Transactions IAU, Volume XXIXA
Proc. XXIXA IAU General Assembly, August 2015
Thierry Montmerle, ed.

doi:10.1017/S1743921316000843

DIVISION F
COMMISSION 22

METEORS, METEORITES, AND INTERPLANETARY DUST

MÉTEORES, MÉTÉORITES ET POUSSIÈRE INTERPLANÉTAIRE

PRESIDENT	**Peter Jenniskens**
VICE-PRESIDENT	**Jiří Borovička**
PAST PRESIDENT	**Jun-ichi Watanabe**
SECRETARY	**Tadeusz Jopek**
ORGANIZING COMMITTEE	**Shinsuke Abe, Guy J. Consolmagno, Masateru Ishiguro, Diego Janches, Galina O. Ryabova, Jérémie Vaubaillon, Jin Zhu**

COMMISSION 22 WORKING GROUPS

Div. F / Commission 22 WG	**Professional-Amateur Cooperation in Meteors**
Div. F / Commission 22 WG	**Meteor Showers Nomenclature**

I. THE CONTRIBUTION OF COMMISSION 22 TO THE DEVELOPMENT OF OUR UNDERSTANDING OF METEORS

Iwan P Williams

School of physics and Astronomy, Queen Mary University of London,
Mile End Road London E1 4NS
e-mail: i.p.williams@qmul.ac.uk

1. Introduction

Commission 22 (Meteors, Meteorites and Interplanetary Dust) was established at the first IAU General Assembly held in Rome in 1922, with William Frederick Denning as its first President. Denning was an accountant by profession, but as an amateur astronomer he contributed extensively to meteor science. Commission 22 thus established a pattern that has continued to this day that non- professional astronomers were welcomed and valued and could play a significant role in its affairs. The field of meteors, meteorites and interplanetary dust has played a disproportional role in the astronomical perception of the general public through the majestic displays of our annual meteor showers. Those in the field deployed many techniques uncommon in other fields of astronomy, studying the "vermin of space", the small solid bodies that pervade interplanetary space and impact Earth's atmosphere, the surface of the Moon, and that of our satellites in orbit. Over time, the field has tackled a wide array of problems, from predicting the encounter with meteoroid streams, to the origin of our meteorites and the nature of the zodiacal cloud. Commission 22 has played an important role in organizing the field through dedicated meetings, a data centre, and working groups that developed professional-amateur relationships and that organized the nomenclature of meteor showers. The contribution of Commission 22 to the field is perhaps most readily seen in the work of the presidents that followed in the footsteps of Denning.

2. The view of meteors up to the time of the formation of the IAU

Meteors can be seen on most clear dark nights as streaks of light that last at most only a few seconds. Most are similar in brightness to the background stars. They can thus be seen by everybody, not just astronomers with specialist equipment, and must have been observed by humanity since the dawn of time. Records exist from Chinese, Japanese and Korean archives, going back 2500 years detailing meteor appearances (see Hasegawa, 1993; Jenniskens, 2006) and the Lyrids, Orionids, Perseids, η Aquariids and Leonids showers can all be found in them, though these were not identified until much later. In contrast there is a lack of records from the western world. The reason is that, following the ideas of Aristotle, meteors were regarded as atmospheric phenomenon and thus of no interest to astronomy. This view was re-enforced by the orthodox religious view of the Harmony of the Universe with planets moving on well defined orbits on celestial spheres. The notion that there could be loose particles or stones moving about the heavens, occasionally colliding with the Earth was an alien concept. Halley (1688) used the numerous observations of a very bright meteor seen on March 21 1676 to calculate its velocity and found it to be at least 4300 ms-1, greater than the rotational speed of the Earth's surface. Halley pondered on whether such a high velocity had something to do with the speed of the Earth about the Sun. Later Halley (1714) compared sketches made by other observers of a meteor against the background stars, to calculate that the meteor was between 65 and 80 km high. His own work on atmospheric pressure had shown that at such a height there was essentially no atmosphere, and so he dismissed this height as impossible (it was actually a pretty good estimate) and reverted to Aristotle's ideas regarding meteors. On November 26 1758 a bright fireball was observed along a 650km long path from central England to western Scotland. Analysis of these observations by Pringle (1759) gave the fireball speed as 4800 ms-1 and a height of 65km. Pringle suggested that meteors have motions of their own relative to the Earth. Some 25 years later, Rittenhouse (1786) calculated the height of a meteor seen over Virginia and Philadelphia on October 31, 1779, as nearly 100km and suggested that these bodies were foreign to the Earth and its atmosphere, accidentally meeting with it as they moved through the great void of space. The evidence against Aristotle's ideas was now mounting. Mother Nature now gave a helping hand, producing a spectacular meteor display in November 1799 (which we now know to be the Leonids) described by Ellicot (1804). This meteor display was also seen by both von Humbolt and Bonpland who were in South and Central America. Their observations were not published until 1852 (von Humbolt & Bonpland, 1852). Other accounts of this display can be found in Littman (1998) and Jenniskens (2006).

