching!! Several ACAC and NEFAS members joined us and a few guests as well for an experience we will long remember...;o)..*"

Paul gave some additional information via email: "*I'll do my best, the weather was a major problem for us and very cloudy for most of the Aug. 12/13 morning here in NE Florida. We only had 'sucker holes" most of the time. Sometimes up to 80% of the sky was overcast and 3/4 moon interference, so I was not able to get really good solid Perseid counts of any kind. It finally cleared off for most of the sky about 5:00 a.m. local time (9 UT) on 12/13. The Perseid rate started picking up quite a bit about 4:00 a.m. local time (8 UT) on 12/13 morning and most of the bright Perseids we saw were between 4:00 a.m. and 5:30 a.m. local time (EDT). We could not observe at all on Aug. 11/12 morning as the sky was overcast all night long.... We went back out on 13/14 morning, but the activity had waned quite a bit from the morning before, once again clouds were covering large parts of the sky during our 13/14 session as well*".

Paul Jones's email shows that it was fairly clear on August 13, 2020 between 08$^h$00$^m$ and 09$^h$30$^m$ UT. Most of the bright meteors fell during that period. It is a pity that he was unable to provide good data due to the highly variable circumstances. In *Figure 2* the radio ZHR curve of Hirofumi Sugimoto's Perseids 2020 is marked with two red stripes. This is the time window mentioned above in which Paul Jones's group saw the beautiful Perseid display. So, they were exactly observing during the peak of Perseid activity!

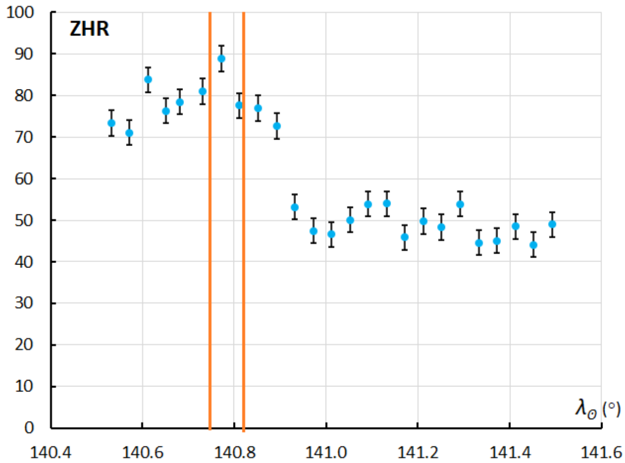


*Figure 2* – Hirofumi Sugimoto's Perseid radio ZHR curve between solar longitude 140.4° and 141.6°. Based on data from RMOB.

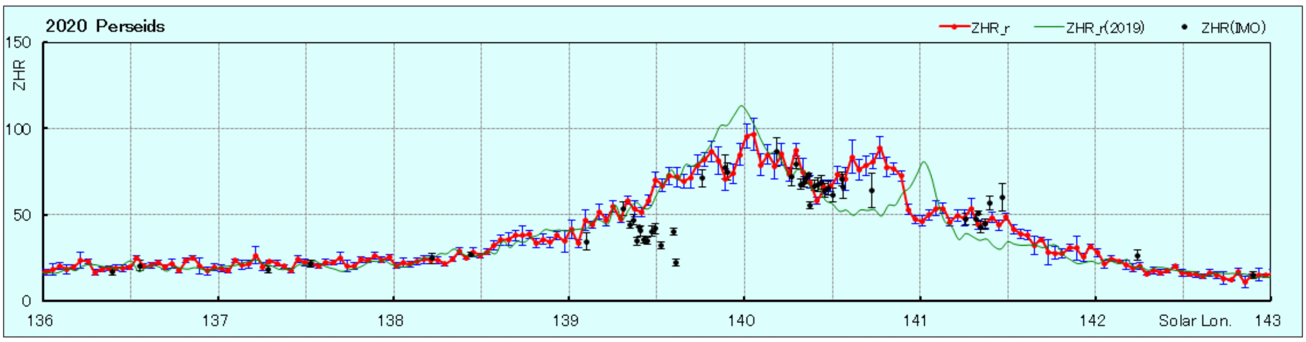


*Figure 3* – Perseid ZHR curve based on radio observations (RMOB). The green line is last year's Perseids graph.

*Table 1* – Overview of the three peaks found from 2018–2020 and the possible times when they occur at the same solar longitudes in the period 2021–2024.

| Year | $\lambda_\odot$ | $\lambda_\odot$ | $\lambda_\odot$ | Moon |
|---|---|---|---|---|
| 2018 | | 140.935° | | |
| 2019 | | | 141.020° | |
| 2020 | 140.772° | | | |
| | Date & time | Date & time | Date & time | |
| 2021 | 13-8-2021 14$^h$36$^m$ UT | 13-8-2021 18$^h$40$^m$ UT | 13-8-2021 20$^h$48$^m$ UT | + 45% |
| 2022 | 13-8-2022 20$^h$48$^m$ UT | 14-8-2022 00$^h$45$^m$ UT | 14-8-2022 02$^h$53$^m$ UT | –95% |
| 2023 | 14-8-2023 02$^h$53$^m$ UT | 14-8-2023 06$^h$57$^m$ UT | 14-8-2023 09$^h$05$^m$ UT | –20% |
| 2024 | 13-8-2024 09$^h$03$^m$ UT | 13-8-2024 13$^h$08$^m$ UT | 13-8-2024 15$^h$15$^m$ UT | + 60% |

## 4 Discussion and questions

As a result of all this, there are a number of questions:

- Is this “new” structure caused by the same phenomenon over and over again? There is quite a difference in time between 2019 and 2020. The latter fell almost six hours earlier than in 2019 and is therefore somewhat closer to the traditional maximum. The 2018 visual curve is in between.
- In 2019 and 2020 there is clearly a beautiful display with many bright meteors. This is somewhat supported by visual observations. In 2018, the *r* value remained virtually unchanged during the new peak with normal values of around 2.0.
- Will this structure remain active? *Table 1* provides an overview of the past three years and at what time any peaks in 2021–2024 will occur. In soft yellow, the preferred times for Europe if the observed peaks occur at the same solar length.

The motto here is clear: observe, observe and observe again!

## Acknowledgment

Many thanks to Carl Johannink and Michel Vandeputte for reading this article critically. Also, a word of thanks to Hirofumi Sigumoto for providing the radio data and Paul Jones for providing extra information regarding the observations of 2020.

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# July 2020 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of July 2020 is presented. July 2020 allowed to obtain meteor orbits during 28 nights resulting in 12834 multiple station meteors, with a total number for July 2020 of 3823 orbits. A maximum of 90 cameras was operational at 24 camera stations during this month.

## 1 Introduction

Although a summer month, the weather in July is often unfavorable for astronomy in the BeNeLux area. The short nights with only about 6 hours of observing time are easily ruined by bad weather. The overall meteor activity increases significantly during this month with some well-established showers late July while Perseid activity becomes clearly visible. So far, July 2018 and 2019 were both excellent months of July for our CAMS network, would July 2020 become another successful month of July?

## 2 July 2020 statistics

CAMS BeNeLux collected 12834 multi-station meteors, good for 3823 orbits (against 13243 multi-station meteors and 4139 orbits in July 2019). This is a nice result although slightly less than previous two years.

While July 2018 and 2019 had more than half of all July nights with almost completely clear nights for the network, July 2020 had about half of its nights with unfavorable weather. Three nights ended without any single orbit, 14 nights had more than 100 orbits (17 in 2019), 6 nights had more than 200 orbits (9 in 2019). July 30–31 was the most successful night with 542 orbits, an absolute record for a July night. Last year, July 29–30 was the record night with 504 orbits for July 2019, thanks to the delta Aquariids South shower maximum. The statistics of July 2020 are compared in *Figure 1* and *Table 1* with the same month in previous years since the start of CAMS BeNeLux in 2012. In 9 years, 219 July nights allowed to obtain orbits with a grand total of 18463 orbits collected during this month in all these years.

No new cameras were added to the network and relatively few technical problems interfered, which helped to have good coverage of the atmosphere. The BeNeLux CAMS network had its last major expansion in the summer of 2017 and since then every now and then some new cameras were added. The biggest progress came with AutoCams which allowed almost all CAMS camera stations to function all nights. This way the coverage of the atmosphere is also guaranteed during nights with variable weather. The northern part of the network still has less good coverage because of a lack of stations using AutoCams.

July 2020 had 90 cameras operational at best, 4 more than in July 2019, while the minimum number of operational cameras dropped back to the July 2018 level with 59 cameras but still, the average with 79.1 remained higher than all previous months of July.

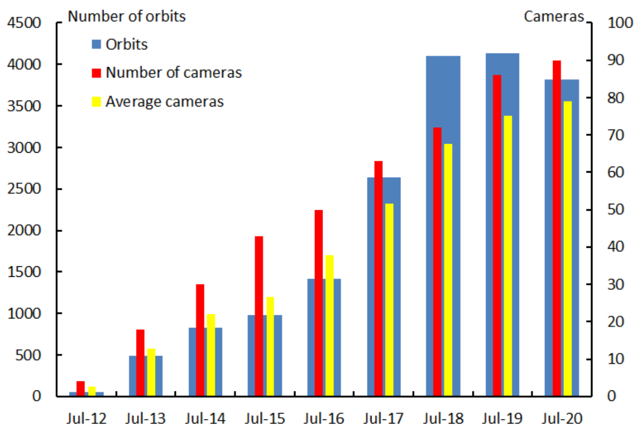


*Figure 1* – Comparing July 2020 to previous months of July in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras capturing in a single night and the yellow bar the average number of cameras capturing per night.

*Table 1* – July 2020 compared to previous months of July.

| Year | Nights | Orbits | Stations | Max. Cams | Min. Cams | Mean Cams |
|---|---|---|---|---|---|---|
| 2012 | 7 | 49 | 4 | 4 | - | 2.6 |
| 2013 | 22 | 484 | 10 | 18 | - | 12.9 |
| 2014 | 19 | 830 | 14 | 30 | - | 22.0 |
| 2015 | 28 | 976 | 15 | 43 | - | 26.7 |
| 2016 | 28 | 1420 | 18 | 50 | 10 | 37.9 |
| 2017 | 27 | 2644 | 20 | 63 | 30 | 51.6 |
| 2018 | 30 | 4098 | 19 | 72 | 59 | 67.7 |
| 2019 | 30 | 4139 | 21 | 86 | 63 | 75.2 |
| 2020 | 28 | 3823 | 24 | 90 | 59 | 79.1 |
| Total | 219 | 18463 | | | | |

*Table 2* lists the 20 best performing cameras in the network in terms of orbits. Note the scores of the RMS cameras. Although the scores are good in terms of orbits and the quality of the orbits proves to be very good, still some RMS cameras suffer too often technical problems, either due to the RPi or due to network problems.

*Table 2* – Comparing RMS cameras among the twenty cameras of the CAMS BeNeLux network with the best score in terms of orbits during July 2020.

| Camera | Total orbits | Total nights |
|---|---|---|
| **003814 (RMS, Grapfontaine, BE)** | **930** | **31** |
| **003815 (RMS, Genk, BE)** | **413** | **29** |
| **003800 (RMS, Langenfeld, DE)** | **344** | **31** |
| **000378 (RMS, Kattendijke, NL)** | **309** | **31** |
| **003830 (RMS, Mechelen, BE)** | **290** | **31** |
| 000384 (Watec, Mechelen, BE) | 260 | 31 |
| 000394 (Watec, Dourbes, BE) | 257 | 31 |
| 003005 (Watec, Gronau, DE) | 254 | 20 |
| **003831 (RMS, Mechelen, BE)** | **246** | **31** |
| 000395 (Watec, Dourbes, BE) | 238 | 31 |
| **000329 (RMS, Hengelo, NL)** | **234** | **31** |
| 000814 (Watec, Grapfontaine, BE) | 233 | 31 |
| 003003 (Watec, Gronau, DE) | 231 | 20 |
| 000380 (Watec, Wilderen, BE) | 218 | 31 |
| 000399 (Watec, Mechelen, BE) | 214 | 31 |
| **000328 (RMS, Hengelo, NL)** | **199** | **31** |
| 000815 (Watec, Grapfontaine, BE) | 199 | 31 |
| 000809 (Watec, Mechelen, BE) | 194 | 31 |
| 000391 (Watec, Mechelen, BE) | 194 | 31 |
| 000393 (Watec, Ukkel, BE) | 184 | 31 |

## 3 Conclusion

July 2020 became a successful month of July in the CAMS BeNeLux history although the total orbits remained a bit less than previous two years.

## Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[16]. The CAMS BeNeLux team is operated by the following volunteers:

*Hans Betlem* (Leiden, Netherlands, CAMS 371, 372 and 373), Felix Bettonvil (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 328 and 329), *Guiseppe Canonaco* (Genk, RMS 3815), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806 and 888), *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 003814), *Uwe Glässner* (Langenfeld, Germany, RMS 3800), *Luc Gobin* (Mechelen, Belgium, CAMS 390, 391, 807 and 808), *Tioga Gulon* (Nancy, France, CAMS 3900 and 3901), *Robert Haas* (Alphen aan de Rijn, Netherlands, CAMS 3160, 3161, 3162, 3163, 3164, 3165, 3166 and 3167), *Robert Haas* (Texel, Netherlands, CAMS 810, 811, 812 and 813), *Robert Haas / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822), *Kees Habraken* (Kattendijke, Netherlands, RMS 000378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain Belgium, CAMS 816), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Koen Miskotte* (Ermelo, Netherlands, CAMS 351, 352, 353 and 354), *Tim Polfliet* (Gent, Belgium, CAMS 396), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *Paul and Adriana Roggemans* (Mechelen, Belgium, CAMS 383, 384, 388, 389, 399 and 809, RMS 003830 and 003831), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).

[16] http://cams.seti.org/FDL/index-BeNeLux.html

# August 2020 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of August 2020 is presented. The CAMS BeNeLux network experienced favorable weather circumstances this month. As many as 28479 multiple station meteors were recorded. A total of 8756 orbits were collected during this month with a maximum of 90 operational cameras available at 24 stations.

## 1 Introduction

The Perseid month of August remains the favorite observing month for many amateurs. Moon wise, the circumstances were favorable in 2020 and the only uncertain factor remained the weather. The corona pandemic kept most amateur astronomers at home so that most camera owners remained available for meteor work at home. During most past years, August was the best month of the year in terms of number of orbits. What would August 2020 bring?

## 2 August 2020 statistics

CAMS BeNeLux collected 28479 multi-station meteors (33231 in August 2019 and 15286 in 2018), good for 8756 orbits (9921 in 2019 and 5403 in 2018). The total for 2020 is less than the absolute record of previous year and still slightly better than August 2017 when 8738 orbits were recorded.

Weather was favorable until August 18–19, the last part of August had rather unstable weather. As many as 25 August nights had more than 100 orbits, 5 nights had more than 500 orbits and the best night was August 12–13 with 720 orbits in a single night. Not any night remained without orbits. The weather was definitely less favorable than in 2019 as less meteors were caught in 2020 with more cameras available than ever before.

The statistics of August 2020 are compared in *Figure 1* and *Table 1* with the same month in previous years since the start of CAMS BeNeLux in 2012. In 9 years, 249 August nights allowed to obtain orbits with a grand total of 45086 orbits collected in this month during all these years together.

Most camera operators use AutoCams, only some CAMS stations in the Netherlands and Germany do not yet use AutoCAMS. Remote control allows to operate the cameras and to report data during the summer holidays without causing any delays. Three more cameras were active than during August 2019, but a number of technical problems kept the minimum of operational cameras at 59, 6 less than previous year. This year as many as 90 cameras were operational at maximum, 80.7 on average. Especially the RMS cameras generate large numbers of orbits. Their larger field of view and a very good resolution provides overlap with many of the small FoV Watecs at most CAMS stations.

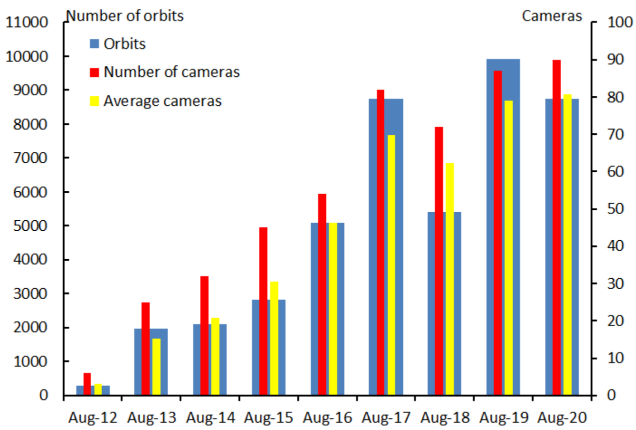


*Figure 1* – Comparing August 2020 to previous months of August in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras capturing in a single night and the yellow bar the average number of cameras capturing per night.

*Table 1* – August 2020 compared to previous months of August.

| Year | Nights | Orbits | Stations | Max. Cams | Min. Camas | Mean Cams |
|---|---|---|---|---|---|---|
| 2012 | 21 | 283 | 5 | 6 | | 3.2 |
| 2013 | 27 | 1960 | 13 | 25 | | 15.3 |
| 2014 | 28 | 2102 | 14 | 32 | | 20.8 |
| 2015 | 25 | 2821 | 15 | 45 | | 30.4 |
| 2016 | 30 | 5102 | 20 | 54 | 15 | 46.2 |
| 2017 | 28 | 8738 | 21 | 82 | 45 | 69.9 |
| 2018 | 30 | 5403 | 19 | 72 | 56 | 62.4 |
| 2019 | 29 | 9921 | 23 | 87 | 65 | 79.0 |
| 2020 | 31 | 8756 | 24 | 90 | 59 | 80.7 |
| Total | 249 | 45086 | | | | |

It is worthwhile to look at the number of orbits collected with these RMS cameras, compared to the Watecs in the CAMS BeNeLux network. The 20 best scoring cameras during August 2020 are listed in *Table 2*.

*Table 2* – Comparing RMS cameras among the twenty cameras of the CAMS BeNeLux network with the best score in terms of orbits during August 2020.

| Camera | Total orbits | Total nights |
|---|---|---|
| **003814 (RMS, Grapfontaine, BE)** | **1481** | **31** |
| **000378 (RMS, Kattendijke, BE)** | **902** | **31** |
| **00329 (RMS, Hengelo, BE)** | **617** | **31** |
| 000816 (Watec, Humain, BE) | 613 | 28 |
| 000384 (Watec, Mechelen, BE) | 568 | 31 |
| **003800 (RMS, Langenfeld, DE)** | **568** | **31** |
| **003815 (RMS Genk, BE)** | **552** | **31** |
| 000379 (Watec, Wilderen, BE) | 507 | 31 |
| 000391 (Watec, Mechelen, BE) | 487 | 31 |
| 000394 (Watec, Dourbes, BE) | 477 | 31 |
| 000399 (Watec, Mechelen, BE) | 466 | 31 |
| 000390 (Watec, Mechelen, BE) | 465 | 31 |
| 000353 (Watec, Ermelo, NL) | 462 | 24 |
| 003005 (Watec, Gronau, DE) | 447 | 23 |
| **003830 (RMS Mechelen, BE)** | **446** | **24** |
| 000395 (Watec, Dourbes, BE) | 443 | 31 |
| 003003 (Watec, Gronau, DE) | 433 | 23 |
| 000388 (Watec, Mechelen, BE) | 579 | 31 |
| **000328 (RMS, Hengelo, NL)** | **425** | **31** |
| 003035 (Watec, Oostkapelle, NL) | 424 | 29 |

## 3 Conclusion

August 2020 counted many favorable nights for the CAMS BeNeLux network during the first 18 nights, the last part of August was less favorable. Altogether this month is good for a second-best month of August in the CAMS BeNeLux history.


## Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[17]. The CAMS BeNeLux team is operated by the following volunteers:

*Hans Betlem* (Leiden, Netherlands, CAMS 371, 372 and 373), Felix Bettonvil (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 328 and 329), *Guiseppe Canonaco* (Genk, RMS 3815), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806 and 888), *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 003814), *Uwe Glässner* (Langenfeld, Germany, RMS 3800), *Luc Gobin* (Mechelen, Belgium, CAMS 390, 391, 807 and 808), *Tioga Gulon* (Nancy, France, CAMS 3900 and 3901), *Robert Haas* (Alphen aan de Rijn, Netherlands, CAMS 3160, 3161, 3162, 3163, 3164, 3165, 3166 and 3167), *Robert Haas* (Texel, Netherlands, CAMS 810, 811, 812 and 813), *Robert Haas / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822), *Kees Habraken* (Kattendijke, Netherlands, RMS 000378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain Belgium, CAMS 816), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Koen Miskotte* (Ermelo, Netherlands, CAMS 351, 352, 353 and 354), *Tim Polfliet* (Gent, Belgium, CAMS 396), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *Paul and Adriana Roggemans* (Mechelen, Belgium, CAMS 383, 384, 388, 389, 399 and 809, RMS 003830 and 003831), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).


[17] http://cams.seti.org/FDL/index-BeNeLux.html

# September 2020 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of September 2020 is presented. September 2020 counted many clear nights. 12997 multiple station meteors were recorded. A record number of 6132 orbits were collected during this month with a maximum of 90 cameras available at 24 locations.

## 1 Introduction

Previous years the month of September brought favorable weather circumstances combined with a rich meteor activity, although no major showers are active this time of the year. Nights are getting longer, about two hours more nighttime between begin of September and the end of the month. What did 2020 bring us?

## 2 September 2020 statistics

CAMS BeNeLux collected 12997 multi-station meteors (14826 in September 2019), good for 6132 orbits (4609 previous year). This is an absolute record for the month September. This month counted as many as 20 nights with more than 100 orbits (15 in 2019). The best September night was 18–19 with as many as 514 orbits in a single night, the best score in orbits ever for a September night. Four nights remained without any orbits (1 previous year). The statistics of September 2020 are compared in *Figure 1* and *Table 1* with the same month in previous years since the start of CAMS BeNeLux in 2012. In 9 years, 235 September nights allowed to obtain orbits with a grand total of 30145 orbits collected during September during all these years together.

The weather was very favorable in September 2020, but although the network had 1829 multi-station meteors less than in 2019, we got 1523 more orbits. September 2020 had 526 orbits more than the previous record month September 2018. This is thanks to the larger number of cameras that were operational compared to previous years. The northern part of the CAMS BeNeLux network suffered less good coverage as some of the CAMS stations were temporarily inactive or unable to contribute for various reasons.

The first three weeks of September had favorable weather, from September 24 onwards the BeNeLux got rather very poor weather with completely overcast sky.

The volume of atmosphere monitored by the CAMS BeNeLux cameras is huge. If all or most cameras are kept operational, most of the meteors registered will help to obtain an orbit. It is important to keep as many cameras operational as possible. This remains a challenge as technical failures cannot be ruled out. Some extra camera stations would be very welcome to reinforce the northern and entire western part of the network.

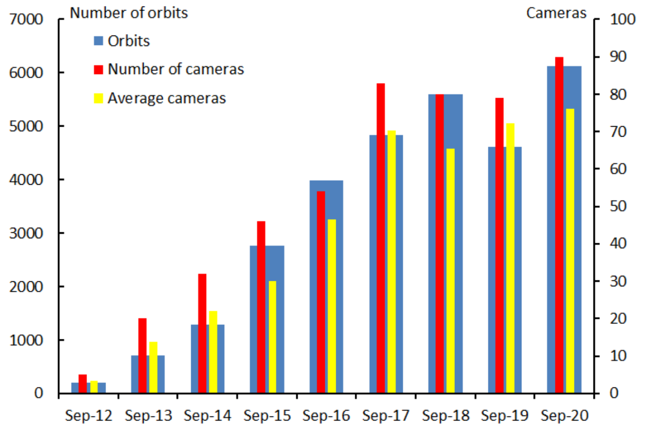


*Figure 1* – Comparing September 2020 to previous months of September in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bar the average number of cameras running per night.

*Table 1* – September 2020 compared to previous months of September.

| Year | Nights | Orbits | Stations | Max. Cams | Min. Cams | Mean Cams |
|---|---|---|---|---|---|---|
| 2012 | 18 | 209 | 5 | 5 | - | 3.4 |
| 2013 | 19 | 712 | 9 | 20 | - | 13.7 |
| 2014 | 27 | 1293 | 14 | 32 | - | 22.0 |
| 2015 | 29 | 2763 | 15 | 46 | - | 30.0 |
| 2016 | 30 | 3982 | 19 | 54 | 32 | 46.5 |
| 2017 | 29 | 4839 | 22 | 83 | 47 | 70.2 |
| 2018 | 28 | 5606 | 20 | 80 | 57 | 65.4 |
| 2019 | 29 | 4609 | 20 | 79 | 64 | 72.3 |
| 2020 | 26 | 6132 | 24 | 90 | 52 | 76.2 |
| Total | 235 | 30145 | | | | |

## 3 Conclusion

September 2020 confirmed the reputation of this month with a very rich background meteor activity and favorable weather. It will be hard to improve the record number of orbits in the future.