Chladni (1794) considered reports that a 700kg lump of iron that had fallen from the sky in Siberia as well as reports of other fallen stones and concluded that only an extraterrestrial origin made sense. Howard (1802) analyzed several meteorites recovered from Europe and India and concluded that they were not of terrestrial origin. A further Leonid meteor storm was seen in 1833. Olmstead (1834, 1835) and Twining (1834) analyzed this event and naturally looked for a connection between the 1799 and 1833 showers. They noted that the meteors seemed to emanate from a fixed point in the constellation of Leo and coined the term 'radiant' and proposed that meteors are caused small particles on heliocentric orbits interacting with the Earth's atmosphere. However, opposition to the extra-terrestrial origin theory continued, Epsy and Clarke (both in 1835), and Bache (in 1836), were particularly vociferous.

Herrick (1837, 1838) found eleven instances where meteors had been seen on August 9 or 10 and proposed that a second annual shower existed and that these also had a 'radiant'. Earlier, Locke (1834) has shown that a shower in August 1834 had a radiant in constellation of Perseus. This was obviously the same shower as studied by Herrick. Herrick also suggested that there could be another shower towards the end of April and hinted at a connection between meteors and comets. Quetelet (1837, 1839) stated that, averaged over a year one, should expect to see 8 meteors per hour and produced a catalogue of times where the number of meteors was higher, indicating that the difference between 'showers' and the sporadic background had been recognized.

However, more and more interest was being shown in the science of meteors, aided by the increasing speed of communication allowing details of observations to be circulated and theories to be tested (in the 1830's Morse had invented telegraphic communication, the Penny Black and Two Pence Blue, world's first postage stamps, became valid for the pre-payment of postage in 1840, followed by similar developments across the world and the telephone made it appearance in 1876).

Eminent mathematicians of the time became interested in calculating orbital properties of meteoroids. Newton (1863) studied the information on the Lyrid, Perseid and Leonid showers and concluded that they returned at intervals that were periodic on a sidereal rather than a tropical year, further proof that the cause is extra-terrestrial in origin. This was the age when mathematicians began calculating the effects of planetary perturbations on orbits an indeed had their greatest success with the discovery of the planet Neptune in 1846. It was thus natural that perturbation theory should also be applied to meteors. Adams (1867) showed that the Leonid meteoroids must move on an orbit with a 33.25 year period. LeVerrier (1867) pointed out that planetary perturbations would spread the meteoroids all around the orbits given sufficient time and concluded that the Leonid stream must be young.

So by the mid 1860's there was a basic understanding of meteoroid stream dynamics, leading to the observed meteor showers. There was however no real understanding of how meteoroids got on such orbits, or indeed where they had come from initially. It was left to Kirkwood (1861) to propose that shower meteors were debris of ancient comets. Kirkwood chose rather a peculiar journal to present these ideas, a northern Kentucky Presbyterian journal of theology and current affairs. Hence his ideas did not reach the wider scientific population until publication of his book (Kirkwood, 1867). Schiaparelli, (1867a, b) identified the pairing of the Perseid stream and comet 109P/Swift-Tuttle. The honour of correctly identifying the pairing with 55P/Temple-Tuttle goes to Peters (1867). Weiss (1867) had identified the April Lyrid shower with C/1861 G1 (Thatcher) and that the Andromedid shower was on a similar orbit to the now defunct comet 3D/Biela. Herrick & Bradley (1846) observed a second fainter comet north-west of the primary. At its next appearance, the double comet was extensively observed. The comets were never seen after that. Weiss (1868) predicted that a large storm of Andromedid meteors would be seen in 1872 when the Earth would pass close to the location of the disintegrated Biela. This was duly observed and the meteor comet connection was finally accepted. More detail of the history of meteor science can be found in Jenniskens (2006) and Williams (2011), for example.

There are several points in this account that serve to illustrate the important role that Commission 22 was to play in the development of meteor science. First, at the time of formation on the IAU, meteors had been studied for a considerable time and some reliable data existed. It could be argued that all the fundamental points in the field had been established, unlike the subject of many of the other commissions that existed in 2015. Meteors were caused when particles, originally released by comets, moved in swarms or streams on heliocentric orbits similar to that of the comet. Showers occurred when the Earth passed through this stream. Planetary perturbations caused the stream to gradually spread until eventually no memory of the original orbit remained and the particles had joined the interplanetary background resulting in sporadic meteors and the zodiacal cloud.

However, many key aspects remained unclear. There were no reliable prediction models. Many physical mechanisms had been proposed to explain meteoroid stream evolution, but it was unclear which of those were important. How did the meteoroids get on their initial orbits? The most important requirement now was for more high quality data to verify this and Commission 22 immediately set about doing this.

Second, and perhaps more important, as meteors at that time were essentially a naked eye phenomenon, observational contributions have been made by many people from many fields, few were paid professional meteor scientists. An analysis of the occupations of the names mentioned above is interesting. Ernst Chlandi was an inventor of quirky musical instrument who gave public performances on them. Andrew Ellicot was a surveyor. Edward Herrick was a book shop owner and later a librarian while John Lock and John Pringle were both medical doctors. Adolphe Quetelet was a statistician (indeed may have invented the subject) while David Rittenhouse was an engineer and inventor of scientific instruments. Alexander Twining was also an engineer and surveyor (who invented a machine for the manufacture of artificial ice in commercial quantities). Finally Alexander van Humbolt and Aime Bonpland were botanists. The recognition of the contribution of people whose main expertise lies in other fields has continued throughout the life of Commission 22, as we shall see, enriching it and allowing major advances to be made. These people have been welcomed and encouraged to take an active part in the life of Commission 22 as well as contributing to the field in general.

3. The first 25 years of Commission 22

With the outlines of a model to explain meteors in place, the obvious strategy to further advance the field is to gather more data. One aim was be to identify further meteor showers and establish their radiant points while a second aim was to identify comet-meteor shower pairs. The first aim requires an accurate determination of the apparent meteor path across the sky, while the second aim needs an accurate determination of the speed of the meteor so that a heliocentric orbit can be determined before the pairing can be regarded as certain. However early on in this period, this was difficult and a slightly different strategy was used whereby predictions were made as to whether meteoroids on orbits close to that of the comet could intersect the Earth at a given time. Davidson (1915) had predicted that comet 21P/Giocobibi-Zinner would produce a storm in October 1915, but little was seen. Similar geometric conditions existed in 1926 and a large meteor storm was observed. This allowed Denning (1926) to identify the comet meteor pairing of the Draconids and comet 21P/Giacobinni-Zinner.

The Draconids were to play further significant roles in the development of the meteor story as we shall see. Other pairings, for example 7P/Pons-Winnecke and the June Bootids (τ Draconids) were recognized in this general period (Denning, 1921). A related question is whether there is any structure within a meteoroid stream reflecting perhaps different periods when meteoroids were introduced into the stream from the comet. Denning (1926) identified several sub-streams within the Taurid complex. As well as Denning

https://doi.org/10.1017/S1743921316000843 Published online by Cambridge University Press

in the UK, Olivier pioneered the scientific visual study of meteors during this period in the USA, identifying many radiant. His best known publication, still widely cited today, is his monograph called 'Meteors' (Olivier, 1925) which served to inspire many a would-be meteor scientist in his day.

There were other activities ongoing during this time interval, all essentially driven by the need to obtain more and better data. In 1933 Vladimír Guth became the first astronomer to attempt to observe meteors from above the clouds using an aircraft rather than a balloon. He and four others flew in a three engine Fokker FVII aircraft. In total they observed 21 meteors, 18 being Leonids. The results were described in Guth (1924).

Spectroscopy was also in its infancy. Obtaining spectra of meteors is difficult simply because their position is unknown before they appear and so getting their image to fall onto the slit requires luck, though the chances are increased during a meteor storm. Spectra were observed visually during the Leonid storm of 1866 (Browning, 1867), but there was a long wait before the technique would become routine. However, Sodium was identified in the upper atmosphere by Cabannes, Dufay & Gauzit (1935) and though its source was not universally identified at the time, we now know that it is a result of meteor ablation.