 

## Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[18]. The CAMS BeNeLux team was operated by the following volunteers during September 2020:

*Hans Betlem* (Leiden, Netherlands, CAMS 371, 372 and 373), Felix Bettonvil (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 328 and 329), *Guiseppe Canonaco* (Genk, RMS 3815), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806 and 888), *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 003814), *Uwe Glässner* (Langenfeld, Germany, RMS 3800), *Luc Gobin* (Mechelen, Belgium, CAMS 390, 391, 807 and 808), *Tioga Gulon* (Nancy, France, CAMS 3900 and 3901), *Robert Haas* (Alphen aan de Rijn, Netherlands, CAMS 3160, 3161, 3162, 3163, 3164, 3165, 3166 and 3167), *Robert Haas* (Texel, Netherlands, CAMS 810, 811, 812 and 813), *Robert Haas / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822), *Kees Habraken* (Kattendijke, Netherlands, RMS 000378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain Belgium, CAMS 816), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Koen Miskotte* (Ermelo, Netherlands, CAMS 351, 352, 353 and 354), *Tim Polfliet* (Gent, Belgium, CAMS 396), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *Paul and Adriana Roggemans* (Mechelen, Belgium, CAMS 383, 384, 388, 389, 399 and 809, RMS 003830 and 003831), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).

[18] http://cams.seti.org/FDL/index-BeNeLux.html

# Worldwide Radio Meteor Observation Report September 2020

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The meteor activity in September has been observed by radio meteor observers worldwide. Aurigids (AUR#206) and September ε-Perseids (SPE#208) showed very weak activities. At the end of September, some increased activity has been observed according to the monthly report from Japan.

## 1 Introduction

Radio meteor observations in the world covered the meteor shower activity of the Aurigids and the ε-Perseids 2020. Worldwide radio meteor observation data were provided by Radio Meteor Observation Bulletin (RMOB) (Steyaert, 1993) and by the radio meteor observations network in Japan (Ogawa et al., 2001).

## 2 Method

For analyzing worldwide radio meteor observation data, meteor activities are calculated by the "Activity Level" index (Ogawa et al., 2001). The activity profile was estimated by the Lorentz activity profile (Jenniskens, 2000).

## 3 Results

### 3.1. Aurigids (AUR#206)

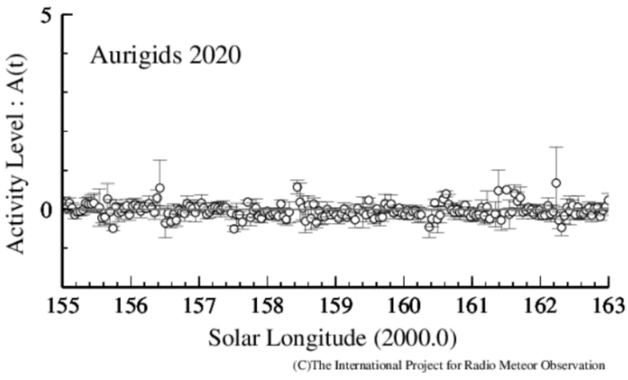


*Figure 1* – Aurigids 2020 using worldwide radio meteor observations.

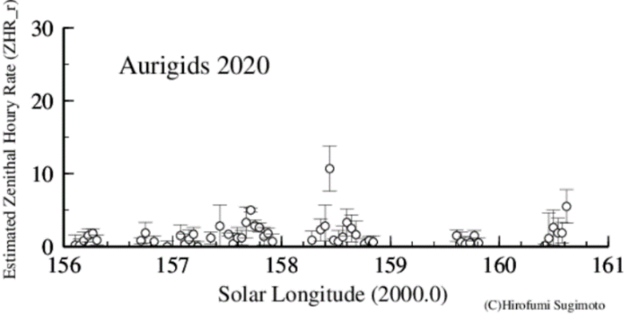


*Figure 2* – Estimated ZHR by radio meteor observations (provided by Hirofumi Sugimoto).

*Figure 1* shows the result for the Aurigids with 34 observations from 13 countries. Although the peak position is expected around Solar Longitude $\lambda_{\odot}$ = 158.6°, no unusual activity has been observed during this year. *Figure 2* shows the estimated ZHR using radio meteor observation data by Hirofumi Sugimoto (Sugimoto, 2017).

### 3.2. September ε-Perseids (SPE#208)

No clear activity from the September ε-Perseids could be found by using 34 observations from 13 countries (*Figure 3* and *Figure 4*). It showed very weak activity, about less than an activity level of 0.5. The estimated ZHR provided by Hirofumi Sugimoto also shows a weak activity level.

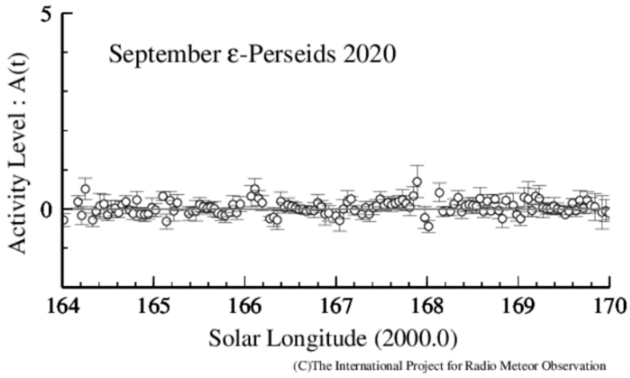


*Figure 3* – September ε-Perseids 2020 using worldwide radio meteor observations.

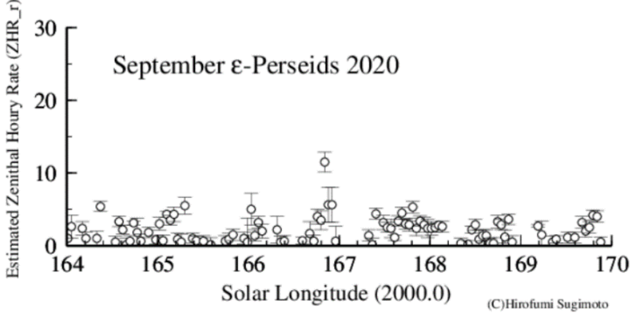


*Figure 4* – Estimated ZHR by radio meteor observations (provided by Hirofumi Sugimoto).

 

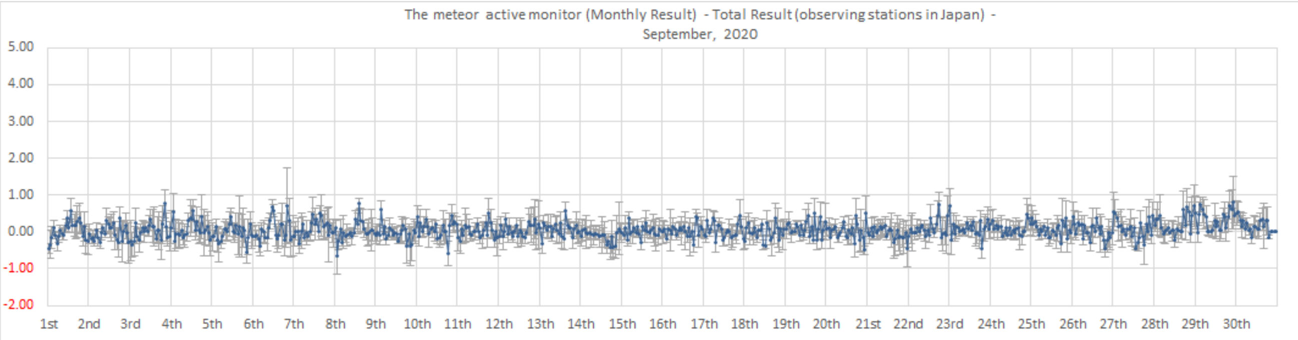


*Figure 5* – Monthly report for September 2020 (only Japanese observing stations).

### 3.3. The monthly report in September from Japanese radio observers

*Figure 5* shows the monitored result in September by using the data from Japanese radio meteor observers. Although there was no clear high activity, a little increase can be seen around the end of September. This is possible due to one of the daytime meteor showers, the Daytime Sextantids (DSX#221). I intend to analyze the DSX#221 activity including the October reports.

## Acknowledgment

The Aurigids (*Figure 1*) and September ε-Perseids data (*Figure 3*) were provided by the following observers:

*Chris Steyaert* (Belgium), *Felix Verbelen* (Belgium), *Daniel D SAT01_DD* (France), *Jacques Molne* (France), *Jean Marie F5CMQ* (France), *Pierre Micaletti* (France), *Fred Espey* (Germany), *Per DL0SHF* (Germany), *WHS Essen* (Germany), *Balogh Laszlo* (Hungary), *AAV Planetario_di_Venezia* (Italy), *Associazione Pontina di Astronomia _APA_* (Italy), *Fabio Moschini_IN3GOO* (Italy), *GAML Osservatorio_Astronomico_Gorga* (Italy), *Mario Bombardini* (Italy), *Oss_Monte_San_Lorenzo DLF* (Italy), *Kenji Fujito* (Japan), *Hirofumi Sugimoto* (Japan), *Hironobu Shida* (Japan), *Hirotaka Otsuka* (Japan), *Masaki Kano* (Japan), *Masaki Tsuboi* (Japan), *Tomohiro Nakamura* (Japan), *Salvador Aguirre* (Mexico), *Kees Meteor* (Netherlands), *RondaRonda* (Spain), *Jochen Richert* (Switzerland), *Ian Evans* (UK), *Philip Norton* (UK), *Eric Smestad_KC0RDD* (USA), *Mike Otte* (USA), *Stan Nelson* (USA).

The worldwide data were provided by the Radio Meteor Observation Bulletin[19] (RMOB).

*Figure 2* and *Figure 4* were provided by *Hirofumi Sugimoto*.

*Figure 5* was provided by *Hirofumi Sugimoto*, *Masaki Tsuboi*, *Kenji Fujito*, *Hirotaka Otsuka*, *Tomohiro Nakamura* and *Hironobu Shida*.

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Sugimoto H. (2017). “The New Method of Estimating ZHR using Radio Meteor Observations”. *eMetN*, **2**, 109–110.

[19] http://www.rmob.org/

# October Camelopardalids and October Draconids 2020 with Worldwide Radio Meteor Observations

**Hiroshi Ogawa**

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Worldwide Radio Meteor Observations detected activity of the October Camelopardalids and the October Draconids during the first ten days of October 2020. Their peak times occurred respectively at $\lambda_{\odot}$ = 192.61° with an estimated ZHR of 20 and at $\lambda_{\odot}$ = 194.05° with an estimated ZHR of 25.

## 1 Introduction

Radio meteor observations in the world covered the meteor shower activity of the October Camelopardalids and the October Draconids 2020. Worldwide radio meteor observation data were provided by the Radio Meteor Observation Bulletin (RMOB)[1] (Steyaert, 1993) and by the radio meteor observations network in Japan (Ogawa et al., 2001).

The October Camelopardalids displayed an estimated ZHR of over 40 in 2016. For the 2020 return no dust trail encounters were predicted. For the October Draconids 2020 there were two trail encounters based on calculations by J. Vaubaillon and P. Jenniskens on October 7, at $01^{h}25^{m}$ UT (the 1704-trail) and at $01^{h}57^{m}$ UT (1711-trail). (Rendtel, 2019).

## 2 Method

For analyzing worldwide radio meteor observation data, meteor activities are calculated by the "Activity Level" index (Ogawa et al., 2001). The activity profile was estimated by the Lorentz activity profile (Jenniskens, 2000). Besides of this analysis, also the Zenithal Hourly Rates were estimated (Sugimoto, 2017).

## 3 Results

### 3.1. October Camelopardalids (OCT#208)

*Figure 1* shows the result for the October Camelopardalids 2020 based on calculations by Hirofumi Sugimoto. The activity showed an estimated maximum ZHR = 20 on October 5 $17^{h}$ UT ($\lambda_{\odot}$ = 192.61°). On the other hand, however, the calculation based on the Activity Level did not detect any unusual activity. Therefore, it is possible that the ZHR was weaker than the estimated value calculated by Hirofumi Sugimoto.

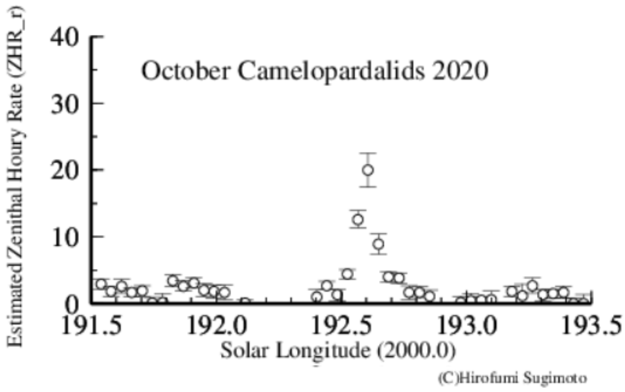


*Figure 1* – Estimated ZHR by radio meteor observations (provided by Hirofumi Sugimoto).

### 3.2. October Draconids (DRA#009)

The unusual activity has been calculated based on 39 observations from 12 countries. *Figure 2* shows the result based on the Activity Level index. The peak time was estimated at October 7 $3^{h}$ UT ($\lambda_{\odot}$ = 194.05°). The full width half maximum (FWHM) had –3.0hr / +1.5hr. Although the maximum peak time was earlier than predictions, the ascending branch was longer than the descending branch. *Figure 3* shows the activity around the peak time. Besides of the Activity Level index, the estimated ZHR based on calculations by Sugimoto are plotted.

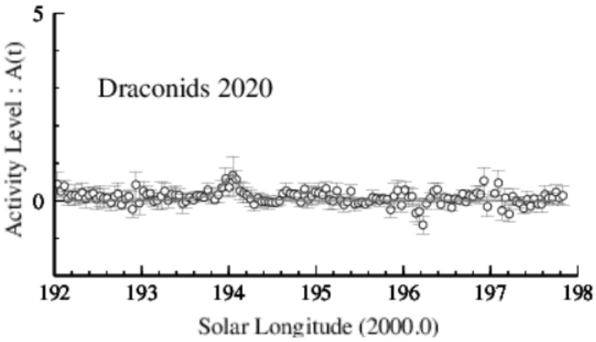


*Figure 2* – October Draconids 2020 using Activity Level index by worldwide radio meteor observations.

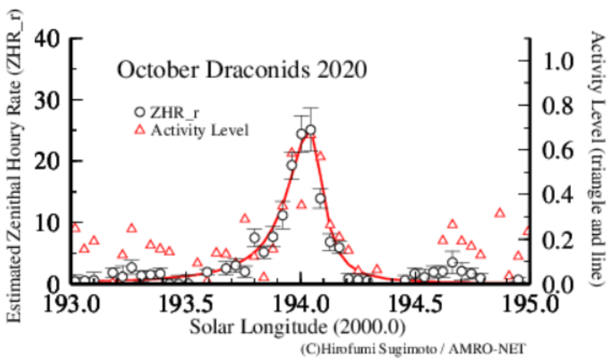


*Figure 3* – Activity profile around the peak with the Activity Level index and the estimated ZHR.

## Acknowledgment

The October Camelopardalids and October Draconids data were provided by the following observers:

*Chris Steyaert* (Belgium), *Felix Verbelen* (Belgium), *Johan Coussens* (Belgium), *DanielD SAT01_DD* (France), *Jacques Molne* (France), *Jean Marie F5CMQ* (France), *Pierre Micaletti* (France), *Fred Espey* (Germany), *WHS Essen* (Germany), *Per DL0SHF* (Germany), *Balogh Laszlo* (Hungary), *AAV Planetario_di_Venezia* (Italy), *Associazione Pontina di Astronomia _APA_* (Italy), GAML Osservatorio_Astronomico_Gorga(Italy), *Mario Bombardini* (Italy), *Oss_Monte_San_Lorenzo DLF* (Italy), *Fabio Moschini_IN3GOO* (Italy), *Hirofumi Sugimoto* (Japan), *Hironobu Shida* (Japan), *Hirotaka Otsuka* (Japan), *Kenji Fujito* (Japan), *Masaki Kano* (Japan), *Masaki Tsuboi* (Japan), *Nobuo Katsura* (Japan), *Tomohiro Nakamura* (Japan), *Salvador Aguirre* (Mexico), *Kees Meteor* (Netherlands), *RondaRonda* (Spain), *Jochen Richert* (Switzerland), *Ian Evans* (UK), *Philip Norton* (UK), *Eric Smestad_KC0RDD* (USA), *Mike Otte* (USA), *Stan Nelson* (USA).

The worldwide data were provided by the Radio Meteor Observation Bulletin[20] (RMOB).

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Sugimoto H. (2017). "The New Method of Estimating ZHR using Radio Meteor Observations". *eMetN*, **2**, 109–110.

[20] http://www.rmob.org/

# Radio meteors August 2020

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An overview of the radio observations during August 2020 is given.

## 1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of "all" reflections counted automatically, and of manually counted "overdense" reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of August 2020.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

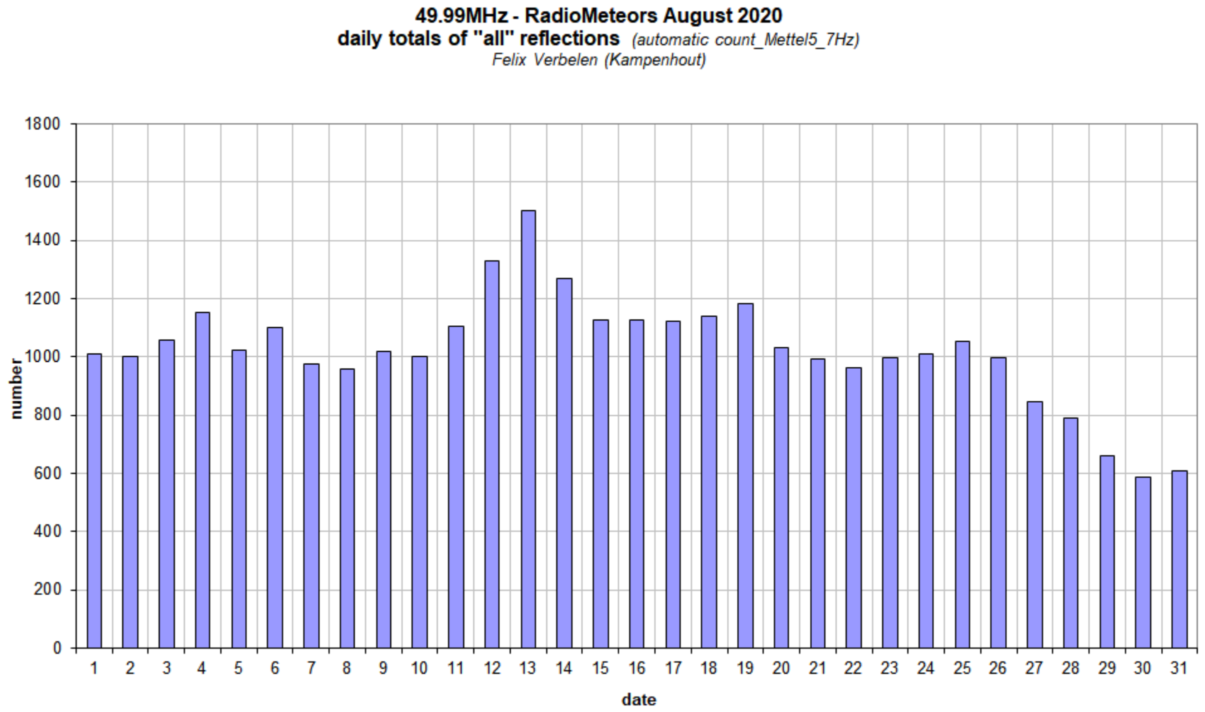
$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference remained moderate during most of the month, but unidentified noise and especially strong lightning activity during the period $9^{th}$-$18^{th}$ of August complicated the automatic counting of "all" reflections. Most automatic counting problems were addressed manually, sometimes by comparing the registrations on 49.99 MHz to those obtained on 49.97 MHz (beacon located at Dourbes/BE and operated by the BRAMS group, part of the Royal Belgian Institute for Space Aeronomy).

Eye-catchers of the month were of course the Perseids (PER) which were quite surprising by showing their main peak on August $13^{th}$, but with also strong overdense activity on the $12^{th}$ and $14^{th}$, after a period of increasing activity. As expected, the PER-activity quickly decreased after the $14^{th}$. Several other minor showers showed up, with several very strong and long-lasting overdense reflections during the period $23^{th}$-$27^{th}$ of August.

This month 52 reflections longer than 1 minute were observed here. A selection of these, together with some other interesting reflections has been included (*Figures 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27 and 28*).

If you are interested in the actual figures, or in plots showing the observations as related to the solar longitude (J2000) rather than to the calendar date. I can send you the underlying Excel files and/or plots, please send me an e-mail.



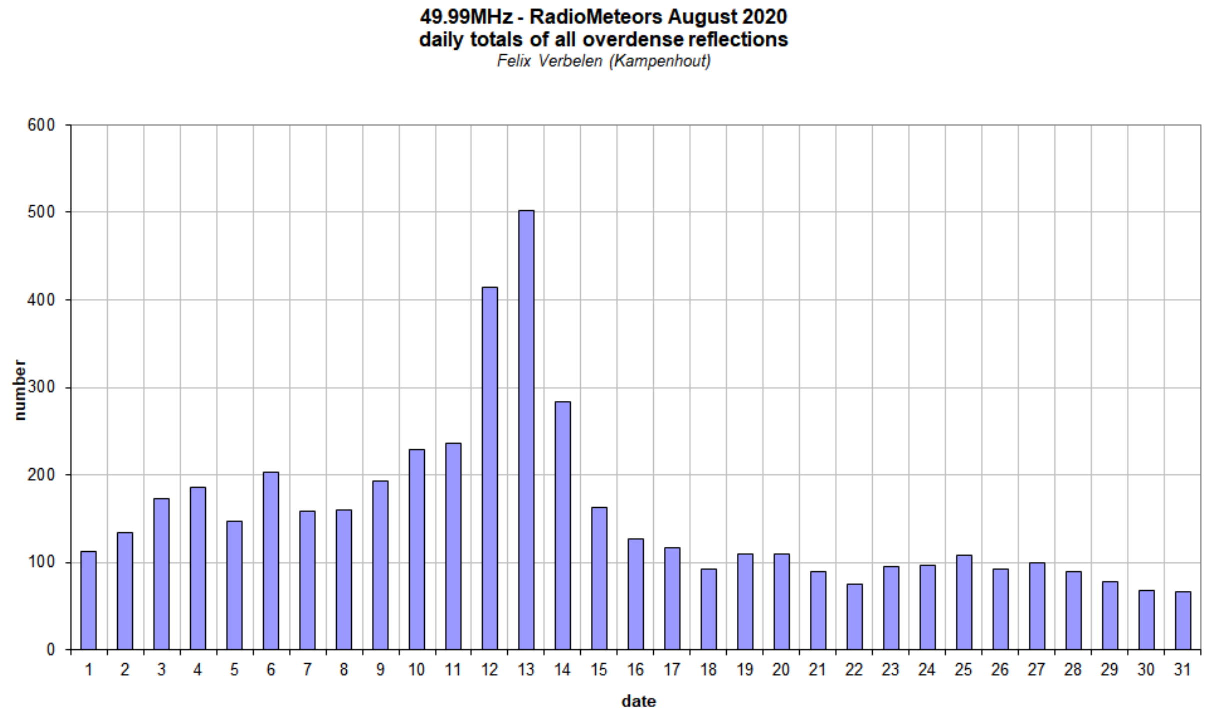
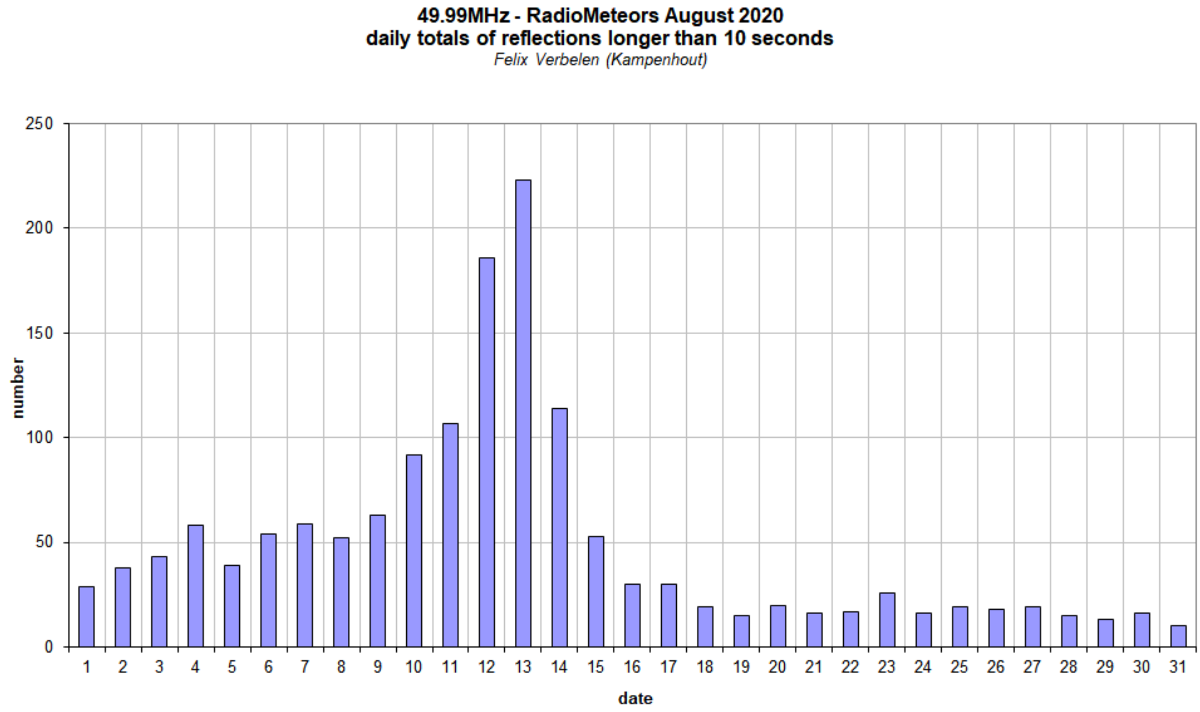




*Figure 1* – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2020.



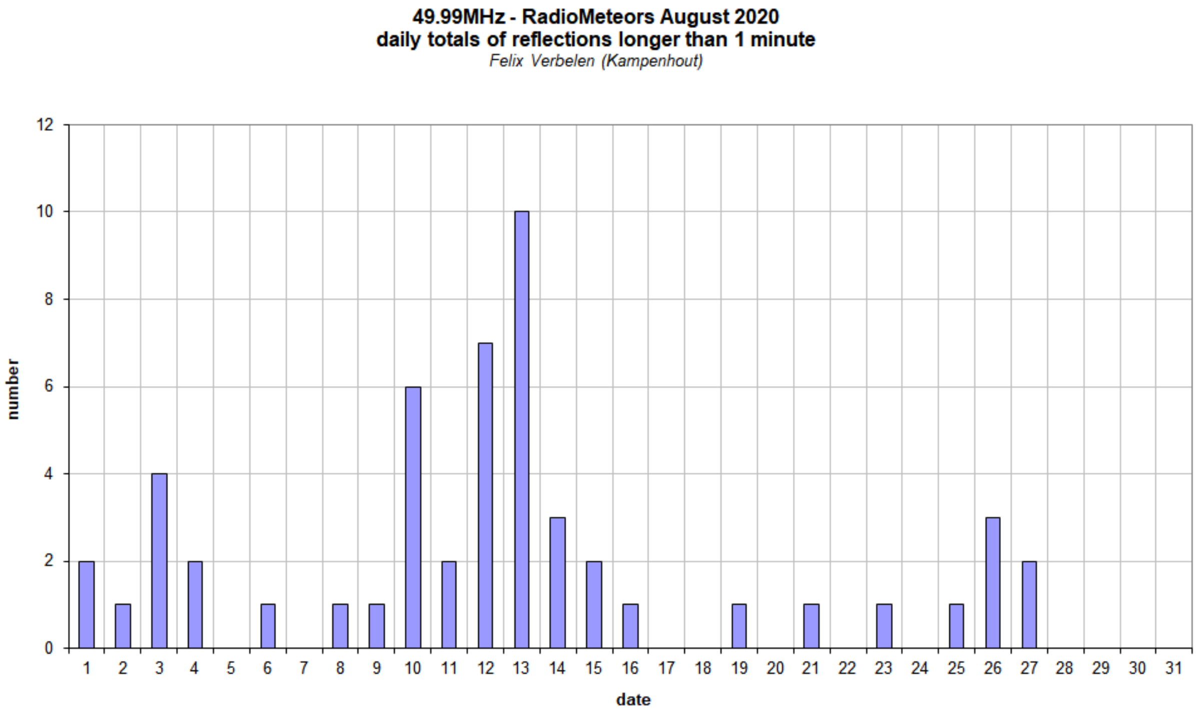
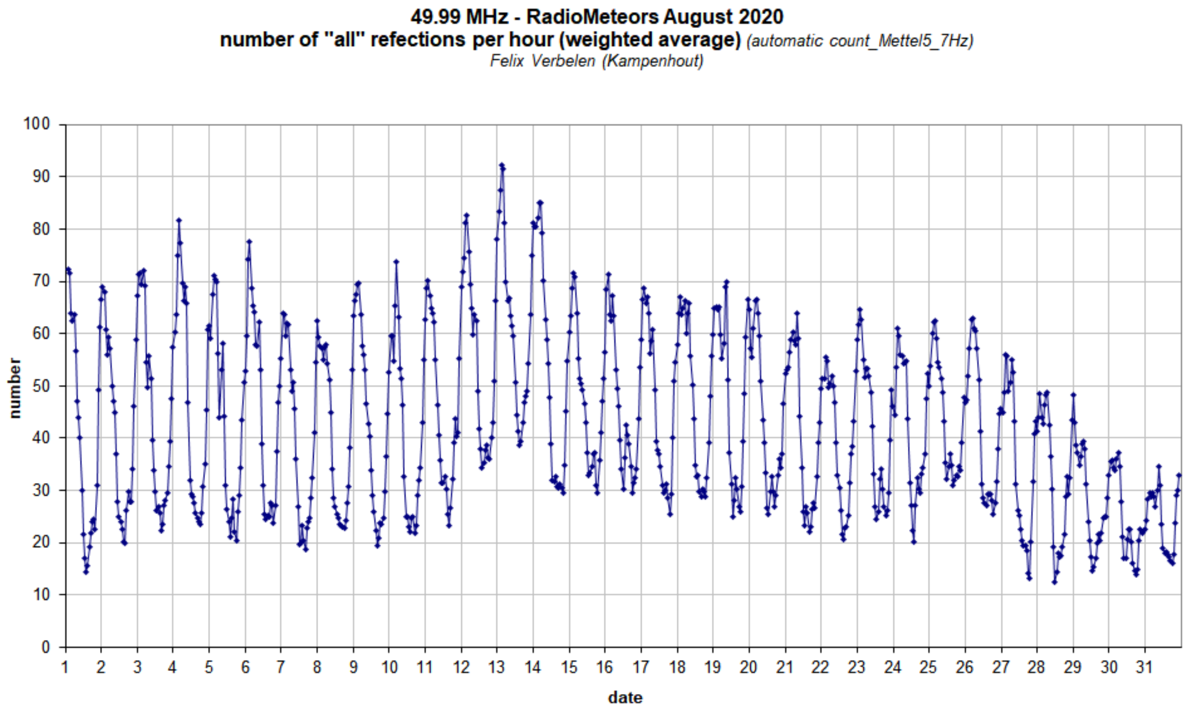




*Figure 2* – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2020.



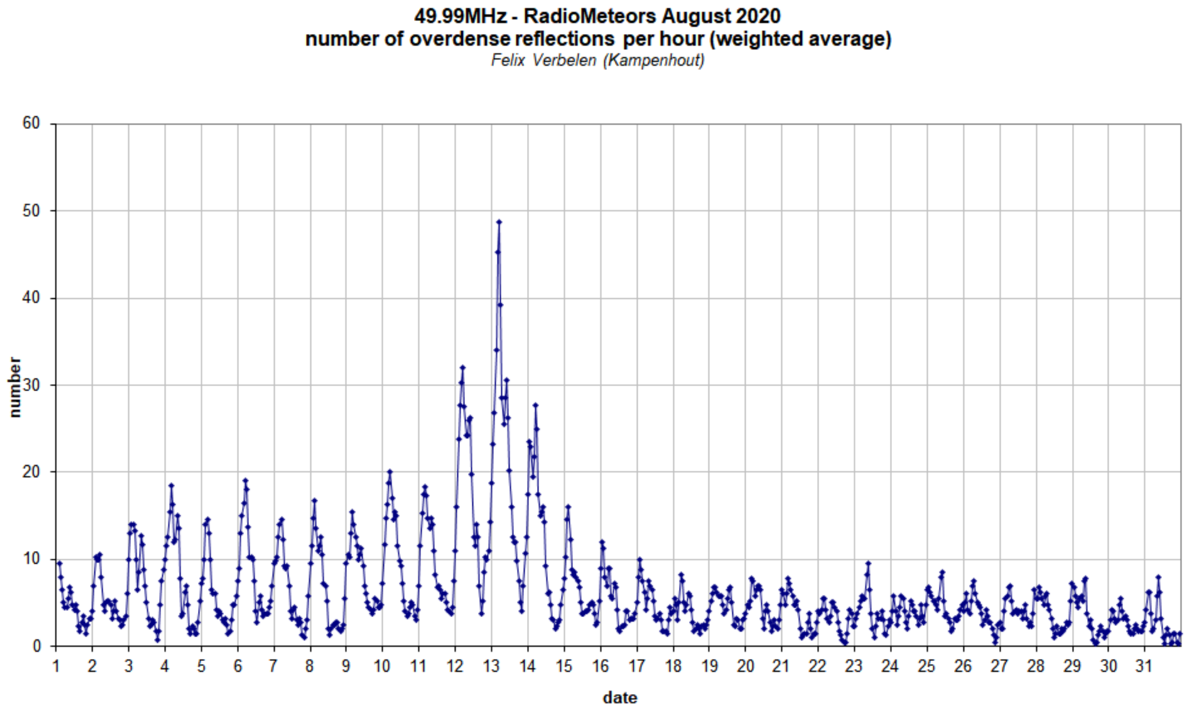
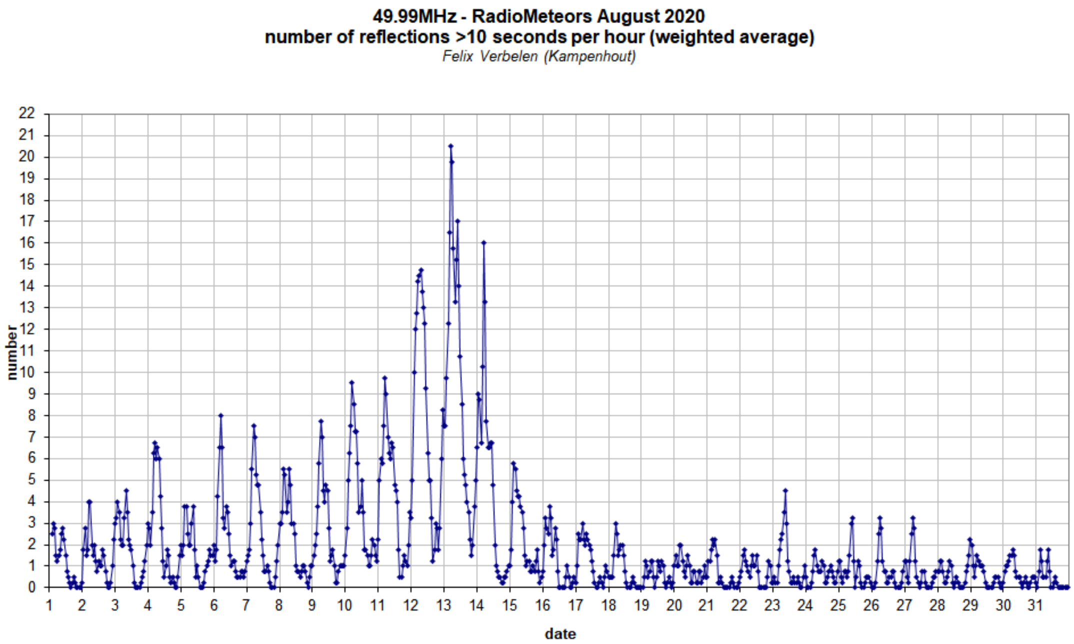




*Figure 3* – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2020.



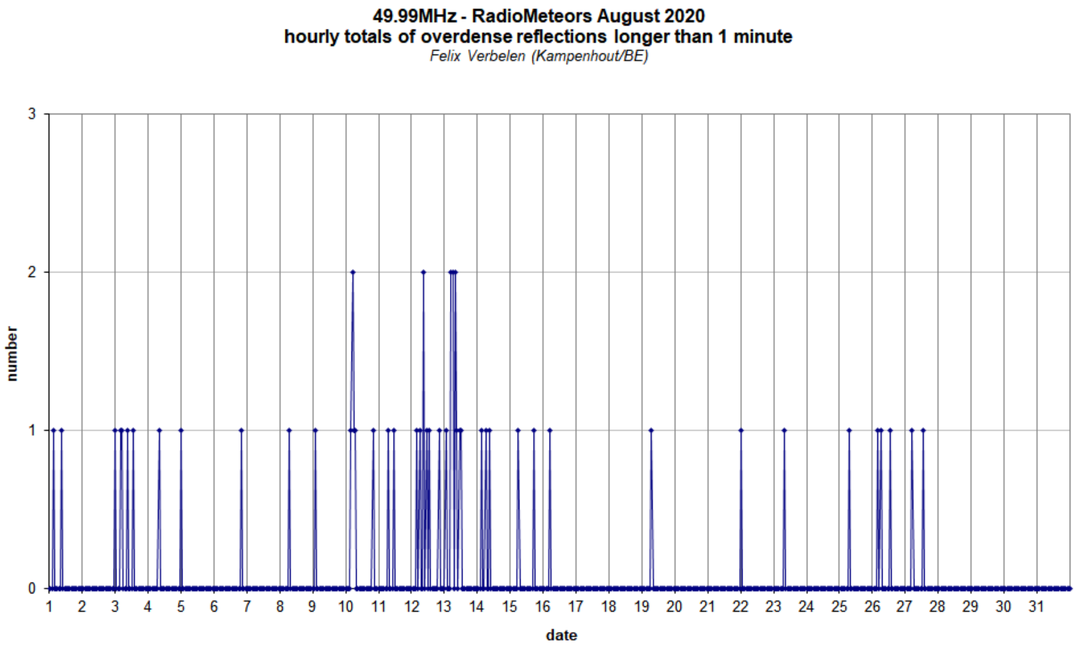




*Figure 4* – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2020.

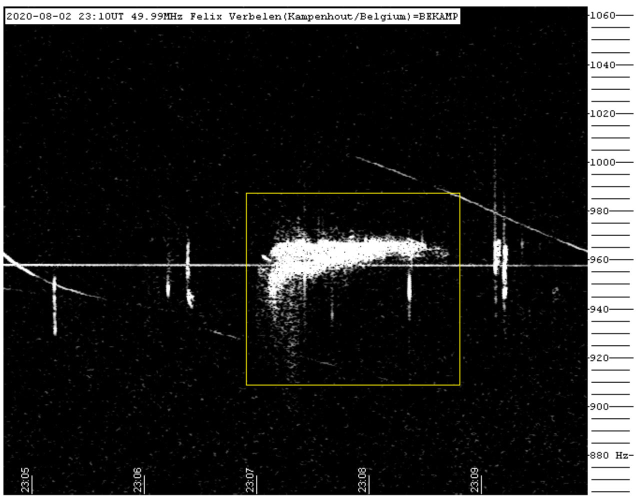



*Figure 5* – 2020 August 02 at 23$^h$10$^m$ UT.

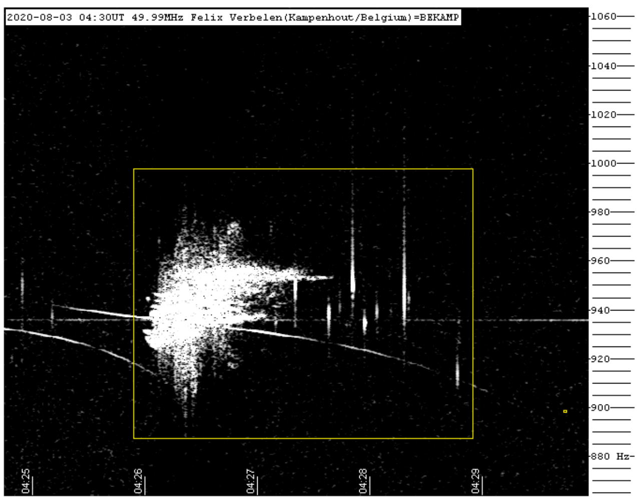



*Figure 6* – 2020 August 03 at 04$^h$30$^m$ UT.

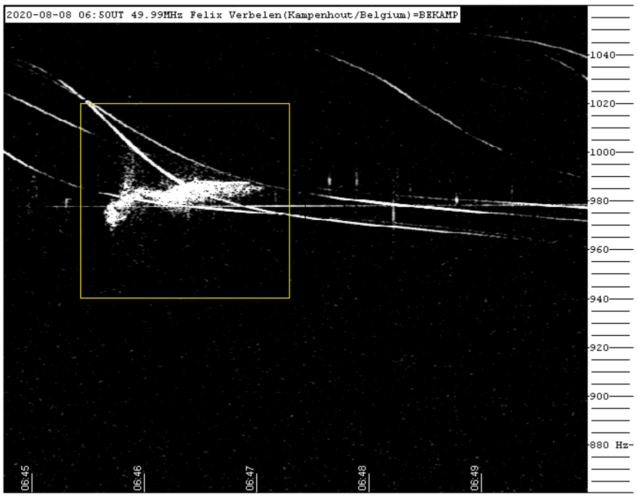



*Figure 7* – 2020 August 08 at 06$^{h}$50$^{m}$ UT.

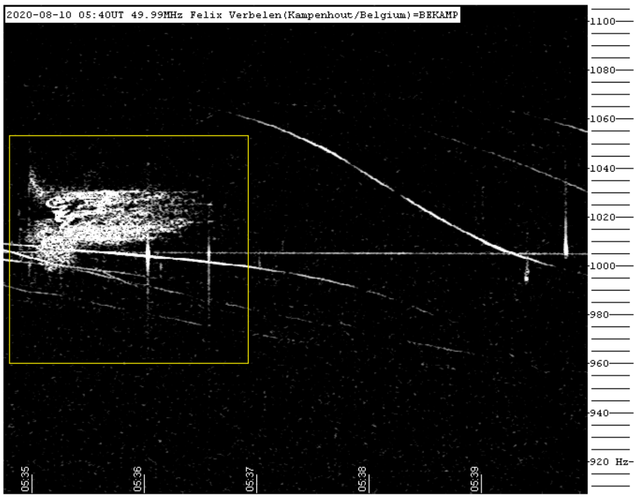



*Figure 8* – 2020 August 10 at 05$^{h}$40$^{m}$ UT.

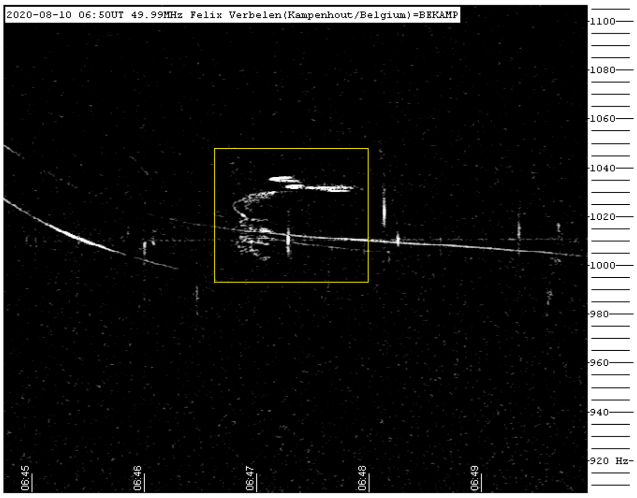



*Figure 9* – 2020 August 10 at 06$^{h}$50$^{m}$ UT.

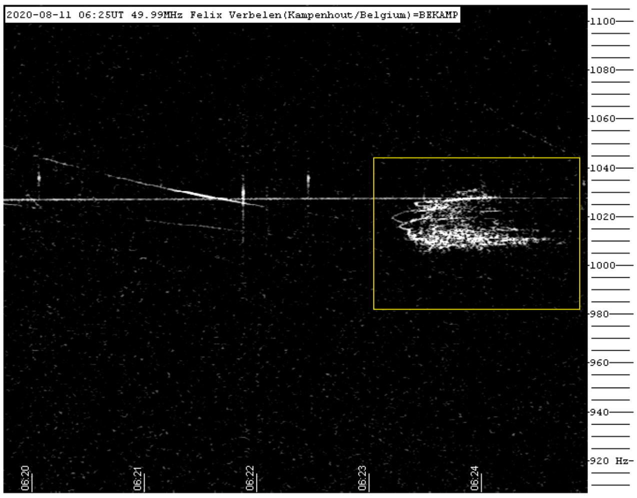



*Figure 10* – 2020 August 11 at 06$^{h}$25$^{m}$ UT.

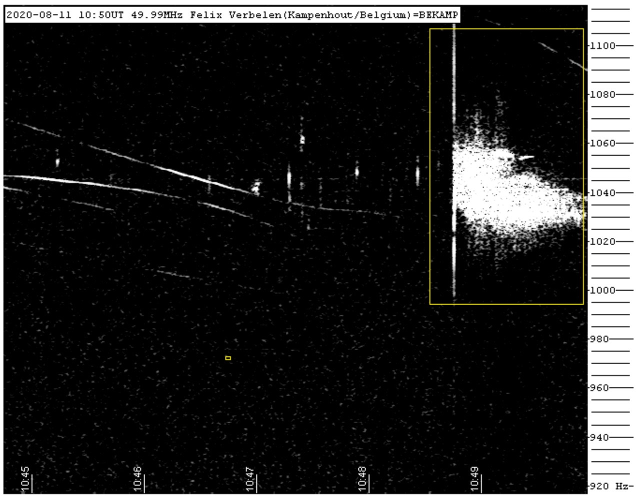



*Figure 11* – 2020 August 11 at 10$^{h}$50$^{m}$ UT.

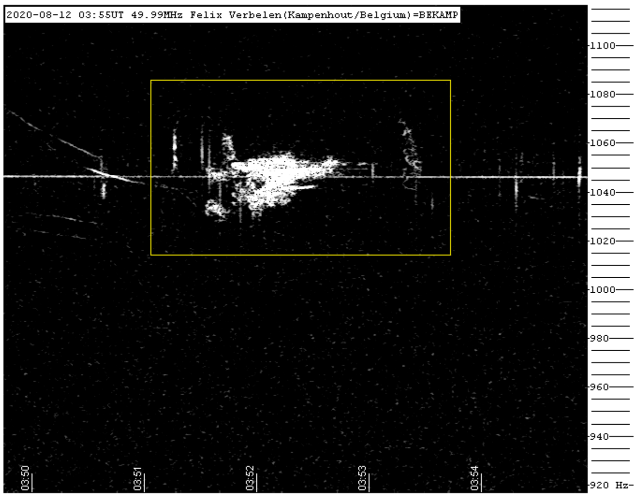



*Figure 12* – 2020 August 12 at 03$^{h}$55$^{m}$ UT.

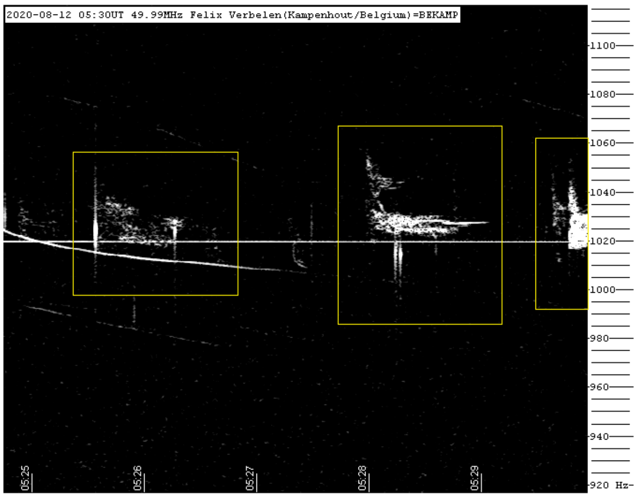



*Figure 13* – 2020 August 12 at 05ʰ30ᵐ UT.

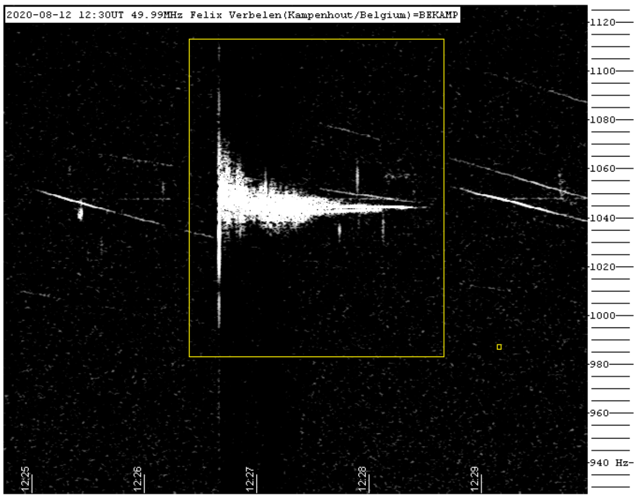



*Figure 14* – 2020 August 12 at 12ʰ30ᵐ UT.

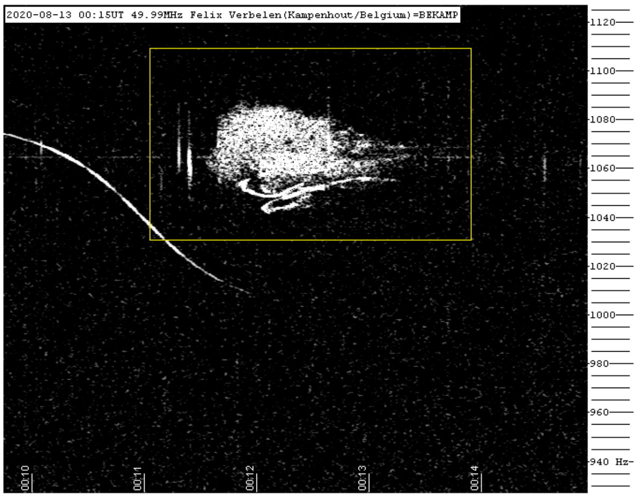



*Figure 15* – 2020 August 13 at 00ʰ15ᵐ UT.

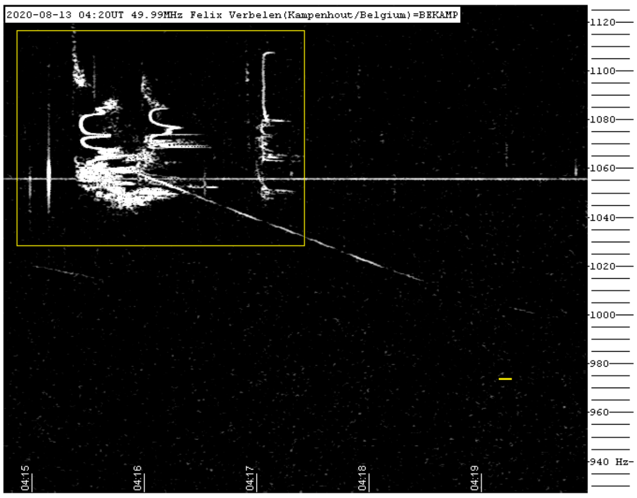



*Figure 16* – 2020 August 13 at 04ʰ20ᵐ UT.