The main source of error in visual meteor observations was in determining the velocity, when all that was available were sketches and notes made from naked eye observations with an estimate of the duration of the trail. However, photography was being developed. Photographing meteors presented the same problems as described for spectroscopy. Weinek, (1888) obtained one streak of light during the Andromedid storm of 1885 and meteor photography was born. Just obtaining a photograph did not help in determining meteor velocity as there was no real indication of when the trail started or ended. In an attempt to overcome this, Elkin (1899) placed a bicycle wheel in front of his cameras with obscuring material in half the wheel. With the wheels turning at a known rate, gaps were produced in the meteor trail, allowing the time to be determined. With improvements, this was extensively used in the 1930s and 40s. It was still in use until CCD and Video imaging became common. A second method was developed to measure meteor velocities, the tilting mirror method. Here a mirror tilts or oscillates at a known rate, usually about 10 oscillations per second. The effect is that the meteor trail appears as an epicycle on the photograph and the cusps can easily be identified and measured. A big controversy emerged at this point as to whether many meteoroids were on hyperbolic orbits and thus originating outside the Solar System. In a catalogue by von Niessel & Hoffmeister (1925) 79% of meteoroids were hyperbolic. The results of an expedition to Arizona (Shapely et al., 1932) showed that out of 1436 meteor velocities measured, 60% were hyperbolic (Öpik, 1934, 1940). The opposite view was taken by Whipple (1938, 1940) and Porter (1943), who found that only 10% of sporadic meteors were hyperbolic. With eminent and established astronomers on one side and a young Fred Whipple on the other, Commission 22 took no official view on the matter, but they did elect Whipple as President in 1948 (before he became famous in the field of comets!) In this period, through photography, accurate meteor velocities and radiant positions became possible, allowing for a much better determination of meteoroid heliocentric orbits and thus making the task of establishing connections much easier. The last years of this period were interrupted by World War II, so that astronomy in general and meteor astronomy in particular were severely curtailed, though advances in technology made during the war for other purposes did have a big impact on meteor science afterwards.

As to Commission 22, Olivier was elected as second president in 1925 at the GA in Cambridge (UK), and re-elected in 1928 in Leiden and 1932 in Cambridge (Mass). (In those days, Presidents were not restricted to one term of office). Charles Pollard Olivier was a professional astronomer, being director of the Flower Observatory at the University of Pennsylvania. Apart from his own work on meteors, he is best remembered for his encouragement and support for amateur astronomy, founding for example the American Meteor Society. Thus, the tradition of Commission 22 of supporting amateur astronomy was re-enforced by his appointment. Dufay was elected President of Commission 22 in 1935 at the GA in Paris. Jean Claude Barthélemy Dufay was honorary director of the Lyon and Haute- Provence observatories and an eminent astronomer, but only partially a meteor scientist. He also studied nebulae, interstellar matter, zodiacal light, comets and computed the altitude of the Earth's ozone layer. He was followed by de Roy who was elected in Stockholm in 1938. He died in 1942, but no new President took office until the next General Assembly in 1948. Felix de Roy was a Belgian journalist, writing at different times for the newspapers La Métropole, l'Action National, Le Neptune and Le Matin. He was a keen amateur astronomer, who was interested in many subjects. His main interest in meteors was in recording the paths of bright fireballs. He took refuge in Britain during World War1. While there, de Roy became well enough known to later serve as Director of the British Astronomical Association Variable Star Section for seventeen years and made about 91,000 visual estimates of the brightness of a number of different variable stars. He was a member of Commission 27, on Variable Stars and indeed became its secretary at the same time as he became President of Commission 22, the commission demonstrating yet again the wide interest of its members and that anyone with an interest in meteors can hold office.

4. The next 35 years, significant break-through again

During the war many technical advances took place, whose main purpose was certainly not the advancement of astronomy. However, sometimes big benefits come from unexpected quarters. Stanley Hey was given resources to investigate interference in the British Radar System designed to detect incoming V2 rockets. He found that a number of false alarms in the detection were caused by reflection from ionized meteor trails but this obviously could not be published until after hostilities ceased. Hey realized that radar could be used to investigate meteors and ensured that military radar equipment he had been using became available for civil use allowing Jodrell Bank to be started as an observatory, just in time to observe the Draconid meteor storm of 1946. Several papers reported these results (e.g., Clegg Hughes & Lovell 1947, Hey & Stewart 1947, Lovell Banwell & Clegg 1947). Many other countries eventually did similar things with their spare military equipment.