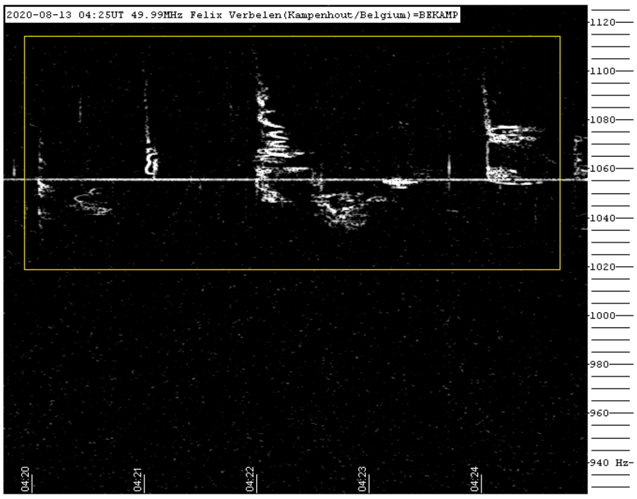



*Figure 17* – 2020 August 13 at 04ʰ25ᵐ UT.

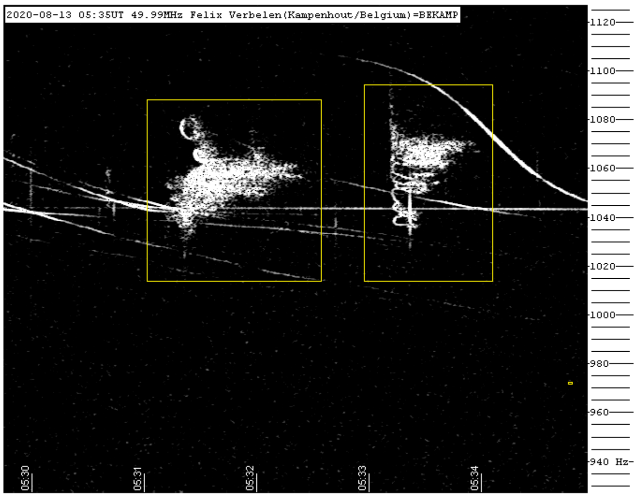



*Figure 18* – 2020 August 13 at 05ʰ35ᵐ UT.

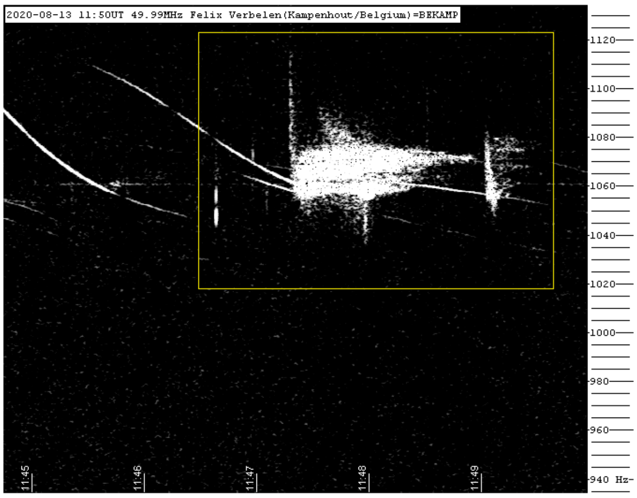



*Figure 19* – 2020 August 13 at 11$^{h}$50$^{m}$ UT.

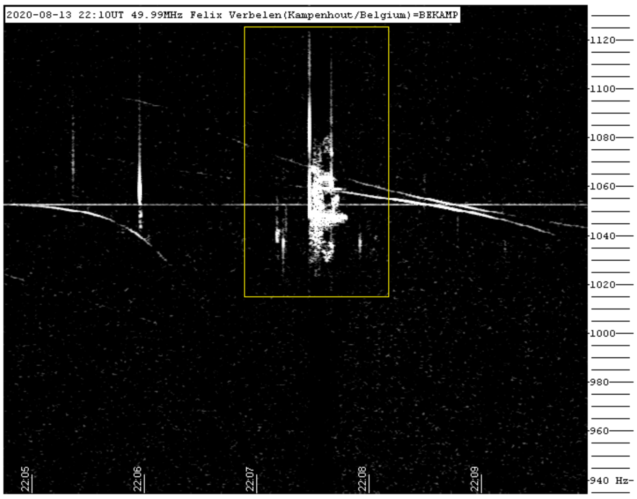



*Figure 20* – 2020 August 13 at 22$^{h}$10$^{m}$ UT.

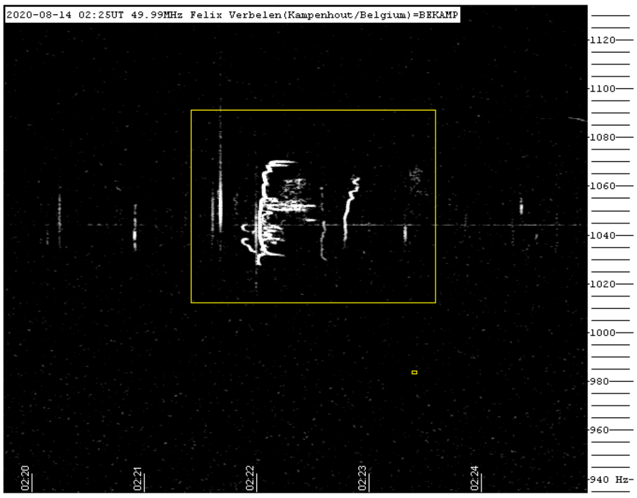



*Figure 21* – 2020 August 14 at 02$^{h}$25$^{m}$ UT.

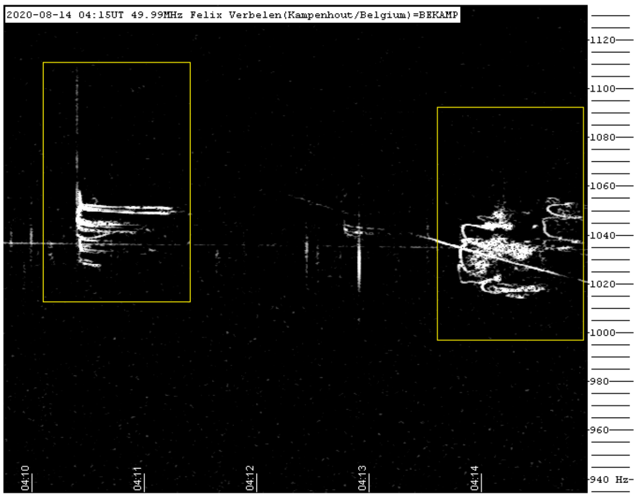



*Figure 22* – 2020 August 14 at 04$^{h}$15$^{m}$ UT.

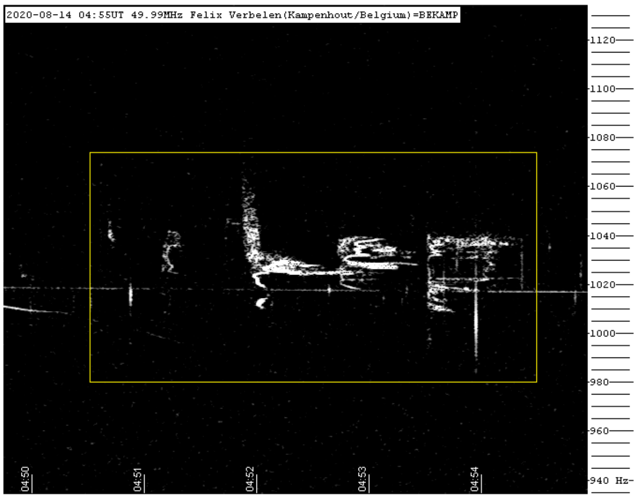



*Figure 23* – 2020 August 14 at 04$^{h}$55$^{m}$ UT.

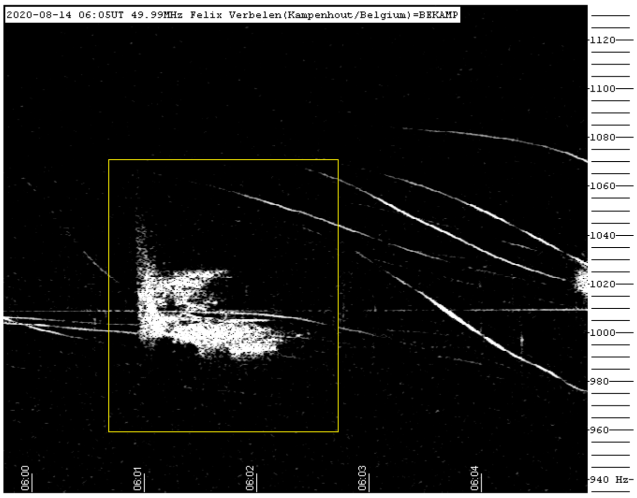



*Figure 24* – 2020 August 14 at 06$^{h}$05$^{m}$ UT.

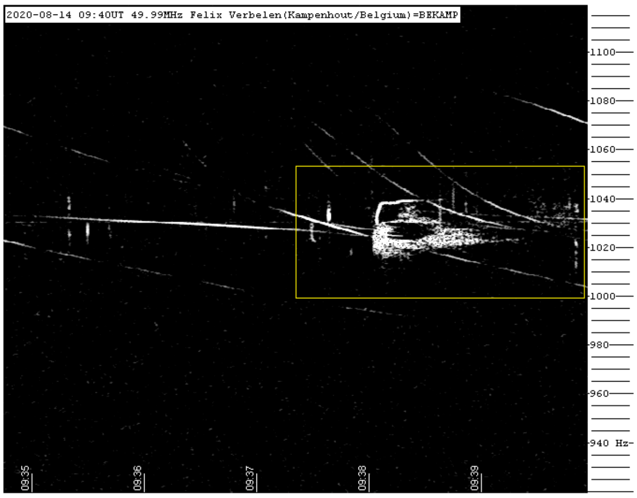



*Figure 25* – 2020 August 14 at 09$^h$40$^m$ UT.


*Figure 27* – 2020 August 16 at 04$^h$15$^m$ UT.

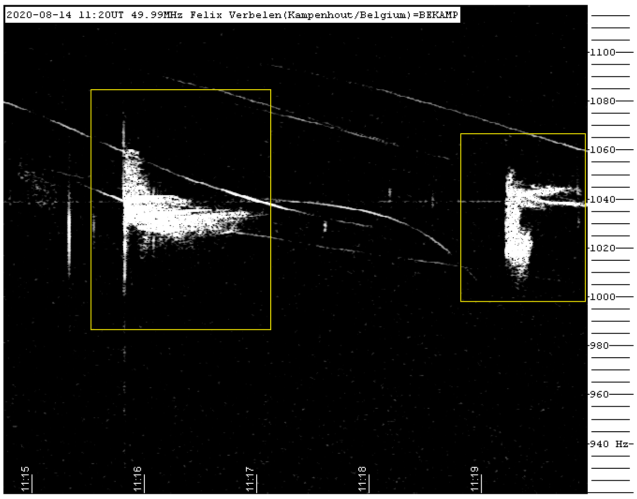



*Figure 26* – 2020 August 14 at 11$^h$20$^m$ UT.

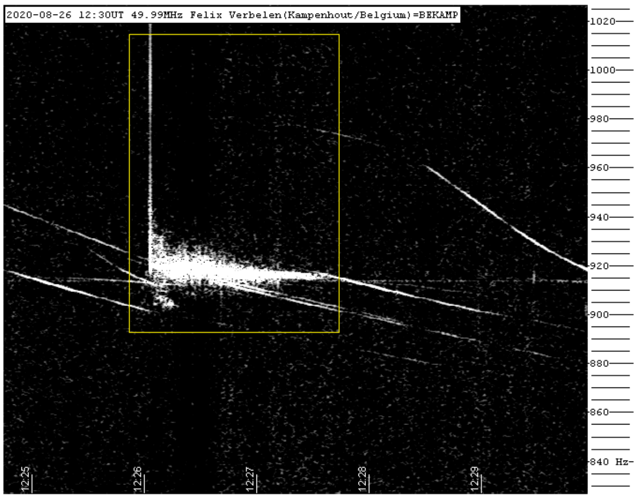



*Figure 28* – 2020 August 26 at 12$^h$30$^m$ UT.

# Radio meteors September 2020

**Felix Verbelen**

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felix.verbelen@skynet.be

An overview of the radio observations during September 2020 is given.

## 1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of “all” reflections counted automatically, and of manually counted “overdense” reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of September 2020.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

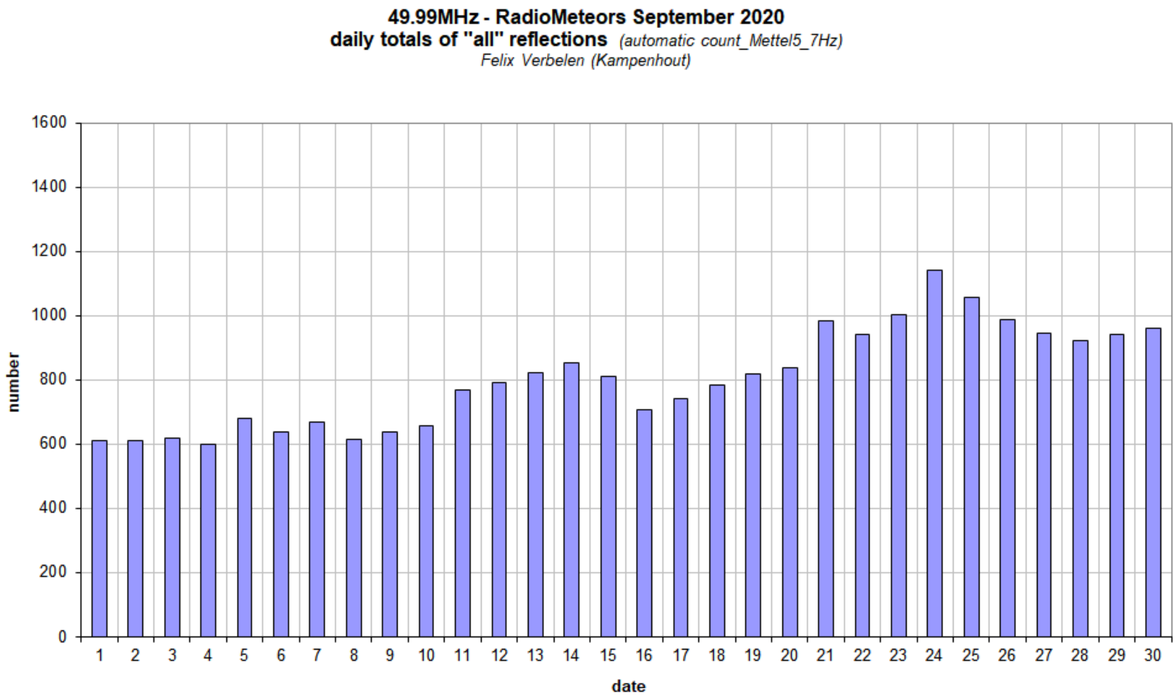
$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference and unidentified noise remained moderate during most of the month. No lightning activity was detected.

During this month no real eye-catching shower was active, but nonetheless the activity remained interesting, showing both a number of minor showers, a fair number of long reflections, and a gradual activity increase towards the end of the month.

This month 12 reflections longer than 1 minute were observed here. A selection of these, together with some other interesting reflections are included. (*Figures 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12*).

If you are interested in the actual figures, or in plots showing the observations as related to the solar longitude (J2000) rather than to the calendar date. I can send you the underlying Excel files and/or plots, please send me an e-mail.



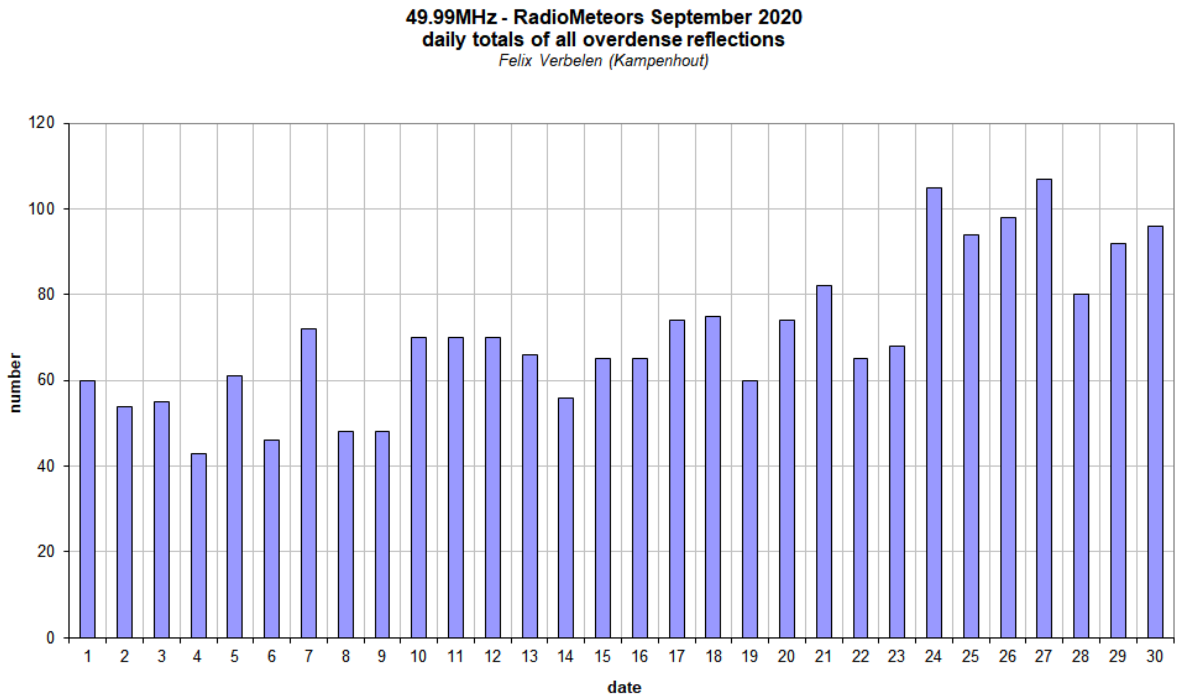
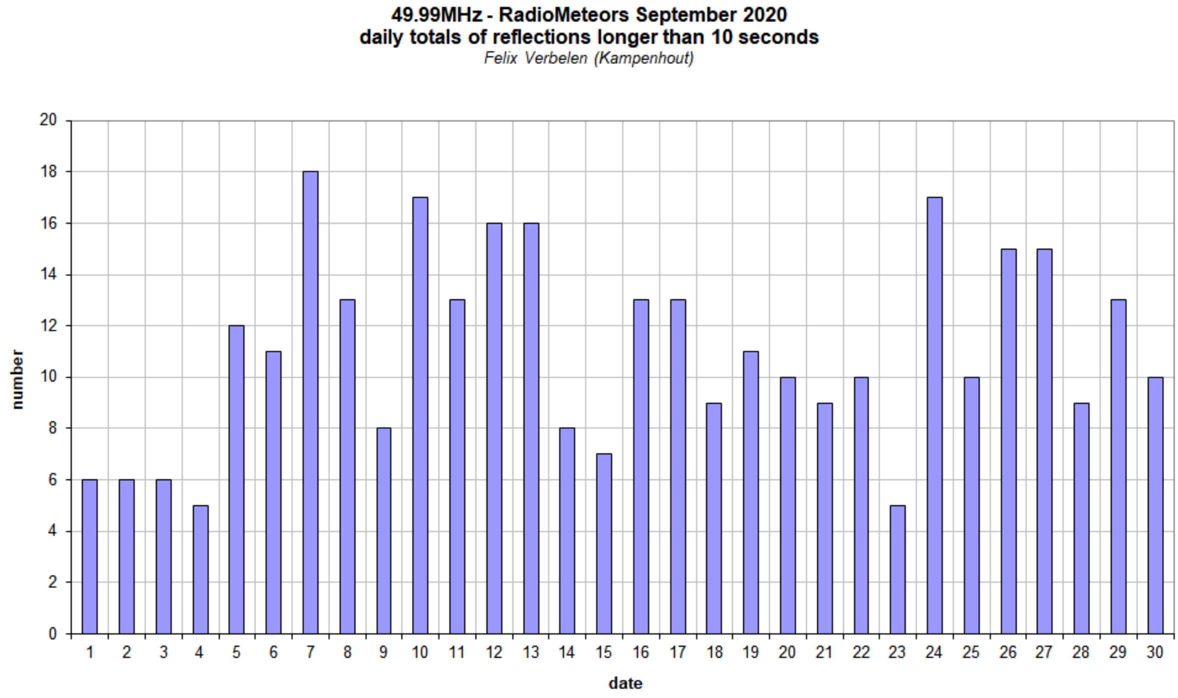




*Figure 1* – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2020.



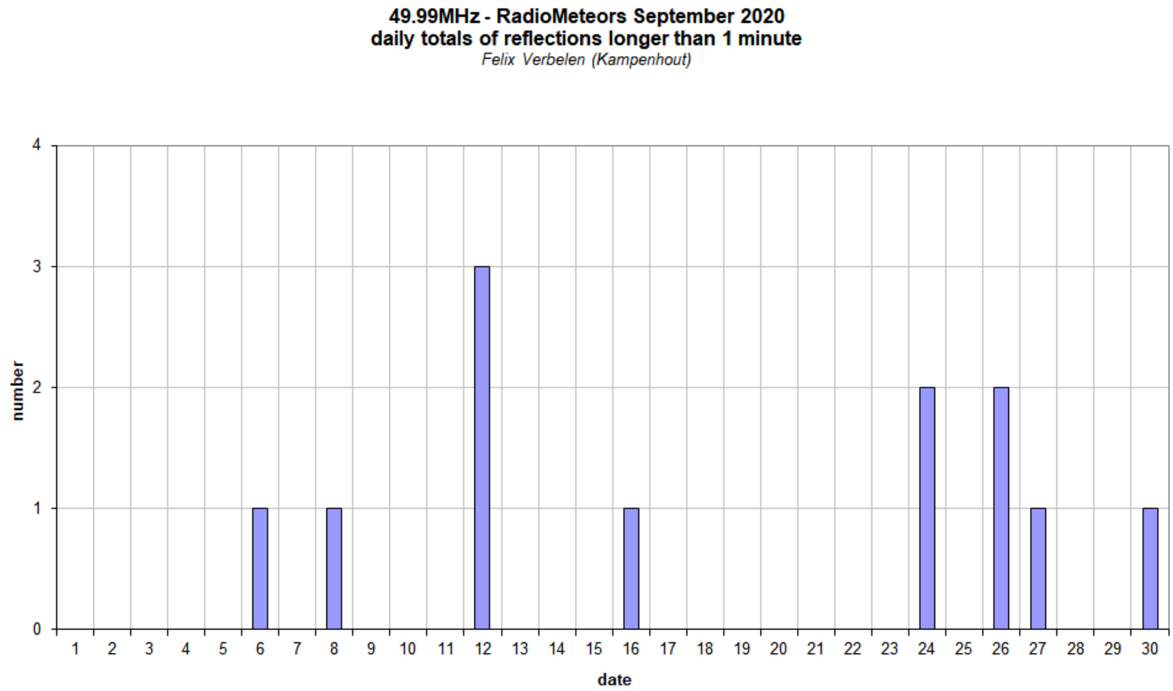
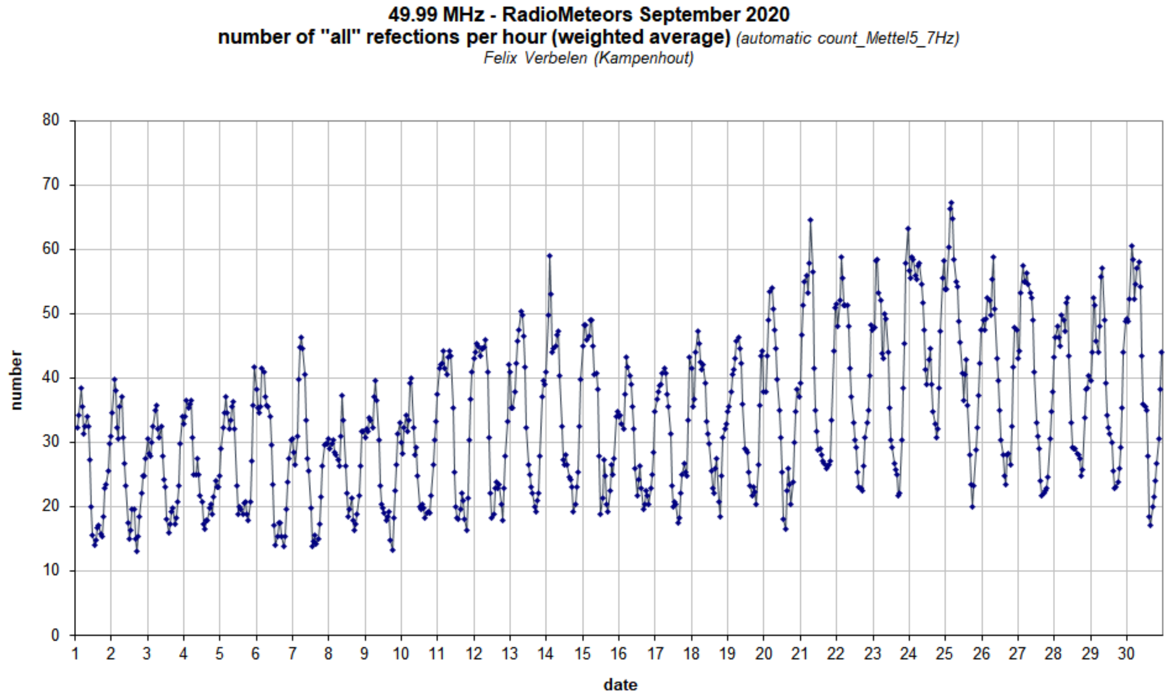




*Figure 2* – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2020.



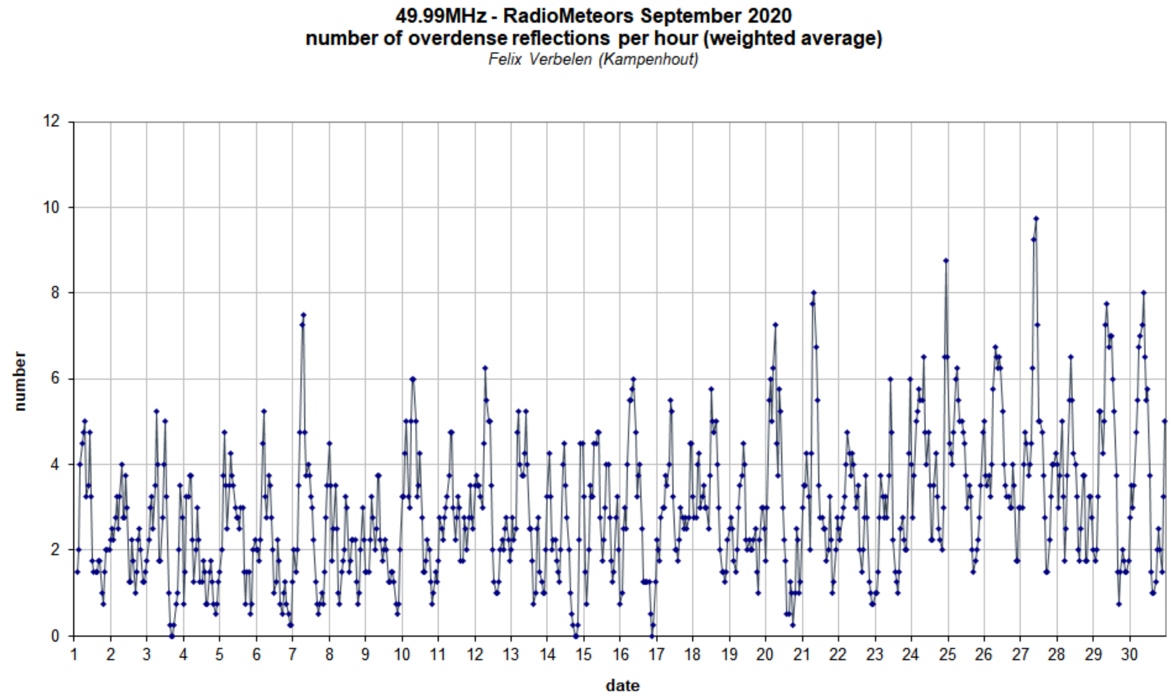
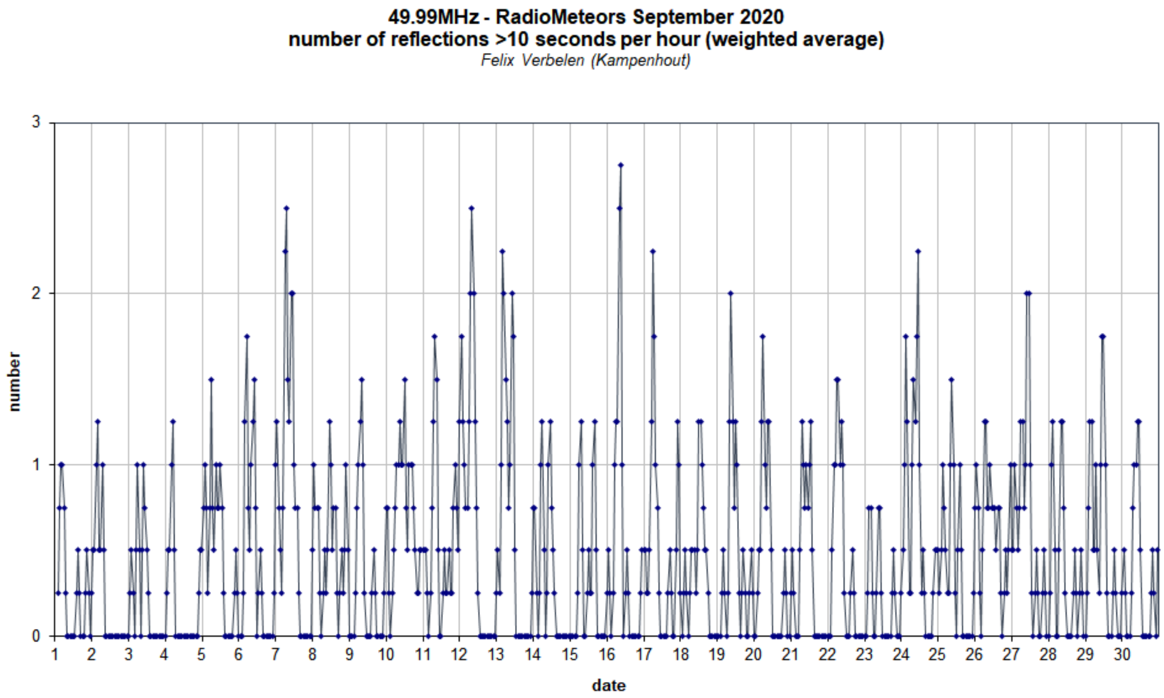




*Figure 3* – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2020.



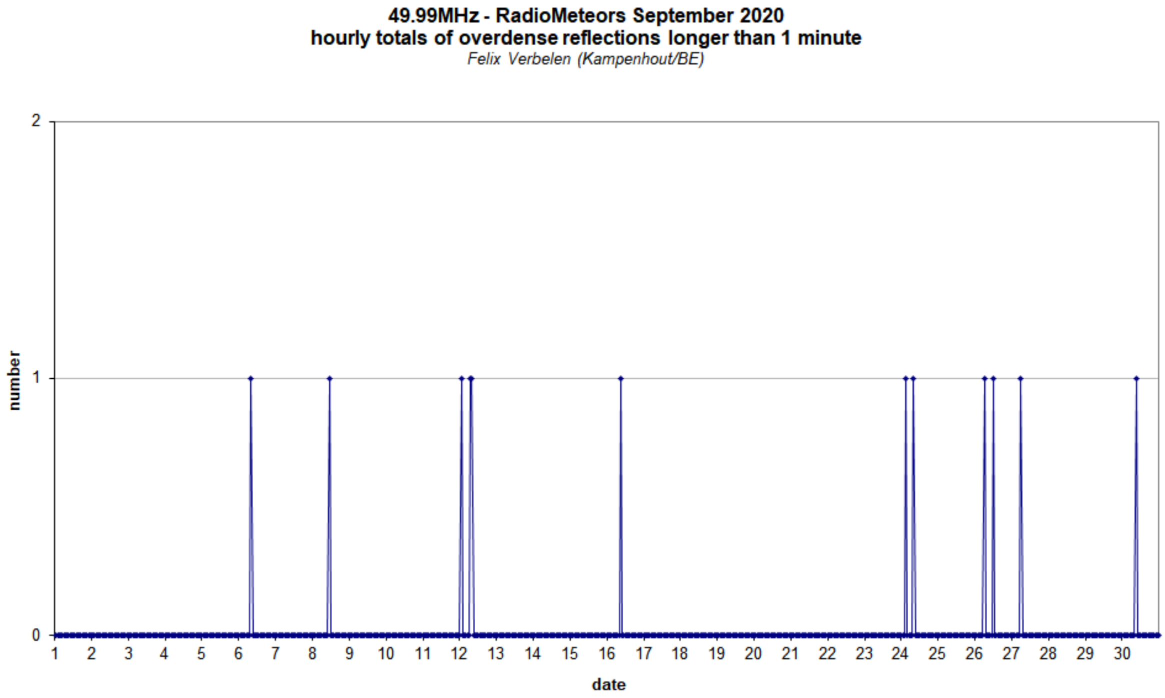




*Figure 4* – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2020.

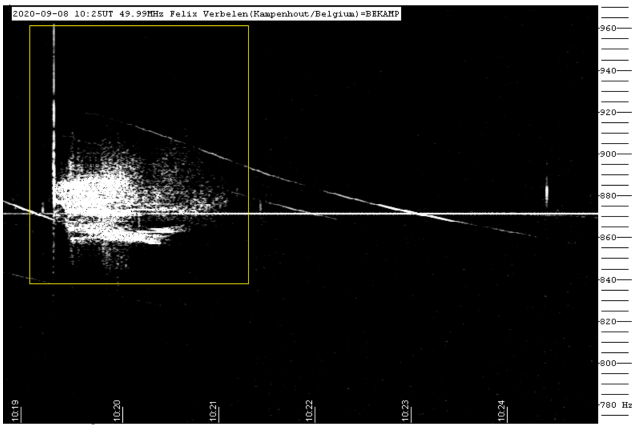



*Figure 5* – 2020 September 08 at 10$^h$25$^m$ UT.

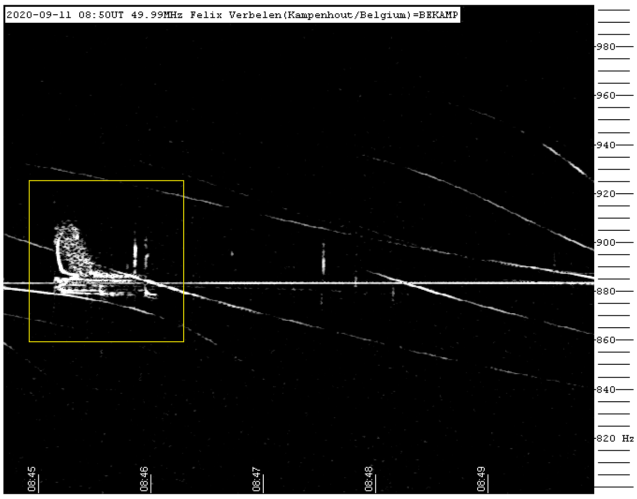



*Figure 6* – 2020 September 11 at 08$^h$50$^m$ UT.

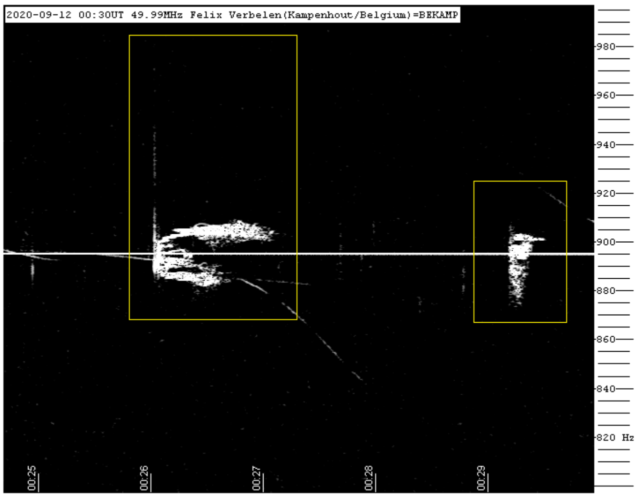



*Figure 7* – 2020 September 12 at 00$^h$30$^m$ UT.

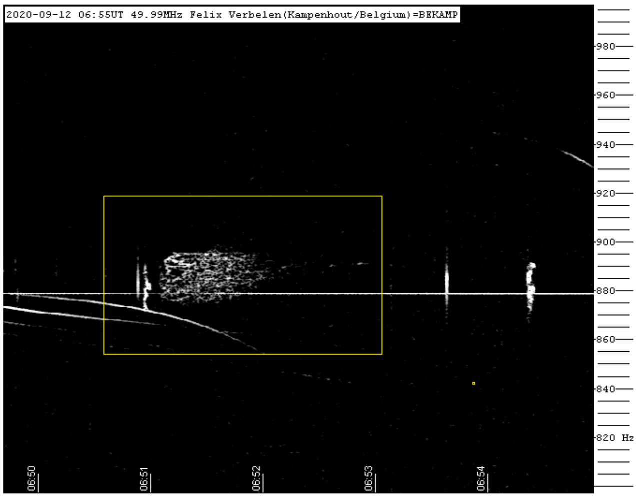



*Figure 8* – 2020 September 12 at 05$^h$55$^m$ UT.


*Figure 9* – 2020 September 12 at 07$^h$50$^m$ UT.

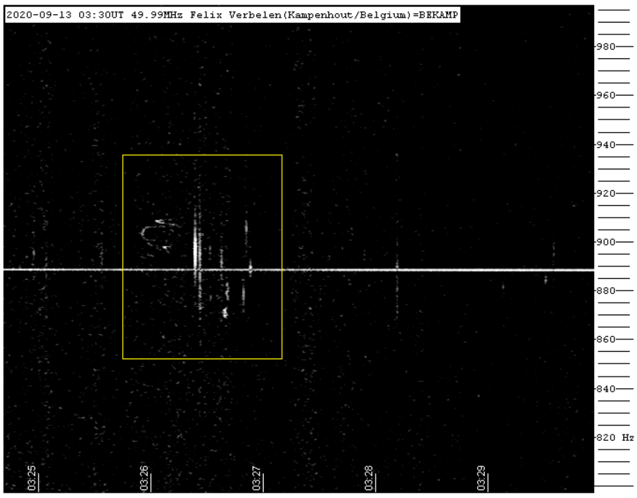



*Figure 10* – 2020 September 13 at 03$^h$30$^m$ UT.

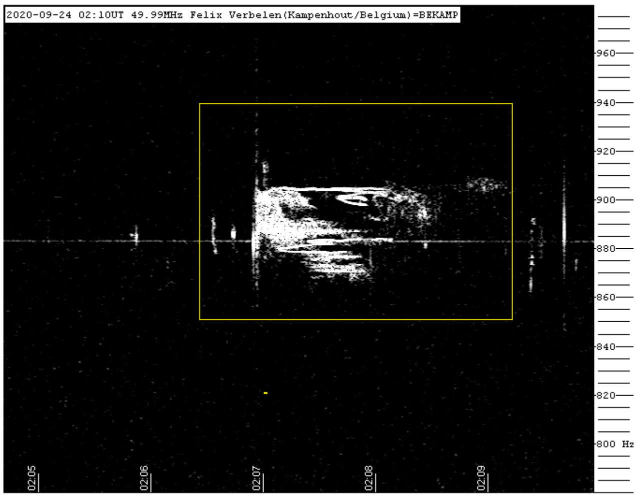



*Figure 11* – 2020 September 24 at 02$^h$10$^m$ UT.

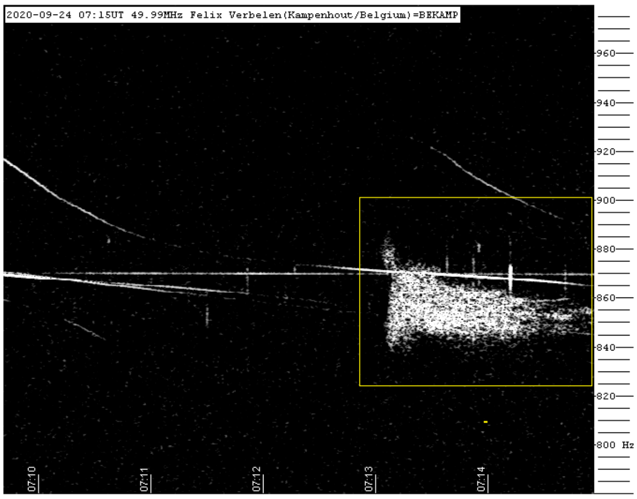



*Figure 12* – 2020 September 24 at 07$^h$15$^m$ UT.

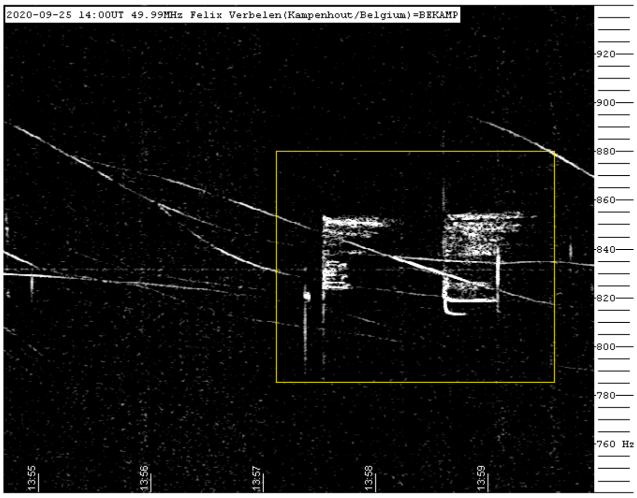



*Figure 13* – 2020 September 25 at 14$^h$00$^m$ UT.

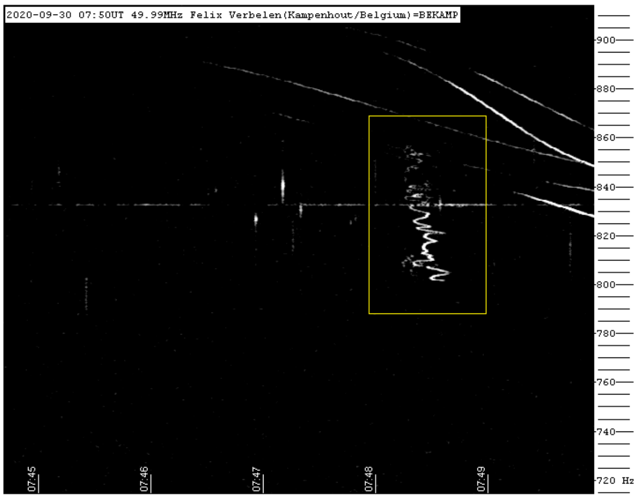



*Figure 14* – 2020 September 30 at 07$^h$50$^m$ UT.

# April Lyrids 2020 visual observations

**Pierre Martin**

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An overview is given of the 2020 meteor observations by the author, covering the April Lyrid meteor shower.

## 1 Observations April 22–23, 2020

I'm catching up on observations I've made so far this year, starting with the April Lyrids. The peak night was washed out, but the following night was crystal clear, so it was a good chance for me to see some post-maximum activity. I drove out late at night to a dark sky site near Renfrew, and it was a beautiful night. Light domes from distant city light pollution were possibly a bit lower than usual due to Covid-19 lockdowns. Despite a mild day, temperature dropped to –7C, and my only regret was not bringing a sleeping bag. I was well dressed for the weather, but I was a little bit chilled towards the end of the night.

Although the Lyrids were my main attention, I also kept an eye for minor activity including the possibility of Alpha Virginids (AVB#021) as stated in the IMO's 2020 Meteor Shower Calendar: "*There may be weak activity from the α-Virginids (021 AVB) related to the minor planet 2010GE35 on 2020 April 24 near $06^h25^m$ UT ($\lambda_\odot$ = 34.273°) from a radiant α = 198°, δ = +7°, showing slow meteors ($v_\infty$ = 18 km/s), according to theoretical modelling of Jérémie Vaubaillon. This is more than 30° apart from the ANT which is centered at α = 226°, δ = −17°.*".

As I setup, I saw a possible AVB high overhead, a slow and distinct meteor.

I had a great session! In three hours, I saw 36 meteors (15 Lyrids, 2 anthelions, 2 Alpha Virginids candidates and 17 sporadics). One of the AVB's was a very slow +1 golden meteor moving from Corona Borealis to Hercules. The highlight was a –5 blue-green SPO fireball earthgrazer low in the west that moved slowly for 50 degrees, lasted several seconds and fragmented at the end of its path!

Observation April 22–23, 2020, $05^h25^m$–$08^h25^m$ UT ($01^h25^m$–$04^h25^m$ EDT). Location: Renfrew, Ontario, Canada (45°25'48"N 76°38'24"W).

Observed showers:

- h Virginids (HVI) – $12^h56^m$ (194°) –08°
- Anthelion (ANT) – $14^h44^m$ (221°) –16°
- Lyrid (LYR) – $18^h09^m$ (272°) +33°
- eta Aquariids (ETA) – $21^h34^m$ (323°) –07°
- Alpha Virginids (021 AVB) – $13^h12^m$ (198) +07°

$05^h25^m$–$06^h25^m$ UT ($01^h25^m$–$02^h25^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.38; facing SSE50 deg; $t_{eff}$ 1.00 hr.

- LYR: seven: 0; +1; +2; +3(2); +5(2)
- ANT: one: +5
- AVB: one: +2
- Sporadics: five: –5; +3; +4(2); +5
- Total meteors: Fourteen

$06^h25^m$–$07^h25^m$ UT ($02^h25^m$–$03^h25^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.43; facing SSE50 deg; $t_{eff}$ 1.00 hr.

- LYR: three: +3(2); +4
- ANT: one: 0
- AVB: one: +1
- Sporadics: seven: +2; +3(3); +4(2); +5
- Total meteors: Twelve

$07^h25^m$–$08^h25^m$ UT ($03^h25^m$–$04^h25^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.43; facing SSE50 deg; $t_{eff}$ 1.00 hr.

- LYR: five: 0; +1; +2; +4; +5
- Sporadics: five: +3(2); +4; +5(2)
- Total meteors: Ten

## 2 Observations April 23–24, 2020

On the following night, I observed for two hours. The sky was decent but not quite as good as the previous night with occasional cirrus clouds, and reduced transparency.

In nearly two hours, I saw 11 meteors (4 anthelions, 1 Lyrid and 6 sporadics). The Lyrids were clearly on the way out with only one seen. No Alpha Virginids candidates were seen. The highlight was a pair of ANT meteors seen just two seconds apart at 2h00m am EDT.

Observation April 23–24, 2020, $05^h10^m$–$07^h00^m$ UT ($01^h10^m$–$03^h00^m$ EDT). Location: Renfrew, Ontario, Canada, (45°25'48"N 76°38'24"W).

Observed showers:

- h Virginids (HVI) – $12^h56^m$ (194°) –08°
- Anthelion (ANT) – $14^h44^m$ (221°) –16°
- Lyrid (LYR) – $18^h09^m$ (272°) +33°
- eta Aquariids (ETA) – $21^h34^m$ (323°) –07°
- Alpha Virginids (021 AVB) – $13^h12^m$ (198°) +07°

05$^h$10$^m$–06$^h$10$^m$ UT (01$^h$10$^m$–02$^h$10$^m$ EDT); A few clouds; 3/5 trans; *F* 1.01; *LM* 6.25; facing S55 deg; $t_{eff}$ 1.00 hr.

- ANT: three: +4(2); +5
- Sporadics: three: +1; +3; +5
- Total meteors: Six

06$^h$10$^m$–07$^h$00$^m$ UT (02$^h$10$^m$–03$^h$00$^m$ EDT); increasing clouds; 3/5 trans; *F* 1.08; *LM* 6.30; facing S55 deg; $t_{eff}$ 0.83 hr.

- LYR: one: +4
- ANT: one: +1
- Sporadics: three: +3; +4; +5
- Total meteors: Five

# Visual observations May 23–24, 2020

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An overview is given of the visual meteor observations by the author in May 2020.

## 1 Observations May 23–24, 2020

A very clear sky on May 23 lured me out to the Renfrew area to observe for a couple of hours around midnight. The mosquitoes were vicious early in the evening, but nearly absent when the temperature cooled down later on. I watched from 11pm–1am EDT and I saw only 5 meteors (1 anthelion and 4 sporadics). The first hour was entirely absent of meteors. Activity thankfully picked up a bit more during the second hour but it was still a pretty slow night. No tau Herculid candidates were seen.

My trusty chair finally broke after 20 years of use. I had to improvise a way to temporarily prop up the back so that I could continue this session, so all was well!

Observation May 23–24, 2020, $03^h00^m$–$05^h00^m$ UT ($23^h00^m$–$01^h00^m$ EDT). Location: Renfrew, Ontario, Canada, (45°25’48”N 76°38’24”W).

Observed showers:

- tau Herculids (TAH) – $14^h50^m$ (223°) +38°
- Anthelion (ANT) – $17^h00^m$ (255°) –23°
- June mu Cassiopeiids (JMC) – $23^h58^m$ (000°) +50°

$03^h00^m$–$04^h00^m$ UT ($23^h00^m$–$00^h00^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.30; facing S55 deg; $t_{eff}$ 1.00 hr.

- Total meteors: None

$04^h00^m$–$05^h00^m$ UT ($00^h00^m$–$01^h00^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.35; facing S55 deg; $t_{eff}$ 1.00 hr.

- ANT: one: +2
- Sporadics: four: +3(2); +4; +5
- Total meteors: Five

 

# Visual observations July, 2020

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An overview is given of the visual meteor observations by the author in July 2020, covering the Capricornids, Southern delta Aquariids and early Perseids.

## 1 Observations July 17–18, 2020

The morning of July 18 was my first of a series to observe the summer meteor activity. At this time of the year, several minor shower radiants are active and the famous Perseids are slowly coming to life. It was a very mild 20C (68F) even late at night, so no sleeping bag was required. The mosquitoes were a pest but I managed to keep them under control with my thermacell. The sky was slightly hazy with average quality transparency (*LM* 6.4).