Radar can detect smaller meteoroids (down to sub-millimetre size) and so detected many more meteors and an understanding of the trail formation process was developed (Appleton & Naismith 1947, McKinley & Millman 1949). Also both the Doppler shift and diffraction waves (Ellyett & Davies, 1948) can be used to measure velocities, thus eliminating the need for double station observing. Radar also worked in the day as well as by night, thus doubling the coverage and discovering many new streams (Ellyett 1949). Equipment improved and capabilities increased so that radio astronomy was measuring velocities and orbits of thousands of meteors and so generating a data-base that could not have been dreamt of 15 years earlier.

At the other end of the meteoroid size scales, three programs were set up to measure fireball trails from photographic data and recover any fragment that fell to Earth as meteorites. The European Network was set up initially in Czechoslovakia in 1963 (Ceplecha and Rajchl 1965), inspired by the successful photographic observation of the Příbram meteorite fall in 1959 (Ceplecha 1961). The network soon expanded to cover a significant fraction of central Europe. It is still operational. The Prairie Network was started in 1964 to cover the mid- West of the USA (McCrosky and Boeschenstein 1965). Sadly it closed in 1975. Finally the Meteor Observation and Recovery Project (MORP) started operating in Canada in 1971 (Halliday *et al.* 1978). It closed in 1985. These increased the data base on large meteoroids and gave some insight into the connection between meteorites and asteroids.

Finally, the most important break-through came from the theoretical side. Comets had still been regarded as a loose agglomeration of dust particles, the flying sand-bank model (Proctor & Crommelin 1937, Lyttleton 1951). Whipple (1950) proposed a new model in which a comet had an icy nucleus with dust grains embedded within it, the dirty snowball model. In this model as a comet approaches the sun, solar heating causes the ices to sublimate and the resulting gas outflow carries away small dust grains with it, the larger ones becoming meteoroids and the very small ones forming the dust tail. Whipple, (1951) modelled this and produced an expression for the ejection velocity. At last it became possible to tie together the release of meteoroids from the parent comet and the formation of a meteoroid stream. With a means of establishing the ejection velocity of meteoroids from a comet, only a fairly simple calculation is required to determine the initial heliocentric orbit of the meteoroid (see Williams, 2002, 2004 for the exact formulae).

In this period, computing capabilities were too limited to allow direct integration of the subsequent orbital evolution under the effects of the gravitational perturbations of the Planets of a significant set of meteoroids. Only the evolution of a single orbit, taken to be the mean orbit of a stream could be followed, and secular perturbation methods were used to do this, generally based on an algorithm by Brouwer (1947). This method was used by Whipple & Hamid (1950) to follow the evolution of the Taurid stream over 4700 years. Babadzhanov & Obrubov (1980, 1983) used the Halphen-Goryachev method, described in Hagihara (1972), to investigate the evolution of the orbits of Quadrantid and Geminid streams.