In an hour and a half, I saw 17 meteors (4 anthelions, 2 July gamma Draconids, 2 Perseids, 2 phi Piscids, 1 July Pegasid, 1 psi Cassiopeiid, 1 c-Andromedid and 4 sporadics). The meteors seen were not particularly bright but the nicest one was a +3 GDR that moved a long 20 degrees path and flared twice.

Observation July 17–18, 2020, $06^h00^m$–$07^h30^m$ UT ($02^h00^m$–$03^h30^m$ EDT). Location: Bootland Farm (Stewartville), Ontario, Canada, (45°23’N 76°29’W).

Observed showers:

- July gamma Draconids (GDR) – $18^h24^m$ (276°) +50°
- alpha Capricornids (CAP) – $19^h40^m$ (295°) –12°
- Anthelion (ANT) – $20^h36^m$ (309°) –19°
- Northern June Aquilids (NZC) – $21^h40^m$ (325°) –01°
- South delta Aquariids (SDA) – $22^h00^m$ (330°) –21°
- epsilon Pegasids (EPG) – $22^h29^m$ (337°) +16°
- July Pegasids (JPE) – $23^h41^m$ (355°) +13°
- Perseids (PER) – $00^h48^m$ (012°) +51°
- zeta Cassiopeiids (ZCS) – $00^h58^m$ (014°) +53°
- eta Eridanids (ERI) – $01^h37^m$ (024°) –19°
- 49 Andromedids (FAN) – $01^h37^m$ (024°) +48°
- psi Cassiopeiids (PCA) – $02^h06^m$ (032°) +73°
- phi Piscids (PPS) – $02^h06^m$ (032°) +31°
- c-Andromedids (CAN) – $02^h40^m$ (040°) +51°
- July chi Arietids (JXA) – $02^h45^m$ (041°) +11°

$06^h00^m$–$07^h00^m$ UT ($02^h00^m$–$03^h00^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.39; facing S50 deg; $t_{eff}$ 1.00 hr.

- ANT: three: +4; +5(2)
- GDR: two: +3(2)
- PCA: one: +5
- PPS: one: +3
- CAN: one: +3
- Sporadics: four: +4; +5(3)
- Total meteors: Twelve

$07^h00^m$–$07^h30^m$ UT ($03^h00^m$–$03^h30^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.39; facing S50 deg; $t_{eff}$ 0.50 hr.

- PER: two: +2; +3
- ANT: one: +5
- JPE: one: +2
- PPS: one: +3
- Sporadics: none
- Total meteors: Five

## 2 Observations July 28–29, 2020

The period towards near the end of July has long been one of my favorites of the year to observe meteors. There is always a wide variety of meteors visible especially after midnight. The Southern delta Aquariids reach a broad peak, the slow moving Capricornids are active, the swift Perseids are ramping up, and there’s a bunch of other minor showers adding up to the overall counts. On this night, the various cloud model forecasts showed that the sky would clear up near 1am with very good transparency, just as the Moon set. I decided to venture out to Westmeath Lookout, a beautiful elevated site located north-west of Cobden. When I got there, the sky was still more than half cloudy. I saw a number of meteors in the clear patches so I could tell the activity was quite good. Unfortunately, the wind seemed to have changed direction and the cloud cover persisted at this location. I knew I’d have zero luck if I stayed put. It appeared a bit clearer further north into Quebec, so I jumped in the car and drove another 20 minutes until I found a spot on the side of a quite farm road with an open view of the sky.

My effort only marginally paid off and all was not lost. It was on and off clouds until $3^h30^m$am EDT when it finally cleared enough (with 20% clouds) to observe formally for an hour. During that hour, I saw 14 meteors (7 South delta Aquariids, 1 anthelion, 1 July Pegasid, 1 Perseid, 1 eta Eridanid and 3 sporadics). The best meteor was a nice mag

0 eta Eridanid that shot degrees and left a one second train. It was not all that quiet out there: The cows moo'ed non stop, echoing through the fields, and occasional distant flashes and "thump" sounds of artillery fire exercises at CFB Petawawa were heard.

Observation July 28–29 2020, $07^h30^m$–$08^h30^m$ UT ($03^h30^m$–$04^h30^m$ EDT). Location: Chapeau, Quebec, Canada, (45.9795°, –77.1145°).

Observed showers:

- July gamma Draconids (GDR) – $18^h37^m$ (279°) +50°
- alpha Capricornids (CAP) – $20^h07^m$ (302°) –10°
- Anthelion (ANT) – $21^h04^m$ (316°) –17°
- North delta Aquariids (NDA) – $22^h00^m$ (330°) –05°
- South delta Aquariids (SDA) – $22^h26^m$ (337°) –18°
- July Pegasids (JPE) – $00^h04^m$ (001°) +15°
- Perseids (PER) – $01^h29^m$ (022°) +53°
- eta Eridanids (ERI) – $02^h01^m$ (030°) –17°
- 49 Andromedids (FAN) – $02^h07^m$ (032°) +50°
- phi Piscids (PPS) – $02^h33^m$ (038°) +33°
- psi Cassiopeiids (PCA) – $02^h54^m$ (043°) +75°
- July chi Arietids (JXA) – $03^h12^m$ (048°) +13°

$07^h30^m$–$08^h30^m$ UT ($03^h30^m$–$04^h30^m$ EDT); cirro-cumulus clouds; 3/5 trans; *F* 1.14; *LM* 6.16; facing S60 deg; $t_{eff}$ 1.00 hr.

- SDA: seven: +2; +3(3); +4(3)
- ANT: one: +3
- JPE: one: +5
- PER: one: +5
- ERI: one: 0
- Sporadics: three: +1; +2; +5
- Total meteors: Fourteen

## 3 Observations July 29–30, 2020

I had much better luck on this night at Bootland Farm, a dark site located south-west of Arnprior. The post-midnight sky was completely clear with above average transparency, and it looked fantastic! The Milky Way was thick and the Summer Triangle was full of faint stars. In fact, I was impressed at the sky quality even just prior to the waxing gibbous moon setting at $1^h41^m$am EDT. Ground fog was a concern but it was never too thick to cause any issues, however it was very dewy. Temperature was just cool enough to prevent any mosquitoes from being a pest.

In three hours until morning dawn, I saw 76 meteors (37 South delta Aquariids, 9 Perseids, 5 49-Andromedids, 4 alpha Capricornids, 4 July Pegasids, 2 Anthelions, 2 eta Eridanids, 2 psi Cassiopeiids and 11 sporadics). The SDA's dominated all the other activity with my best rates from them seen during the first and final hours.

The highlight of the night was a 60 degrees long eta Eridanid earthgrazer! It only reached +4 but it was still a neat sight!

Also notable during this session was the high number of artificial satellites, including some very fast moving (low orbit) satellites during morning twilight.

All in all, a very enjoyable night with an average of a meteor every two of three minutes!

Observation July 29–30 2020, $05^h30^m$–$08^h34^m$ UT ($01^h30^m$–$04^h34^m$ EDT). Location: Bootland Farm (Stewartville), Ontario, Canada, (45°23'N 76°29'W).

Observed showers:

- July gamma Draconids (GDR) – $18^h37^m$ (279°) +50°
- alpha Capricornids (CAP) – $20^h07^m$ (302°) –10°
- Anthelion (ANT) – $21^h04^m$ (316°) –17°
- North delta Aquariids (NDA) – $22^h00^m$ (330°) –05°
- South delta Aquariids (SDA) – $22^h26^m$ (337°) –18°
- July Pegasids (JPE) – $00^h04^m$ (001°) +15°
- Perseids (PER) – $01^h29^m$ (022°) +53°
- eta Eridanids (ERI) – $02^h01^m$ (030°) –17°
- 49 Andromedids (FAN) – $02^h07^m$ (032°) +50°
- phi Piscids (PPS) – $02^h33^m$ (038°) +33°
- psi Cassiopeiids (PCA) – $02^h54^m$ (043°) +75°
- July chi Arietids (JXA) – $03^h12^m$ (048°) +13°

$05^h30^m$–$06^h30^m$ UT ($01^h30^m$–$02^h30^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.44; facing SSE50 deg; $t_{eff}$ 1.00 hr.

- SDA: seventeen: +1(2); +2(3); +3(4); +4(4); +5(4)
- CAP: two: +4; +5
- PER: two: +5(2)
- JPE: one: +3
- ERI: one: +4
- FAN: one: +3
- PCA: one: 0
- Sporadics: three: +3; +4(2)
- Total meteors: Twenty-eight

$06^h30^m$–$07^h30^m$ UT ($02^h30^m$–$03^h30^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.54; facing SSE50 deg; $t_{eff}$ 1.00 hr.

- SDA: six: +3; +4(2); +5(3)
- PER: five: +1; +2(2); +3; +4
- CAP: two: +3(2)
- FAN: two: +5(2)
- JPE: two: +2(2)
- ANT: one: +5
- Sporadics: seven: +2; +4(3); +5(3)
- Total meteors: Twenty-five

$07^h34^m$–$08^h34^m$ UT ($03^h34^m$–$04^h34^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.37; facing S50 deg; $t_{eff}$ 1.00 hr.

- SDA: fourteen: +2(2); +3(6); +4(3); +5(3)
- PER: two: +2; +4
- FAN: two: +4; +5
- ANT: one: +4
- JPE: one: +4
- ERI: one: +5

- PCA: one: +5
- Sporadics: one: +1
- Total meteors: Twenty-three

# 4 Observations July 30–31, 2020

The weather continued to be favorable so I went out again on the July 30–31 night to observe during the short two hours window before dawn (moonset at 2h34mam). The sky was again very clear, although the temperature was warmer at 18°C so the pesky bugs were out, but they were not too bad.

In two hours, I saw 55 meteors (14 South delta Aquariids, 9 Perseids, 5 North delta Aquariids, 3 alpha Capricornids, 3 July chi Arietids, 2 49-Andromedids, 2 psi Cassiopeiids, 2 July Pegasids, 1 Anthelion, 1 July gamma Draconid and 13 sporadics). It's a bit challenging keeping track of all these radiants at this time of the year, but that is part of the fun!

The nicest meteor was at 2h32mam; a mag –1 yellow-orange CAP near the zenith, that traced a 15 degrees path. A close second was at 4h13mam; a –3 blue PER in Aquarius that flared and left a 3 sec train.

Observation July 30–31 2020, 06h25m–08h30m UT (02h25m–04h30m EDT). Location: Bootland Farm (Stewartville), Ontario, Canada, (45°23'N 76°29'W).

Observed showers:

- July gamma Draconids (GDR) – 1h37m (279°) +50°
- alpha Capricornids (CAP) – 20h30m (309°) –09°
- Anthelion (ANT) – 21h28m (322°) –15°
- North delta Aquariids (NDA) – 22h26m (336°) –02°
- South delta Aquariids (SDA) – 22h53m (343°) –15°
- Piscis Austrinids (PAU) – 23h08m (347°) –23°
- July Pegasids (JPE) – 00h04m (001°) +15°
- Perseids (PER) – 02h09m (032°) +55°
- eta Eridanids (ERI) – 02h26m (036°) –15°
- 49 Andromedids (FAN) – 02h36m (039°) +53°
- psi Cassiopeiids (PCA) – 02h54m (043°) +75°
- July chi Arietids (JXA) – 03h12m (048°) +13°

06h25m–07h25m UT (02h25m–03h25m EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.45; facing S50 deg; $t_{eff}$ 1.00 hr.

- SDA: six: +1; +2(2); +4(3)
- PER: four: +1; +4(2); +5
- CAP: three: –1; +3(2)
- JXA: two: +4; +5
- GDR: one: +3
- ANT: one: +5
- NDA: one: +5
- FAN: one: +5
- PCA: one: +4
- JPE: one: +4
- Sporadics: five: +2; +5(4)
- Total meteors: Twenty-six

07h25m–08h30m UT (03h25m–04h30m EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.19; facing S50 deg; $t_{eff}$ 1.08 hr.

- SDA: eight: +2(2); +3(2); +4(2); +5(2)
- PER: five: –3; +2; +4(2); +5
- NDA: four: +3(3); +5
- JPE: one: +5
- FAN: one: +5
- PCA: one: +3
- JXA: one: +5
- Sporadics: eight: +3(2); +4(3); +5(3)
- Total meteors: Twenty-nine

# Visual observations August, 2020

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An overview is given of the visual meteor observations by the author in August 2020, covering the Perseid maximum.

## 1 Observations August 7–8, 2020

On the evening of August 7, I enjoyed a short one-hour meteor session just as the gibbous moon was rising in the east. To minimize the glare, I faced the north-north-east to keep the Perseids radiant in view.

During that hour, I saw 10 meteors (7 Perseids, 1 Anthelion and 2 sporadics). These numbers are quite low, but it was quite early in the night and the moon was very bright. There were a few nice Perseids that reached +1 and 0. The brightest one left a two sec train.

Observation August 7–8 2020, $02^h50^m$–$03^h52^m$ UT ($22^h50^m$–$23^h52^m$ EDT). Location: Bootland Farm (Stewartville), Ontario, Canada, (45°23’N 76°29’W).

Observed showers:

- kappa Cygnids (KCG) – $18^h52^m$ (283°) +48°
- alpha Capricornids (CAP) – $21^h01^m$ (315°) –07°
- Anthelion (ANT) – $21^h56^m$ (329°) –13°
- North delta Aquariids (NDA) – $22^h51^m$ (343°) +00°
- South delta Aquariids (SDA) – $23^h20^m$ (350°) –13°
- Piscis Austrinids (PAU) – $23^h34^m$ (353°) –20°
- Perseids (PER) – $02^h49^m$ (042°) +57°
- eta Eridanids (ERI) – $02^h50^m$ (042°) –13°

$02^h50^m$–$03^h52^m$ UT ($22^h50^m$–$23^h52^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 5.95; facing NNE60 deg; $t_{eff}$ 1.01 hr.

- PER: seven: 0; +1(2); +2; +3; +4(2)
- ANT: one: +3
- Sporadics: two: +4(2)
- Total meteors: Ten

Breaks: $02^h55^m$–$02^h56^m$ UT (1 min dead time).

*Figure 1* – Composite image of 19 Perseids, Canon 5D, Rokinon 24mm f/1.4, 40 sec x 19 exposures, ISO 1600. By Pierre Martin.

*Figure 2* – Composite image of 7 Perseids in the fog, Canon 6D, Rokinon 14mm f/2.8, 25 sec x 7 exposures, ISO 3200. By Pierre Martin.

## 2 Observations August 11–12–13, 2020

For the Perseids peak nights, I made plans with Raymond Dubois and Nicholas Zuger to get together at the Irvine Lake airstrip; a very dark sky site located south of Denbighand about a two hours' drive west of Ottawa. The weather was favorable for both nights (August 11–12 and 12–13) at this location so we opted to pack all the camping gear, food, observing and photography equipment that we'd need to spend the two nights. The site is just a very wide-open area without any facilities, so being well prepared is an absolute must!

**August 11–12 2020 summary**

On the first night, I arrived just past 11pm. Raymond greeted me and he was all setup with his cameras and ready to go. Another small group of people (Off Roading Club) were camping out at the north end of the airstrip and they were very respectful in minimizing and blocking lights for us. The sky overhead was impressively clear but the humidity was building up quickly due to the rain from earlier in the day. I debated between observing right away or setting up my tracking mount and cameras. I decided to setup the equipment first and wait for the radiant to rise up higher before beginning to observe. Unfortunately, fog was building up and intensified until the sky quality suffered significantly. Eventually, the fog became so thick that formal counts would be impossible on this night, but I managed to get some images (*Figures 1 and 2*).

**August 12–13 2020 summary**

We were thankful for the morning sun to help dry up the damp equipment after the humid night. It quickly got hot

*Figure 3* – Composite image of 87 Perseids, Canon 6D, Rokinon 14mm f/2.8, 30 sec x 87 exposures, ISO 3200. By Pierre Martin.

*Figure 4* – Composite image of 88 Perseids, Canon 5D, Rokinon 24mm f/1.4, 30 sec x 88 exposures, ISO 1600. By Pierre Martin.

and humid (over 30°C) and staying in the shade to stay cool was a must. We spent the day adjusting equipment, enjoying conversations, napping and getting ready for another clear (and hopefully) dryer night. Nicholas Zuger arrived late in the afternoon and so far the weather was looking really promising. Indeed, we were treated to a splendid night that was not only much dryer but also crystal clear with above-average transparency all the way until the morning! Prior to $12^h32^m$am moonrise, the sky reached *LM* = 6.85 and the Milky Way was very impressive. Irvine Lake airstrip has a small hill and tree line to the east that was advantageous in blocking the moon until we could finally see it after $2^h00^m$ am (EDT). The limiting magnitude dropped very gradually in the hour after moonrise, and the sky quality remained good even as the moon rose up high late at night. I avoided the glare by keeping my field of view facing to the north.

What a great night with a lot of action! As soon as my cameras were up and running, I started visual observing soon after $10^h00^m$ pm (EDT) and I continued until $5^h00^m$ am the next morning, for a total of 6 hours of observing (excluding breaks). In that time, I counted 296 meteors (252 Perseids, 7 South delta Aquariids, 4 Anthelions, 4 North delta Aquariids, 2 kappa Cygnids, 1 eta Eridanid and 26 sporadics). PER hourly rates were: 35, 30, 54, 45, 51 and 37 (the final count was a little less than an hour in brightening twilight). These rates were better than I expected especially due to the fact that the traditional peak was expected to occur nearly a day earlier. There was a mix of both bright and faint Perseids. The brightest Perseid was a –5 fireball seen at $12^h51^m$ am that had a terminal flash and a 12 seconds train. I was impressed at Nicholas's ability to see extremely faint meteors with ease — he has young eyes. It was fun to talk about meteor magnitudes estimations and then listen to Nicholas practice this skill.

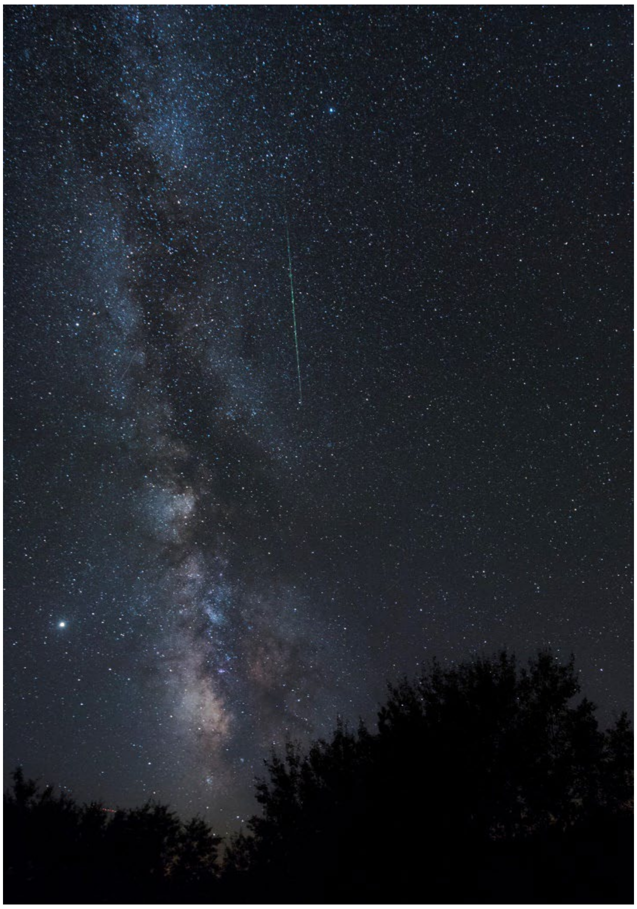

*Figure 5* – Summer Milky Way and a Perseid, Nikon D750, Tamron 15-30mm f/2.8, 15 sec exposure, ISO 3200.

*Figure 6* – The observing site.

*Figure 7* – The observing site.

*Figure 8* – The observing site.

The night had several more highlights… A sporadic earthgrazer was seen at $1^h17^m$ am (EDT) moving very slowly, parallel to the horizon in the north, heading from west to east, and lasting several seconds! At $2^h35^m$ am, we unexpectedly saw a StarLink satellite train from a recent launch and deployment — dozens of satellites all in a tight "string" moving from west to east. It was my first such sighting, and it was equally fascinating and concerning. At $3^h08^m$ am, the whole sky lit up in a flash. None of us saw the meteor. We looked around and found a persistent train left over from a Perseid fireball in the east near the Moon that lasted a good 20 seconds! It was one of those nights you wished didn't end.

*Figure 9* – The observing site.

*Figure 10* – The observing site.

### August 12–13 2020 Visual Details

Observer: Pierre Martin[21] (Session[22]). Session Date: August 12–13 2020, $02^h09^m$–$09^h00^m$ UT ($22^h09^m$–$05^h00^m$ EDT). Location: Irvine Lake Airstrip, Denbigh, Ontario, Canada (Lng: –77 deg 15'46" W; lat: 45 deg 1'47" N).

Observed showers:

- August Draconids (AUD) – $18^h00^m$ (270°) +59°
- kappa Cygnids (KCG) – $18^h52^m$ (283°) +48°

[21] https://www.imo.net/members/imo_user/profile/?user_id=8022

[22] https://www.imo.net/members/imo_vmdb/view?session_id=81140

- alpha Capricornids (CAP) – $21^h01^m$ (315°) –07°
- Anthelion (ANT) – $21^h56^m$ (329°) –13°
- North delta Aquariids (NDA) – $22^h51^m$ (343°) +00°
- South delta Aquariids (SDA) – $23^h20^m$ (350°) –13°
- Piscis Austrinids (PAU) – $23^h34^m$ (353°) –20°
- Perseids (PER) – $02^h49^m$ (042°) +57°
- eta Eridanids (ERI) – $02^h50^m$ (042°) –13°

$02^h09^m$–$03^h15^m$ UT ($22^h09^m$–$23^h15^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.85; facing NE50 deg; $t_{eff}$ 1.00 hr.

- PER: thirty-five: –2; –1; 0; +1(7); +2(8); +3(8); +4(4); +5(5)
- KCG: one: +2
- ANT: one: +4
- NDA: one: +4
- SDA: one: 0
- Sporadics: one: +4
- Total meteors: Forty

$03^h15^m$–$04^h35^m$ UT ($23^h15^m$–$00^h35^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.85; facing NE55 deg; $t_{eff}$ 1.00 hr.

- PER: thirty: –1(2); 0(3); +1(8); +2(4); +3(4); +4(2); +5(7)
- ANT: two: +3; +4
- SDA: two: +3; +4
- NDA: one: +3
- Sporadics: two: +3; +4
- Total meteors: Thirty-seven

$04^h35^m$–$05^h42^m$ UT ($00^h35^m$–$01^h42^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.68; facing N55 deg; $t_{eff}$ 1.01 hr.

- PER: fifty-four: –5; –3; –1; 0(2); +1(4); +2(7); +3(11); +4(11); +5(15); +6
- SDA: four: 0(2); +2; +3
- KCG: one: +4
- ANT: one: +3
- Sporadics: nine: +1; +3; +4; +5(6)
- Total meteors: Sixty-nine

$05^h42^m$–$07^h03^m$ UT ($01^h42^m$–$03^h03^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.42; facing N60 deg; $t_{eff}$ 1.00 hr.

- PER: forty-five: –2(2); –1; +1(4); +2(12); +3(9); +4(11); +5(6)
- NDA: one: +3
- Sporadics: four: +4(2); +5(2)
- Total meteors: Fifty

$07^h03^m$–$08^h05^m$ UT ($03^h03^m$–$04^h05^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 6.28; facing N60 deg; $t_{eff}$ 1.00 hr.

- PER: fifty-one: –3; –2; –1; 0; +1(4); +2(9); +3(11); +4(13); +5(10)
- NDA: one: +3
- Sporadics: six: +2; +3; +4; +5(3)
- Total meteors: Fifty-eight

$08^h05^m$–$09^h00^m$ UT ($04^h$05m–$05^h00^m$ EDT); clear; 4/5 trans; *F* 1.00; *LM* 5.76; facing N60 deg; $t_{eff}$ 0.866 hr.

- PER: thirty-seven: 0(3); +1(4); +2(9); +3(9); +4(6); +5(6)
- ERI: one: +1
- Sporadics: four: +2(2); +4(2)
- Total meteors: Forty-two

Breaks (UT): $02^h35^m$–$02^h41^m$, $04^h02^m$–$04^h22^m$, $05^h02^m$–$05^h04^m$, $05^h05^m$ (30 sec), $05^h15^m$–$05^h19^m$, $06^h00^m$–$06^h14^m$, $06^h15^m$–$06^h22^m$, $08^h01^m$–$08^h03^m$, $08^h33^m$–$08^h36^m$.

Dead time: 58.5 minutes

Thank you to Raymond Dubois and Nicholas Zuger for the enjoyable company on this outing.

# Perseid observations from Ermelo, the Netherlands

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A report is presented about the visual meteor observations by the author during the 2020 Perseid activity.

## 1 Introduction

In 2019, a number of participants decided to repeat the 2018 observing campaign in the Provence. For various reasons one week had been foreseen this year in Revest du Bion, the location where we stayed during the Perseids in 2014, 2015, 2016 and 2017. Unfortunately, due to the corona virus we had to cancel our journey to this location. The author had holidays from 18 July to 3 August. No plans were made for an alternative location, so any observations would have to take place from Ermelo in the Netherlands.

## 2 Comet C / 2020 F3 NEOWISE

In the run-up to the holiday, it turned out that Comet C/2020 F3 NEOWISE became much brighter than predicted. I was able to observe and photograph the comet on July 7, 12, 15 and 21. Visually, the comet was especially worthwhile on July 12, when I visually saw a tail of 3 degrees and estimated the comet at magnitude +1.5.

## 3 Meteor observations

Unfortunately, the weather hardly cooperated during the holiday period in the Netherlands. Only three nights allowed observations.

### 2020 July 20–21[23]

The plan for this night was first to photograph Comet C/2020 F3 NEOWISE and then to observe meteors for a few hours. Unfortunately, it remained a failed attempt on the Groevenbeekse Heide to capture the comet due to equipment failure (the battery did not work properly due to leakage of one of the cells) and when that was finally resolved, it became cloudy.

Fortunately, after a while the clouds dissolved and I could start at $22^h45^m$ UT. The Groevenbeekse Heide is not completely flat, but there are walls created after the last Ice Age. Normally I lie in the lee of such a wall, but due to fog formation I decided to observe at the highest point. I was just above the fog layer. Unfortunately, it didn't take long when clouds started to appear again and I ended the session early.

Between $22^h45^m$ and $23^h27^m$ UT I saw 9 meteors (lm 6.3) with 1 southern delta Aquariid (SDA), 1 Antihelion (ANT) meteor and my first Perseid (PER). No spectacular appearances, a +2 SDA was the most beautiful meteor.

*Figure 1* – Comet C / 2020 F3 NEOWISE photographed on July 12, 2020 around $01^h47^m$ UT. Camera: Sony Alpha A7s mark II. Lens: Canon 85mm F 1.8.

[23] https://www.imo.net/members/imo_vmdb/view?session_id=80662

**2020 July 21–22**[24]

This was the first successful meteor watch from the Groevenbeekse Heide. This session was ended a little earlier due to incoming clouds. Observations were done between 22ʰ15ᵐ and 01ʰ12ᵐ UT, 2.90 hours effective under highly transparent conditions with the lm rising to 6.4. Highest SQM value was 20.47.

The Perseids showed 3 meteors in the second and third hour. These were only faint meteors of +3 and +4. This also applied to the southern delta Aquariids (SDA), with only two of them in the last hour. The Capricornids did well. I counted 2, 1 and 1 per hour respectively. The last was a nice –2 Capricornid in Andromeda at 01ʰ02ᵐ UT. This was also captured with the alls ky camera. The sporadic meteors also showed beautiful things. At 22ʰ56ᵐ UT a yellow magnitude –1 from Pegasus towards Delphinus. Another yellow magnitude -1 traversed Hercules at 0ʰ14ᵐ UT. In total I saw 38 meteors, including 6 Perseids, 2 Southern delta Aquariids, 4 Capricornids, 3 Antihelions and 23 sporadic meteors. Attention was also paid to possible slow gamma Draconids (GDR) but nothing was seen from that region.

**2020 July 30–31**[25]

After more than a week with cloudy skies, it finally became clear on July 30th. In the meantime, the Moon had become quite a disturbing object again, it would only set around 23ʰ45ᵐ UT and was already far towards full (80%). The lack of clear weather last week made me decide to start as soon as it was dark enough. In addition, it was always nice to see how the ambiance of the night changes as the Moon gets lower and lower. And the sky was clear so I expected to see enough. The period at the end of July is also known for the many bright meteors.

Period 21ʰ45ᵐ–22ʰ46ᵐ UT, effective 1.00 hours, Lm 5.7 increasing to 6.0.

Despite the moonlight bucket 12 meteors (2 CAP, 2 PER, 8 SPO). The best was a +1 SPO in Cepheus at 21ʰ58ᵐ UT. A Capricornid of +2 was also nice.

Period 21ʰ46ᵐ–23ʰ47ᵐ UT, effective 1.00 hours, Lm 6.0 increasing to 6.3.

The Moon was now very low in southwestern direction and would set during this period. In this period 16 meteors were seen (2 CAP, 2 ANT, 2 PER, 2 SDA and 8 SPO). The most beautiful meteors were at 23ʰ01ᵐ UT (+1 sporadic in Andromeda) and 23ʰ33ᵐ UT (beautiful blue-green +1 Capricornid moving from Pegasus to Pisces).

Period 23ʰ47ᵐ–00ʰ48ᵐ UT, effective 1.00 hours, lm 6.3 increasing to 6.4.

The beautiful dark sky resulted in 22 meteors, including 4 PER, 4 SDA, 3 CAP, 1 ANT, 1 GDR and 9 SPO. Three meteors were worth mentioning. At 23ʰ50ᵐ UT there was a nice +1 Capricornid in Cassiopeia. A very slow +4 meteor moved from Cepheus to Cassiopeia. This was most likely a gamma Draconid. This meteor had a variable brightness gradient. The most beautiful meteor was a magnitude 0 Perseid with 3 seconds persistent train in Pegasus at 00ʰ43ᵐ UT.

Period 00ʰ48ᵐ–01ʰ49ᵐ UT, effective 1.00 hours, Lm 6.4 decreasing to 6.0.

Due to the setting twilight there were a bit less meteors: 16 in total. Amongst them 5 PER, 3 SDA, 1 CAP, 1 ANT and 6 SPO. The most beautiful meteor of this night was observed during this period. At 00ʰ56ᵐ UT my attention was drawn to “something” bright in a northerly direction. I saw a beautiful bright yellow –3 Southern delta Aquariid moving from Polaris into the Big Dipper. A short, lingering trail was visible. At 01ʰ44ᵐ UT another +1 Perseid was seen in Pegasus, adding a nice end of this fine session.

What a beautiful night! The good transparency, the very calm atmosphere on the heath, some bats and the great owl were also present. When I looked to the southwest around 01ʰ00ᵐ UT, I saw the planets Jupiter and Saturn low on the horizon, in the southeast the star Fomalhaut, a little higher the planet Mars. A part to the left of it the Hyades (with the bright star Aldebaran) and Pleiades and to its left the very bright planet Venus. The Milky Way visible from Perseus to Sagittarius! Wow!

Unfortunately, this was the last meteor watch of my holidays. On August 4 there was also the Full Moon and on August 5 started a heat wave in the Netherlands with regular (reasonably) clear nights. I wanted to resume observing after August 9, but there were regularly high clouds or haze that prevented me from observing. The night of August 10–11 would be the first clear enough night to do a meteor watch.

**2020 August 10–11**[26]

There would be no lunar disturbance during the first hour. However, I almost always have concentration problems when I observe in the evening. So, I just decided to do a morning session, despite the moonlight (almost last quarter).

Despite the slightly hazy skies and the Moon, there was plenty to see! Lm maximum 5.6 and later decreasing slightly. Observations were done between 01ʰ00ᵐ and 02ʰ35ᵐ UT from the meteor roof at home. A total of 19 PER, 1 SDA, 1 ANT and 6 SPO were seen, so 27 meteors in total. Two magnitude 0 Perseids were the highlight. At one point I saw a long lingering trail hanging in Cygnus: I thought: damn, what have I been missing? A fireball? But immediately I realized that this was the new Starlink train (belonging to L9, the tenth launch of this space junk). It was

[24] https://www.imo.net/members/imo_vmdb/view?session_id=80663

[25] https://www.imo.net/members/imo_vmdb/view?session_id=80700

[26] https://www.imo.net/members/imo_vmdb/view?session_id=80893

striking that the individual satellites were not as bright as in April. Then they sometimes became magnitude +1 or 0, now it was not brighter than +3 a +4. I counted about 25 satellites in this row. Several more Starlink satellites were seen in the following minutes.

The 4 CAMS systems registered 240 meteors.

### 2020 August 11–12

This night was 100% cloudy. CAMS only captured hundreds of lightning detections; the all sky captured a number of beautiful lightning bolts.

*Figure 2* – Lightning captured with the all sky camera on August 12, 2020.

### 2020 August 12–13[27]

The weather forecast for the Netherlands was not very good for the night of 12 on 13 August. Thunderstorms over Belgium and the south of the Netherlands created enormous ice caps (cirrus) that stretched over large parts of the Netherlands. Fortunately, in Ermelo things were not too bad. I was able to start around $20^h55^m$ UT and observe without clouds until $22^h30^m$ UT. The sky was hazy during that period. From $22^h30^m$ UT the cirrus slowly increased until I had to stop at $23^h00^m$ UT. In this period $20^h55^m$ to $23^h00^m$ UT I counted 38 PER, 1 KCG, 1 ANT and 9 SPO. The limiting magnitude reached 6.3 for half an hour and then decreased. During this period (effective 2.07 hours) several bright Perseids of –2 (2x), –1 (1x) and 0 (2x) were seen.

On SAT24 (handy such a smartphone!) I saw that new clear sky was approaching so I waited quietly on the heath. I could indeed observe again from $23^h45^m$ UT, but it took until $01^h00^m$ UT before it was completely cloudless. Before that time I usually had a cloud percentage of 10 to 15% and in two periods 30%. After that it remained clear until dusk, the haze had also disappeared, making the transparency much better. There was always some cirrus visible somewhere, but always outside the field of view. For example, there was almost always cirrus present very low east and from $23^h45^m$ UT low in the north. But I also had to change direction four times to keep the cirrus out of the field of view The Perseids seemed slightly less active than previous years in terms of activity, but okay, this is a conjecture.


*Figure 3* – Composition of bright Perseids captured with CAMS 351 during the first hour of the night 2020 August 12–13.

In total I observed 166 meteors. of which 128 Perseids and a few meteors from other minor meteor showers: 3 Southern delta Aquariids. 1 Capricornid. 3 kappa Cygnids. 3 Antihelion meteors and 28 sporadic meteors. The ZHR was around 50 for the first four hours. the last hour slightly higher around 70. For what it is worth due to the occasionally disturbing cirrus clouds. The most beautiful meteor was a –4 Perseid in Cassiopeia. At $00^h11^m$ UT. a Perseid of –5 was captured by the all sky low in the southwest. Since I looked southeast. I was a bit surprised that I had not seen this one. However. there was a small bush in that direction….

*Table 1* – Observations of the author during 2020 August 12–13.

| Period UT | | *Tm* | *T<sub>eff</sub>* | *Lm* | Stream | | | | | Spo | Ntot | *F* | *M* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | [h] | [h] | | PER | SDA | CAP | KCG | ANT | | | | |
| $20^h55^m$ | $22^h00^m$ | 21.48 | 1.08 | 6.16 | 20 | 0 | 0 | 1 | 0 | 6 | 27 | 1.00 | C |
| $22^h00^m$ | $23^h00^m$ | 22.50 | 0.98 | 6.17 | 18 | 0 | 0 | 0 | 1 | 3 | 22 | 1.11 | C |
| $23^h45^m$ | $00^h45^m$ | 0.25 | 0.98 | 5.91 | 19 | 1 | 1 | 0 | 0 | 5 | 26 | 1.21 | C |
| $00^h45^m$ | $01^h45^m$ | 1.25 | 0.97 | 5.93 | 29 | 1 | 0 | 1 | 0 | 7 | 38 | 1.04 | C |
| $01^h45^m$ | $02^h45^m$ | 2.25 | 1.00 | 5.81 | 42 | 1 | 0 | 1 | 2 | 7 | 53 | 1.00 | C |
| | | | | | 128 | 3 | 1 | 3 | 3 | 28 | 166 | | |

[27] https://www.imo.net/members/imo_vmdb/view?session_id=80896

Also, this night a lot of Starlink satellites were seen. The train was now reduced to 11 satellites,. but before and especially after this many Starlinks were seen. And it was also striking that they were now much brighter than on the night of August 10–11, about magnitude +1 a +2. In addition to the 11 satellites mentioned a group of 2 and twice a group of three Starlinks were seen 3 times.

All in all, a very enjoyable night, much better than previously expected! CAMS scored 380 meteors this night. The all sky camera captured 6 meteors, but only two were really bright.

*Figure 4* – The bright Perseid of 2020 August 13 at $00^h11^m$ UT. Camera: Canon 6D with Sigma 8 mm F 3.5 lens and a LC shutter set at 16 breaks per second.

*Figure 5* – The bright Perseid of 2020 August 13 at $01^h41^m$ UT. Camera: Canon 6D with Sigma 8 mm F 3.5 lens and a LC shutter was set at 16 breaks per second.

**2020 August 18–19[28]**

It took a while before the sky was clear enough again to start another meteor watch. In the crystal-clear night of August 18–19 I could observe from the meteor roof between $00^h02^m$ and $02^h32^m$ UT. In these effective 2.50 hours I counted 41 meteors. quite a lot. The Perseids were still clearly active with 10 meteors. Unfortunately, not much clear stuff. only a Perseid of +1 and a sporadic meteor of +1 were the highlight.

## 4 Conclusion

Given the moderate conditions in the Netherlands this year, a reasonable result has been achieved. Successful meteor observing campaigns in the Netherlands are a rarity. Going abroad again next year?

[28] https://www.imo.net/members/imo_vmdb/view?session_id=81097

# Chasing the 2020 chi-Cygnids (CCY#757)

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A report is presented of the observing efforts by the author during September 2020. During these visual observations some chi Cygnids (CCY#757) were seen.

## 1 Introduction

On August 27th, 2020 astronomer Peter Jenniskens published an article in MeteorNews about the possible re-appearance of the chi Cygnids (Jenniskens, 2020). This minor meteor shower was first noticed in 2015, the author observed one CCY member then. During the night of August 20–21, the CAMS networks in Australia, South Africa, Namibia and Chile recorded an outburst of slow meteors from a radiant halfway between Delphinus and Aquila. It turned out to be activity of the chi Cygnids.

With a Full Moon on September 2 and Last Quarter on September 9, the first clear night without moonlight was eagerly awaited.


*Figure 1* – This Chi Cygnid was recorded on 2020 September 12, at 00h22m45s UT with CAMS 353 camera.

## 2 Observations

### 2020 September 13–14

The first clear night of September, happened from Sunday on Monday, in my weekend! I made an early start from the Groevenbeekse Heide, the radiant of the chi Cygnids was at its highest as soon as it was dark. No top conditions this night, the sky remained a bit hazy and after 22h45m UT a bit of thin cirrus appeared.

The kick-off was at 19h56m UT. Let's have a look what there is to see! The expectations of what could be seen were deliberately kept low. Afterall, the CAMS stations had captured some members of this meteor shower, but limited to a few per night. I continued until 23h00m UT when more and more cirrus started to appear. During that period, I saw 5 possible chi Cygnids (CCY). I recorded every meteor coming from the suspected radiant as a CCY, even if the speed was wrong. Here are the timings and specifications of the five possible CCY meteors.

- 20h18m10s UT; +4 CCY or SPO in Pegasus, the speed may be too high, distance from center of view (DCV) 30 degrees.
- 20h54m UT; +3 CCY or SPO in Pegasus, speed a bit too high, DCV 20 degrees.
- 21h15m50s UT; +4 CCY, very nice candidate in terms of speed and direction. Short path from Cygnus to Cepheus.
- 21h39m UT; +3 CCY, also a nice candidate in terms of speed and direction. Short path near the group of stars lambda, kappa and iota Andromeda. DCV 10 degrees.
- 21h41m10s UT; +2 CCY or SPO, but speed perhaps too high, Pisces, DCV 30 degrees, also seemed to come a little further south of the radiant.

In the end two certain CCY meteors. Unfortunately, no confirmation of CAMS observations yet. A total of 32 meteors were counted this night in a 3.00 hours period. Of these, 2 chi Cygnids, 4 September Perseids and 6 Anti-helions. The most beautiful (and brightest) meteor was a yellow sporadic of magnitude 0 with a long path from the "head" of Draco to Aquila.

### 2020 September 18–19

Between 23h20m and 01h38m UT it was possible to observe again, this time from the meteor roof at home. This because fog was expected. Another hazy night and during the last period I was forced to change my field of view from south to north to keep the field of view free of clouds.

During 2.25 hours, 23 meteors were seen, including 3 September Perseids, 5 southern Taurids and no chi Cygnids. The radiant height of the CCY meteors is then of course low. The most beautiful meteor was a +1 sporadic.

### 2020 September 19–20

Finally, a beautiful clear night! This night, the Groevenbeekse Heide was again chosen as the observation location. There I could observe between $23^h50^m$ to $03^h55^m$ UT. Very clear sky and clean air, limiting magnitude 6.4 was achieved at the zenith and an SQM of 20.40. Exactly 4 hours observing time, in those hours I saw resp. 14, 9, 13 and 15 meteors, so in total I counted 51 meteors. Of these, there were 3 September Perseids, 5 Southern Taurids and 1 chi Cygnid. The CCY meteor appeared in the first hour.

The sporadic meteors showed the most beautiful meteors, a magnitude 0 ($03^h01^m$ UT), orange meteor in Eridanus and 3 meteors of magnitude +1 were the highlights. From $3^h45^m$ UT again groups with Starlink satellites were seen, a maximum of 8 were visible at the same time and they were all (with one exception) around magnitude +1 to +2. The group of 8 Starlinks appeared at $03^h55^m$ UT, but number 5 in that train was very weak, magnitude +5 even though it moved exactly the same route. So, this has been a dark Starlink? A total of 32 Starlinks were seen.

### 2020 September 20–21

Due to fatigue from the previous session I started a bit later. Again, excellent conditions, limiting magnitude 6.4 and SQM maximum 20.43. Observations were done between $00^h25^m$ and $03^h54^m$ UT. I counted 42 meteors. Of these, 2 September Perseids, 3 Southern Taurids and 1 possible chi Cygnid. The CCY appeared at $2^h48^m$ UT and it was super slow with an elongated fluffy appearance.

Again, some nice bright sporadic meteors were seen: a nice yellow magnitude 0 moving from Gemini to Taurus with a three second luminous trail. Furthermore, another four sporadics of +1 were seen.

All in all, a few nice sessions in September. A total of 4 chi Cygnids were seen.

Finally, it is worth noting that three fireballs were recorded in September 2020, the most notable of which was the big one of September 24, 2020. This bright and fast fireball was captured simultaneously with four other all sky stations. Unfortunately, the spectacular Earth-grazer of September 23 has not been recorded, due to extremely thick fog in Ermelo around that time.

## References

Jenniskens P. (2020). “Possible upcoming return of the chi Cygnids in September 2020”. *eMetN*, **5**, 287–289.

*Figure 2* – The fireball of September 24, 2020 at $02^h06^m45^s$ UT. The fireball appeared in Pegasus as seen from Ermelo.

# Visual observations Draconids (DRA#009) 2020

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An overview is given of the visual meteor observations by the author in October 2020, covering the Draconid activity.

## 1 Observations October 6–7, 2020

This year had a possibility of enhanced Draconids activity so I made a special effort to observe, particularly on the night of October 6–7 when the two dust trails were predicted. Unfortunately, the weather was poor, and there appeared to be little chance of seeing anything on that night. I kept an eye on the clouds movements all day and I was a bit hopeful when a small opening in between the clouds was predicted to form to the south-west of Ottawa. It was a long shot but worth a try for a chance of seeing rare meteors. I drove 190 km south-west of Ottawa to the Lennox & Addington Dark Sky Site which appeared to be well positioned for the hole. When I arrived in the evening, it was completely overcast however. The satellite imagery showed that any clearing still had a long way to go before I would even see any signs of it. It was a bit discouraging to drive that far and not see anything around the interesting times, but I wasn't ready to give up. I decided to setup my mattress in the car to sleep for a couple of hours, and then check for any improvements.

I woke up at midnight, and the clouds were beginning to break up. Taking a glance at the satellite image showed that a small hole was finally approaching, so I setup my chair up on the observing platform (which had been modified with glow-in-the-dark with spatial distancing in mind). At $12^h30^m$am (EDT), I started casual viewing with around 50% clear skies, and at $12^h50^m$am, I finally signed on with a clear sky. By then, the gibbous Moon was high, the sky had a reduced limiting magnitude of only 5.3, the Draconid radiant was much lower, and the clear break lasted only 53 minutes. Only three meteors were seen (two sporadics and one South Taurid). No Draconids were seen, even though one meteor made a good impression of being one (too large miss distance to radiant). After that, the clouds thickened and it was about to rain, so I packed and headed back home.

Observer: Pierre Martin[29] (Session[30]). Session Date: October 6–7 2020, $04^h50^m$–$05^h43^m$ UT ($00^h50^m$–$01^h43^m$ EDT). Location: L&A County Public Dark Site, Ontario, Canada (Long: –77.116 West; Lat: 44.559 North).

Observed showers:

- Draconids (GIA) – $17^h32^m$ (270°) +56°
- Southern Taurids (STA) – $01^h50^m$ (028°) +08°
- October Camelopardalids (OCT) – $10^h57^m$ (164°) +78°

$04^h50^m$–$05^h43^m$ UT ($00^h50^m$–$01^h43^m$ EDT); clear; 1/5 trans; *F* 1.00; *LM* 5.30; facing NNW60 deg; $t_{eff}$ 0.883 hr.

- STA: one: +5
- Sporadics: two: +2; +4
- Total meteors: Three

## 2 Observations October 8–9, 2020

Two nights after my first attempt for the Draconids, I was able to observe with more success earlier on the October 8 evening. I went to the Moosecreek dark sky site which is 60 km east of Ottawa. Sky was decent with average transparency (3/5) and it was cool at 4C but without any wind. It is a nice quiet area with wide open flat horizons and it is just about as dark as one could expect it to be between Ottawa and Montreal. The T junction in the field is now wider than it used to be and it is OK to setup there rather than at the dead end. Unfortunately, the city light domes have gotten significantly worse compared to years past. The sky is still decent up high and when looking away from these sources of light pollution. It is also closer for me to get to this site than any of the ones west of the city.

In two hours, I saw 14 meteors (2 South Taurids, one Draconid and 11 sporadics). The highlight was at 9:14pm (EDT) with a +1 long 35 degrees blue South Taurid. I packed up just as the sky was clouding over, so my timing worked out well.

Observer: Pierre Martin[1] (Session[31]). Observation October 8–9 2020, $00^h27^m$–$02^h30^m$ UT ($20^h27^m$–$22^h30^m$ EDT). Location: Moose Creek, Ontario, Canada. (45°15'13"N 75°02'57"W).

Observed showers:

[29] https://www.imo.net/members/imo_user/profile/?user_id=8022
[30] https://www.imo.net/members/imo_vmdb/view?session_id=81646
[31] https://www.imo.net/members/imo_vmdb/view?session_id=81647

- Draconids (GIA) – $17^h32^m$ (270°) +56°
- Southern Taurids (STA) – $01^h50^m$ (028°) +08°
- October Camelopardalids (OCT) – $10^h57^m$ (164°) +78°

$00^h27^m$–$01^h29^m$ UT ($20^h27^m$–$21^h29^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.20; facing NW60 deg; $t_{eff}$ 1.00 hr.

- STA: one: +1
- Sporadics: six: +2(2); +3(2); +4; +5
- Total meteors: Seven

$01^h29^m$–$02^h30^m$ UT ($21^h29^m$–$22^h30^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.23; facing NW60 deg; $t_{eff}$ 1.01 hr.

- GIA: one: +1
- STA: one: +3
- Sporadics: five: +2; +3(2); +4; +5
- Total meteors: Seven

Breaks: $00^h37^m$–$00^h39^m$ UT (2 min dead time).

# The Orionids 2020 from Florida, USA

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A report on the visual observations of the Orionids in 2020 by the author is presented.

## 1 2020 October 14–15

Well for the first time in many months, I was actually able to gather some meaningful meteor observations this morning from the overflow parking lot at the St. Johns County Fairgrounds. After many months of sub-par weather during major meteor showers, it was great to be able to gather some data on the pre-maximum Orionids!

When I first got there just before $4^h00^m$ a.m., there was some haze and fog about that degraded the sharp sky a bit. However, that pretty much dissipated during the first hour and the skies were awesome for the second hour! Here's a summary of the observational data I was able to get from this morning's session.

Date: October 14–15, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, OCM – October Ursae Majorids, EGE – epsilon Geminids, NUE – nu Eridanids, SPO – sporadics

$04^h00^m$ – $05^h00^m$ EDT ($08^h00^m$ – $09^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.0, sky conditions: clear, Facing: southeast.

- 2 OCM: +1, +2
- 5 STA:+2(1), +3(2), +4(2)
- 4 ORI: 0(1), +3(2), +4(1)
- 8 SPO: –2 (1), +1(1), +2(1), +3(2), +4(3)

19 total meteors, 1 of the ORIs, both of the OCMs, and two of the SPOs left trains behind them.

$05^h00^m$ – $06^h00^m$ EDT ($09^h00^m$ – $10^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.2. sky conditions: clear, Facing: southeast.

- 1 OCM: +3
- 2 EGE: +3(2)
- 2 STA: +2(1), +3(1)
- 8 ORI: +2(1), +3(3), +4(3), +5(1)
- 13 SPO: –3(1), +1(2), +2(1), +3(4), +4(3), +5(1)

26 total meteors, 1 of the ORIs, and 2 of the SPOs left nice trains behind them.

Overall, the Orionids performed well, considering they are almost a week short of their maximum (Oct. 21). Other than the first Orionid I saw (a bright zero magnitude one low in the SE), most of the other Orionids were classic faint, short and glittery little jewels very challenging indeed to catch visually.

Here's a summary by hour of the highlights:

First hour:

- Two bright, long and surprising members of the obscure minor meteor shower the October Ursae Majorids, first ones I've ever seen!
- The bright zero mag ORI that left a train, low in the SE.
- A stunning faint, earthgrazing sporadic that started in Lepus and skipped across almost 100 degrees of sky going due north. I had it in sight for several seconds. It was awesome!
- A neat little spurt of South Taurids, including three within five minutes of each other!
- The bright, –2 sporadic that shocked the heck out of me as it blasted out of the northern sky heading due south. That one sure woke me up!