By and large, for obvious logistic reasons, both the IAU in general and Commission 22 in particular conducted their affairs via a three yearly meeting, the General Assembly, and a report which was an overview of progress over the previous three years. However, in 1953 the IAU started a Symposium series followed by a Colloquium series. Symposium 4 was held in Manchester in 1955 and entitled Radio Astronomy. Some time was devoted to meteors. In 1967, Symposium 33 Physics and Dynamics of Meteors was held in Tatranská Lomnica, the first symposium devoted entirely to the study of meteors. Finally in 1972 Colloquium 22 entitled Asteroids Comets and Meteoric matter was held in Nice. The first president during this period was Whipple, elected in 1948 at the IAU General Assembly in Zurich. Fred Whipple worked at the Harvard College Observatory for over 70 years. In 1933, he discovered comet 36P/Whipple and asteroid 1252 Celestia. He also co-discovered five other comets, and was heavily involved in the observations of meteors during the early part of his career. He is best known as the proposer of the 'dirty snowball' comet model. Guth, was elected president in Rome in 1952 and was re-elected in Dublin in 1955. Vladimír Guth has already been mention in connection with observation of the Leonid shower from aircraft back in 1933. In 1951 he was appointed director of the Astronomical Institute in Tatranská Lomnica and in 1955 was appointed Deputy Director of the Astronomical Institute of the Czechoslovak Academy of Sciences and placed in charge of the Ondřejov Observatory. During this time, he was responsible for initiation the studies of small solar system bodies within Czechoslovakia. Fedynsky was elected President in 1958 in Moscow. Vsevolod Vladimirovich Fedynsky was primarily a distinguished Geophysicist who was a Professor at the Moscow State University from 1950. In meteor studies, his most notable work concerned the potentially disastrous effect of meteoroid falls on Earth and he predicted the existence of meteoritic craters on Mars, Mercury and planetary satellites. During his presidency, Basic Definitions in Meteoric Astronomy were adopted at the IAU General Assembly in Berkeley (Millman 1961). Millman became President at the GA in Hamburg in 1964. Peter Mackenzie Millman, worked at the University of Toronto from 1933 until 1941. In early 1941 he enlisted with the Royal Canadian Air Force and served with it throughout WW2, eventually attaining the rank of Squadron Leader (equivalent to Major). This had astronomical spinoffs as he was able to organize airborne meteor shower expeditions. In 1946 he joined the Dominion Observatory in Ottawa and transferred to the National Research Council in 1955 to the head Upper Atmosphere Research team. He wrote a weekly astronomy column in The Toronto Star. He can rightly be regarded as the father of the field of meteor spectra. At the Prague GA in 1967 Ceplecha was elected President. Zdeněk Ceplecha worked all his life at the Astronomical Institute of the Academy of Sciences at Ondřejov. Under the influence of Guth he started double station photographic observation of meteors in 1951. Using this, he was able to calculate the path of the very bright Příbram fireball and identifying its impact point, allowing four fragments of the meteorite to be found (Ceplecha 1961). In 1963 he founded the European Fireball Network. He also studied fireball spectra at that time.

In 1970 at the Brighton GA McCrosky became President. From 1962 to 1975 Richard McCrosky, was scientist-in-charge of the Prairie Meteorite Network, a system of 16 camera stations in the Midwest. This network was responsible for predicting the fall location of the Lost City meteorite (McCrosky *et al.* 1971). He then became director of the Harvard-Smithsonian Center for Astrophysics' Oak Ridge Observatory, responsible for tracking and improving the orbits of asteroids. Lindblad became Commission President at the Sydney GA in 1973. Bertil Anders Lindblad started his career carrying out radar observations of meteors, and attempting to correlate these with visual observations of the same showers. He was responsible for the setting up of the IAU Meteor Orbit Centre at Lund, a large data base of meteor orbital elements. He was a strong supporter of cooperation between amateur and professional meteor workers and was elected the first Honorary Member of the International Meteor Organization in 1989, which in the late 1980's took over the leading role in organizing the amateur meteor observing community from the British Astronomical Association's Meteor Section and the British Meteor Society.

Halliday became President at the Grenoble GA in 1976. Ian Halliday joined the Dominion Observatory in Toronto in 1952, working principally the Stellar Physics Division, specializing in meteor spectroscopy. When the Obseratory closed in 1970, he went to National Research Council as a Senior Research Officer in the Planetary Sciences Section. There he set up the twelve-station meteorite recovery project in western Canada (MORP) which lead to the discovery of the Innisfree meteorite (Halliday *et al.* 1978). The final two presidents in this period were Elford, elected in 1979 in Montreal and Belkovich, elected in 1982 at the Patras GA. Both Graham Elford (Adelaide) and Oleg Belkovich (Kazan) are still alive and continue to be active in the meteor field and so a summary of their contribution is not included.

5. The last 35 years of Commission 22

Secular perturbation method, mainly used up to this time as a means of following meteoroid stream evolution is that it deals with the evolution of orbits rather than determining the position of individual meteoroids so that the properties of an observed

https://doi.org/10.1017/S1743921316000843 Published online by Cambridge University Press

individual shower can never be determined. Direct integration methods integrate the path of each individual meteoroid but require much more computing power. As a typical stream contains at least 10^{16} meteoroids, even today's powerful computer can not fully replicate a stream, and a smaller sample of test particles has to be selected to represent the stream. Williams Murray & Hughes (1979) used only 10 test meteoroids, following their evolution for 4500 years, but by 1985, Hunt *et al.* (1985) and Jones (1985) were able to select several hundred meteoroids and were able to produce a theoretical cross section on the ecliptic for the Geminid stream. Many other simulations were carried out in subsequent years and a review of these investigations is given in Williams (2002). By now predicting the likely cross-section at any given time, and thus the observed properties of a meteor shower starting from the ejection of meteoroids from its parent body has become routine and carried out on a large number of streams (e.g., Jenniskens 2006, Jenniskens & Vaubaillon 2008, 2010).