Second hour:

- The sky cleared out and faint meteors were popping all over the sky.
- The Orionids picked up in activity quite a bit with several short, faint meteors, going in every direction. Most were seen close to the radiant.
- Another very bright sporadic meteor blazed out of the northern sky, I just caught the end burst, estimated at –3 (almost a fireball).
- Two members of the epsilon Geminid minor meteor shower were noticed.

All told, it was a very varied and interesting session. I was pleasantly surprised. The activity was evenly distributed, with only a couple of lulls in the action. The addition of the bright planets (Venus and Mars), Sirius and all the other winter Milky Way bright stars scattered and blazing across the entire 180 degrees of the sky was fantastic!

## 2 2020 October 15–16

I had a "rerun" two-hour meteor observing session from the SJC Fairgrounds this morning ($4^h$–$6^h$ a.m., 10/16/20). I say rerun because the overall meteor totals were almost identical to the previous morning, albeit a bit different on the itemized breakout. The first hour was sublime with beautifully dark, clear skies. However, the second half of the second hour was degraded by encroaching streaky cirrus clouds that cut into the meteor activity big time… All told, I had 41 total meteors this morning – 13 Orionids, 6 Taurids, 3 epsilon Geminids, 1 Oct. Ursae Majorid, 1 Nu Eridanid, and 17 sporadics. Here's the summary of the observational data I was able to get from this morning's somewhat "cloud crashed" session:

Date: October 15–16, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, OCM – October Ursae Majorids, EGE – epsilon Geminids, NUE – nu Eridanids, SPO – sporadics

$04^h00^m$ – $05^h00^m$ EDT ($08^h00^m$ – $09^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: southeast.

- 1 EGE: –3
- 1 OCM: +2
- 2 STA:+2(1), +4(1)
- 1 "Other Taurid": +3
- 6 ORI: +2(1), +3(2), +4(3)
- 8 SPO: +1(1), +2(1), +3(3), +4(3)

19 total meteors. The –3 EGE and a couple of the sporadics left trains behind them, the –3 EGE was an intense blue-white in coloration.

$05^h00^m$ – $06^h00^m$ EDT ($09^h00^m$ – $10^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: variable. sky conditions: 20% degradation – cirrus clouds, Facing: southeast

- 2 EGE: +3(1), +4(1)
- 1 NUE: +3
- 1 STA: +2(1)
- 1 "other Taurid": +4
- 7 ORI: +2(1), +3(3), +4(3)
- 10 SPO: +1(1), +2(1), +3(4), +4(3), +5(1)

22 total meteors. 1 of the ORIs, and 3 of the SPOs left nice trains behind them.

Overall, there was a slight uptick in the Orionid activity; however, the meteors were mostly very faint and short, as Orionids usually are. The spectacular –3 EGE in the first hour was the highlight of the session for sure. I've seen many of these meteors over the years, but none have come close to being this bright. It was a real treat!

## 3 2020 October 17–18

I had a very unexpected and appreciated 90-minute opportunity to see the Orionids this morning ($4^h55^m$ – $6^h25^m$ a.m., Oct. 17–18, 2020). I happened to wake up at about $4^h30^m$ a.m., when I looked out and up, I was stunned to see a sky full of stars looking right back down at me! It had been raining for most of the night. So, I high-tailed it out to Fairgrounds overflow lot and was greeted by a very clear, dark sky adorned with stars and winter Milky Way. I sent my thank you prayers skyward…

There in those 90 minutes, I counted 49 total meteors with 24 of them being Orionids. They're definitely picking up! I had a nice "mini-burst" of them with 6 being seen in just ten minutes ($5^h35^m$ – $5^h45^m$ a.m.) during the first hour. No real bright meteors appeared this morning, most of the Orionids were classic – that is, short, fast, and faint. Only two of them even reached +2 in magnitude! Still, they count though. Here's the summary of the observational data I was able to get from this morning.

Date: October 17–18, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, OCM – October Ursae Majorids, EGE – epsilon Geminids, NUE – nu Eridanids, SPO – sporadics

$04^h55^m$ – $05^h55^m$ EDT ($08^h55^m$ – $09^h55^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 2 EGE: +3(2)
- 2 STA:+2(1), +3(1)
- 15 ORI: +2(1), +3(7), +4(5), +5(2)
- 10 SPO: +2(1), +3(4), +4(3), +5(2)

29 total meteors

$05^h55^m$ – $06^h25^m$ EDT ($09^h55^m$ – $10^h25^m$ UT), $T_{eff}$: .5 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 1 EGE: +3
- 1 OCM: +3
- 2 STA: +2(2)
- 9 ORI: +2(1), +3(5), +4(3)
- 7 SPO: +1(1), +2(1), +3(3), +4(1), +5(1)

20 total meteors. 1 of the ORIs, and 2 of the SPOs left short trains behind them.

Since I was not able to get out on Oct. 16–17, 2020 morning due to clouds, there was a noticeable increase in Orionid activity during this morning's session. Unlike my two previous sessions however, there were no very bright meteors of any kind observed this morning.

One thing I noted this morning was that since the Orionid radiant was positioned high on the meridian during my session, (actually, almost on my zenith), the Orionids could be seen shooting out all over the entire sky, spraying out in all directions from the source in the upraised club of Orion.

I really had to maintain my attention at a high level to catch them as they were appearing basically everywhere within the entire dome of the night sky. It really hit home to me on how important developing one's peripheral vision is to spotting meteors better.

I've been observing the Orionids for decades, and one of the many fascinating aspects of this meteor shower to me is its tendency to produce striking and somewhat prolonged, what I call, "mini-bursts"! There will be sudden, marked ramp ups in the number of Orionids seen for periods of time that can last anywhere from a few minutes up to perhaps half an hour. Most of the meteors that occur during these "mini-bursts" are exceptionally faint and short, rarely above +4 in magnitude and they are rarely seen more than twenty degrees from the radiant. Their paths are mostly less than two degrees long also. Such was the ten-minute or so, "mini-burst" I saw from them this morning.

## 4 2020 October 18–19

Once again, Mother Nature chose to clear the skies out beautifully, so I was able to get in an insane 2 1/2-hour pre-dawn Orionid meteor watch from the Fairgrounds this morning ($4^h00^m$ – $6^h30^m$ a.m., Oct. 18–19) under superbly clear, dark skies! The Orionids really "lit up" this morning, both in terms of quantity and quality.

In total, I had 95 meteors in the 2 1/2 hours with 47 of them being Orionids! Orionid counts were: 14, 23, and 10. I had at least a dozen Orionids of zero magnitude or brighter, including a stunning, yellow-white, –4 fireball at $5^h22^m$ a.m. that almost occulted Sirius and left a train hanging on the sky for several seconds – WOW! I also picked an orangey-white, –3 South Taurid near-fireball off the western horizon, just before $6^h00^m$ a.m. I was completely blown away by what I saw this morning… Here is the complete report.

Date: October 18–19, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, NTA – North Taurids, CTA – chi Taurids, EGE – epsilon Geminids, NUE – nu Eridanids, OER – omicron Eridanids, LMI – Leonis Minorids, SPO – sporadics

$04^h00^m$ – $05^h00^m$ EDT ($08^h00^m$ – $09^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 2 EGE: +3(2)
- 3 STA: +1(1), +2(1), +3(1)
- 1 NUE: +4
- 14 ORI: 0(1), +1(1), +2(2), +3(4), +4(3), +5(3)
- 10 SPO: +1(1), +2(1), +3(3), +4(3), +5(2)

30 total meteors. 3 of the 14 ORIs, 1 of the 3 STAs, and 2 of the 10 SPOs left short trains behind them.

$05^h00^m$ – $06^h00^m$ EDT ($09^h00^m$ – $10^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 1 EGE: +2
- 1 OCM: +3
- 4 STA: –3(1), +1(1), +2(2)
- 23 ORI: –4(1), –1(3), 0(3), +1(2), +2(3), +3(5), +4(3), +5(3)
- 1 OER: +3
- 13 SPO: 0(1), +1(2), +2(1), +3(4), +4(3), +5(2)

43 total meteors. 10 of the 23 ORIs, 2 of the 4 STAs, and 2 of the 13 SPOs left trains behind them. The –4 ORIs train lasted for about 4 seconds in the sky and the meteor was blue white in color. The –3 STA was seen about 2 degrees above the western horizon and was orange white in color, with a slight train.

$06^h00^m$ – $06^h30^m$ EDT ($10^h00^m$ – $10^h30^m$ UT), $T_{eff}$: 0.5 hour, no breaks. Limiting magnitude of sky: variable 6.5, sky conditions: 25% degradation due to twilight, Facing: south.

- 1 EGE: +2
- 3 STA: +1(1), +3(1), +4
- 10 ORI: –1(1), 0(1), +1(2), +2(2), +3(2), +4(1), +5(1)
- 1 LMI: +3
- 7 SPO: 0(1), +2(2), +3(2), +4(1), +5(1)

22 total meteors.

The Orionids really picked up in activity from yesterday morning, although there was no noticeable "mini-burst" from them this morning that I saw, at least. The Orionid activity this morning was very even distributed with little obvious clumping effect. They also increased quite a bit in both brightness of the meteors and markedly in train production. There also seemed to be a slight uptick in the South Taurids as well. In addition to the several negative magnitude Orionid meteors, I also saw a stationary +1 Orionid meteor.

We are hoping that the trend towards clear pre-dawn hours will hold, as it has been a remarkable gift to be able to observe these past few mornings under such clear and dark skies.

## 5 2020 October 24–25

I had an unexpected, two-hour meteor session for the post-maximum Orionids this morning. After five straight overcast mornings, I awoke at $3^h30^m$ a.m. this morning to find star-studded skies. I was out $4^h00^m$ – $6^h30^m$ a.m. at the Fairgrounds and had 77 total meteors with 42 of them being Orionids! They were still hitting pretty good this morning indeed.

There were several highlights during the watch – a stunning (what I believe was) piece of re-entering space debris that split the northern sky in a blazing deep orange streak, just after I settled down for the watch; a golden yellow, –2 Orionid shooting NE in Cancer the Crab; a vivid yellow,

–1 member of the Leonis Minorid radiant; and a bright reddish, –1 member of the omicron Eridanid radiant hit just below Mars in the deep western sky. Overall Orionid counts for the two full hours were 17 and 22. Here is the complete report.

Date: October 24–25, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, NTA – North Taurids, CTA – chi Taurids, EGE – epsilon Geminids, NUE – nu Eridanids, OER – omicron Eridanids, LMI – Leonis Minorids, SPO – sporadics

$04^h00^m$ – $05^h00^m$ EDT ($08^h00^m$ – $09^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 1 EGE: +3
- 2 STA: +2(1), +3(1)
- 17 ORI: +1(1), +2(3), +3(6), +4(4), +5(3)
- 9 SPO: –2(1), +1(1), +2(1), +3(4), +4(1), +5(1)

29 total meteors. 4 of the 17 ORIs, 1 of the 2 STAs, and 2 of the 10 SPOs left short trains behind them. The –2 sporadic may have been a piece of re-entering space debris, it was deep orange in color, very slow-moving, tracking due west to east, and ended in a shower of range sparks at the terminal burst. It did not line up with the Taurid radiants.

$05^h00^m$ – $06^h00^m$ EDT ($09^h00^m$ – $10^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 1 EGE: +2
- 1 STA: +1
- 1 OER: –1
- 1 LMI: –1
- 22 ORI: –2(1), 0(2), +1(2), +2(4), +3(5), +4(5), +5(3)
- 14 SPO: 0(1), +1(3), +2(3), +3(4), +4(2), +5(1)

40 total meteors. 9 of the 22 ORIs, 1 STA, OER, and LMI, and 5 of the 14 SPOs left trains behind them. The –2 ORI train lasted for about 2 seconds in the sky and the meteor was golden-yellow in color. The –1 OER was deep reddish-orange, and the –1 LMI was vivid yellow.

$06^h00^m$ – $06^h30^m$ EDT ($10^h00^m$ – $10^h30^m$ UT), $T_{eff}$: .5 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: 25% degradation due to twilight, Facing: south.

- 1 EGE: +2
- 1 STA: +1
- 3 ORI: +2(1), +3(2)
- 3 SPO: +3(2), +4(1)

8 total meteors

The meteor activity in the first hour was fairly mundane, outside of the amazing –2 sporadic that started the session. Most of the Orionids seen in that first hour were faint, short and very fast, as were a majority of the other meteors. I struggled at times to maintain alertness. All that changed quite a bit during the second hour however!

The Orionids picked up both in quantity and especially in quality, and the other radiant sources also contributed bright and colorful meteors in the very busy second hour. My alertness was restored and I was picking up more faint meteors in between the bright ones. At one point about mid-way through the hour, I had three meteors (1 ORI and 2 SPOs) all hit within two seconds of each other around the sky (almost simultaneous)! It's always cool when that happens…;o). There were not any of the very peculiar Orionid "mini-spurts" noticed during the watch however.

The session left me wondering heavily about just how strong the Orionids rates had gotten at the maximum two mornings prior. Seeing over 20 per hour from them 48 hours after the predicted maximum is not unheard of though, and dovetails well with their characteristic "plateau-maximum" behavior.

## 6 2020 October 25–26

We had another very nice 2 1/2-hour Orionid meteor watch this morning ($4^h00^m$ – $6^h30^m$ a.m.) from the Fairgrounds. This time I was joined by several ACAC members and NEFAS friends under sharp, clear skies. The Orionids are finally beginning to wane now, although we still saw quite a few. All told in the 2 full hours, I had 51 total meteors with 26 of them Orionids. Hourly Orionid counts were 14 and 12. I also had 8 Taurids. Highlights of the watch were: a slow, –4 sporadic fireball at $4^h19^m$ a.m., a bright yellow –3 North Taurid, a lovely –3 Leonis Minorid seen casually after $6^h00^m$ a.m., and two bright Orionids (a –2 and a –1). Here's the full report.

Date: October 25–26, 2020, Observer: Paul Jones, Location: overflow parking area of St. Johns County Fairgrounds, St. Augustine, Florida (latitude: 29.76° N, Longitude: 81.45° W).

Observed for radiants: ORI – Orionids, STA- South Taurids, NTA – North Taurids, CTA – chi Taurids, EGE – epsilon Geminids, NUE – nu Eridanids, OER – omicron Eridanids, LMI – Leonis Minorids, SPO – sporadics.

$04^h00^m$ – $05^h00^m$ EDT ($08^h00^m$ – $09^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 4 STA: +2(2), +3(2)
- 14 ORI: +1(1), +2(2), +3(5), +4(3), +5(3)
- 8 SPO: –4(1), +2(1), +3(3), +4(2), +5(1)

26 total meteors.

3 of the 14 ORIs, 1 of the 4 STAs, and 2 of the 8 SPOs left short trains behind them. The –4 sporadic fireball hit at $4^h19^m$ a.m., deep in the SE sky and left a nice train. Too far south to be a Taurid and too slow to be an OER.

$05^h00^m$ – $06^h00^m$ EDT ($09^h00^m$ – $10^h00^m$ UT), $T_{eff}$: 1 hour, no breaks. Limiting magnitude of sky: 6.5, sky conditions: clear, Facing: south.

- 3 STA: +1(1), +2(2)
- 1 NTA: –3
- 12 ORI: –2(1), –1(1), +1(2), +2(3), +3(3), +4(2), +5(1)
- 9 SPO: 0(1), +1(3), +2(3), +3(4), +4(2), +5(1)

40 total meteors. 6 of the 12 ORIs, 1 STA, the –3 NTA, and 5 of the 9 SPOs left trains behind them. The –2 ORI train lasted for about 2 seconds in the sky and the meteor was golden-yellow in color, as was the –1 ORI. The –3 NTA was deep yellowish-orange.

The second hour this morning was again very interesting. Again, there was an uptick in the number of bright meteors of all types. The hour started out with me seeing 5 ORIs in the first ten minutes, then the ORIs almost disappeared for most of the hour, then we had another brief spurt of them just before the end of the hour.

The last half hour ($6^h$ – $6^h30^m$ a.m.) produced the only LMI and EGE that I saw on the entire watch, although I was only causally observing. The LMI was a beautiful, reddish burst at about –3, almost directly overhead, that left a short train hanging on the sky. Only a couple more ORIs were seen that last half hour, as the decline in the activity from them became more and more apparent.

# Visual observations Orionids (ORI#008) 2020

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An overview is given of the visual meteor observations by the author in October 2020, covering the Orionid activity.

## 1 Observations October 16–17, 2020

Here's my meteor observations at Bootland Farm (dark sky site 95 km west of Ottawa) for the morning of October 17. The sky was quite stunning (4/5 transparency) and the limiting magnitude approached 6.5, with the exception of a few small bands of thin clouds that passed through. It was also a bit chilly and below freezing as a layer of frost covered the grassy field.

In a little over two hours from $3^h45^m$ to $6^h10^m$am (EDT), I saw 37 meteors (15 Orionids, 4 Leonis Minorids, 2 Southern Taurids, one epsilon Geminid and 15 sporadics).

I was quite impressed by the Orionids numbers during the first hour. The brightest was a mag 0 blue-green beauty near M45 that left a one second train. Typical Orionids are often so faint, brief and fast that I feel they can be very easily missed if an observer is not fully alert. The Leonis Minorids were pretty active in the first hour with long, swift meteors.

Observation October 16–17 2020, $07^h45^m$–$10^h10^m$ UT ($03^h45^m$–$06^h10^m$ EDT). Location: Bootland Farm (Stewartville), Ontario, Canada, (45°23'N 76°29'W).

Observed showers:

- Southern Taurids (STA) – $02^h34^m$ (038°) +11°
- omicron Eridanids (OER) – $02^h34^m$ (038°) –05°
- Northern Taurids (NTA) – $02^h50^m$ (043°) +20°
- chi Taurids (CTA) – $03^h02^m$ (046°) +23°
- Orionids (ORI) – $06^h17^m$ (094°) +16°
- nu Eridanids (NUE) – $06^h40^m$ (100°) +11°
- epsilon Geminids (EGE) – $06^h47^m$ (102°) +28°
- Leonis Minorids (LMI) – $10^h22^m$ (156°) +38°

$07^h45^m$–$08^h50^m$ UT ($03^h45^m$–$04^h50^m$ EDT); clear; 3/5 trans; *F* 1.00; *LM* 6.46; facing S55 deg; $t_{eff}$ 1.01 hr.

- ORI: nine: 0; +2(2); +3; +4(4); +5
- LMI: three: +3; +4(2)
- STA: one: +5
- EGE: one: +5
- Sporadics: seven: +2(2); +4(2); +5(3)
- Total meteors: Twenty-one

$08^h57^m$–$10^h10^m$ UT ($04^h57^m$–$06^h10^m$ EDT); a few passing clouds; 3/5 trans; *F* 1.06; *LM* 6.36; facing S55 deg; $t_{eff}$ 1.21 hr.

- ORI: six: +1; +2(2); +3; +4(2)
- STA: one: +4
- LMI: one: +2
- Sporadics: eight: +1; +3(2); +4(4); +5
- Total meteors: Sixteen

Breaks: $07^h57^m$–$08^h01^m$ UT (4 min dead time).

## 2 Observations October 21–22, 2020

Here's an observing outing this past Thursday morning (October 21–22) at the Moosecreek site. The sky cleared gradually after midnight, giving me a chance to see the Orionids about one day after their predicted peak. Sky transparency below-average (2/5) and at the end, it clouded over again. The weather is often unstable at this time of the year, which makes the forecasts unreliable.

In two hours between $1^h00^m$–$03^h09^m$ (EDT), I saw 40 meteors (15 Orionids, 9 Southern Taurids, 4 Northern Taurids, 2 Leonis Minorids and 10 sporadics). The Orionids activity seemed a little lower than expected for this night, although the radiant was less than 30 degrees high at the beginning of the session. The rates did improve during the second hour with 9 seen.

Observer: Pierre Martin[32] (Session[33]). Observation October 21–22 2020, 05:00-07:09 UT (01:00-03:09 EDT). Location: Moose Creek, Ontario, Canada, (45°15'13"N 75°02'57"W).

Observed showers:

- Southern Taurids (STA) – $02^h34^m$ (038°) +11°
- omicron Eridanids (OER) – $02^h34^m$ (038°) –05°
- Northern Taurids (NTA) – $02^h50^m$ (043°) +20°
- chi Taurids (CTA) – $03^h02^m$ (046°) +23°

[32] https://www.imo.net/members/imo_user/profile/?user_id=8022

[33] https://www.imo.net/members/imo_vmdb/view?session_id=81649

- Orionids (ORI) – 06$^h$17$^m$ (094°) +16°
- nu Eridanids (NUE) – 06$^h$40$^m$ (100°) +11°
- epsilon Geminids (EGE) – 06$^h$47$^m$ (102°) +28°
- Leonis Minorids (LMI) – 10$^h$22$^m$ (156°) +38°

05$^h$00$^m$–06$^h$00$^m$ UT (01$^h$00$^m$–02$^h$00$^m$ EDT); clear; 2/5 trans; *F* 1.06; *LM* 6.10; facing SEE55 deg; $t_{eff}$ 1.00 hr.

- ORI: six: 0; +1; +3; +4; +5(2)
- STA: three: +3; +4(2)
- NTA: three: +3(2); +4
- LMI: two: +2; +3
- Sporadics: two: +4; +5
- Total meteors: Sixteen

06$^h$00$^m$–07$^h$09$^m$ UT (02$^h$00$^m$–03$^h$09$^m$ EDT); clear; 2/5 trans; *F* 1.00; *LM* 6.10; facing SSEE55 deg; $t_{eff}$ 1.00 hr.

- ORI: nine: +1; +3(2); +4(4); +5(2)
- STA: six: +2; +3(2); +4(3)
- NTA: one: +4
- Sporadics: eight: +2(2); +3(2); +4(3); +5
- Total meteors: Twenty-four

*Figure 1* – Here's an image composite image. It includes bright green Orionid meteors, a few dimmer Taurids and sporadics. Thin haze in the atmosphere caused the halos around the bright stars of Orion and Taurus, highlighting their colours. Taken with Canon 6D, Sigma 35mm f/1.4, ISO 3200, tracking with Skywatcher Adventurer mount.

# Fireball events over Spain in September 2020

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An overview is presented of the exceptional fireball event by the meteor observing stations operated by the SMART Project from Sevilla and Huelva during September 2020.

## 1 Introduction

This beautiful meteor overflew the south of Spain on 2020 September 3 at about $2^h35^m$ local time (equivalent to $0^h35^m$ UT). It was generated by a sporadic meteoroid following an asteroid-like orbit that hit the atmosphere at around 97000 km/h. It began at an altitude of about 80 km over the Gulf of Cadiz (Atlantic Ocean), and ended at a height of around 44 km over the sea level. The event was recorded in the framework of the SMART project, which is being conducted by the Southwestern Europe Meteor Network (SWEMN). The event[34] was spotted from the meteor-observing stations located at Sevilla, La Sagra (Granada), La Hita (Toledo), and Calar Alto.

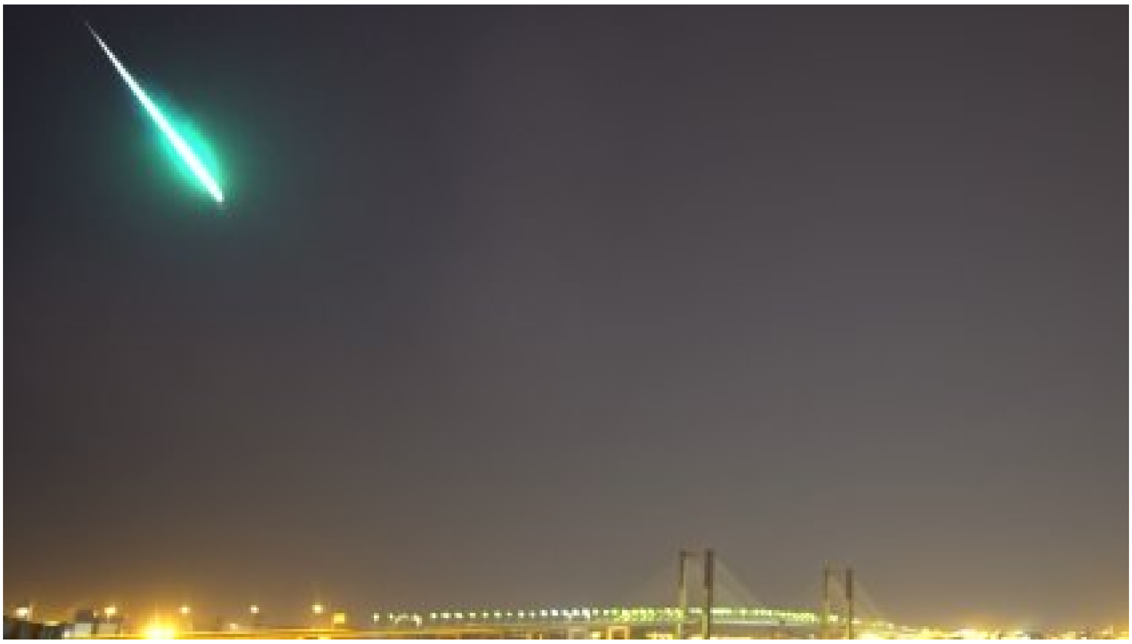

*Figure 1* – The 2020 September 3, $0^h35^m$ UTC fireball.

[34] https://youtu.be/9zb0fjf5Yr4

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