A second benefit of the explosion in technology came through the use of CCD detectors and video cameras. These allowed an accurate determination of the time of flight and geometry of trails to be made for the abundant relatively faint meteors, which in turn means that an accurate determination of the heliocentric orbit of the meteor can be made for large numbers of meteors. A welcome consequence has been the large increase of networks worldwide, many operated most of the time by amateur volunteers. This has resulted in many newly discovered meteor showers and many more observed fireballs being established as the precursor of a meteorite discovery on Earth, a very well known recent example being the Chelyabinsk event (Borovička *et al.* 2013; Popova *et al.*, 2013, Brown *et al.*, 2013). That impact created an airburst that resulted in more than1600 people requiring medical treatment for glass cuts. Commission 22 assisted in the field study (Popova *et al.*, 2013).

Finally, more use was made of aircraft-borne observations, which served to mobilize a wide array of new techniques for meteor studies (e.g., Jenniskens, Butow & Fonda, 2000; Vaubaillon *et al.* 2015). On the ground, more use was made of high-aperture radar, seismic detections, satellite observations and infrasound in observing meteors (e.g., Brown *et al.*, 2002).

The Presidents during this period were Pulat Babadzhanov (elected in 1985 at New Delhi), Colin Keay (elected in 1988 at Baltimore), Jan Štohl (elected in 1991 at Buenos Aires, Iwan Wiliams (who took over following the untimely death of Štohl in 1993 and elected again at The Hague in 1994), Jack Baggaley (elected in 1997 at Kyoto), Vladimír Porubčan (elected in Manchester in 2000), Ingrid Mann (elected in Sydney in 2003), Pavel Spurný (elected in Prague in 2006), Junichi Watanabe (elected in Rio de Janeiro in 2009) and Peter Jenniskens (elected in Bejing in 2012). Jiří Borovička was elected president of the new Commission F1 (Meteors, Meteorites and Interplanetary Dust) at the Honolulu GA in 2015. All but Colin Keay and Ján Štohl are still alive and so again no reference is made to their work. Colin Keay died only a few months ago and a number of obituaries can currently be found. He worked primarily at the University of Newcastle. He first determination of the incidence distribution of radar meteors onto the southern hemisphere and was chair of an IAU Working Group on the Prevention of Interplanetary Pollution. Ján Štohl started work at the Astronomical Institute of the Slovak Academy of Science in Bratislava from 1956 to 1966. He then spent two years working with Peter Millman in Ottawa. He returned to Slovakia and spent the remainder of his life there, becoming Director of the Institute in Tatranská Lomnica in 1989. Throughout his career he was interested in establishing a generic relationship between meteoroid streams and Apollo asteroids, paying particular attention to the Taurid complex.

Commission 22, became very active in encouraging the organization of scientific meetings and encouraging cooperation between professional and amateur workers during this period, resulting in many excellent reviews of all the topics mentioned above being presented and published. For this reason, the account of the scientific developments that were made during this period has been kept to a minimum.

The idea of holding a symposium devoted to meteors emerged from discussions between Commission 22 members at the IAU General Assembly in Baltimore in 1988 when Jan Stohl was elected Vice-President of the Commission. By the time of the General Assembly in Buenos Aires in 1991 the idea had firmed up and the Commission felt that it would be nice to hold it Czechoslovakia in 1992, 25 years after the successful meeting 'Physics and Dynamics of Meteors' mentioned earlier. The newly elected President and Vice-President of Commission 22 (Stohl and Williams) were asked to be joint Chairs of the Scientific Organizing Committee with Anton Hajduk as Chair of the Local Organizing Committee. The Symposium entitled ' Meteoroids and their Parent Bodies' was held at Smolenice Castle from 6-12 July, with more than 100 participants and was a great success. The conference was dedicated to the famous Slovak astronomer Ĺubor Kresák. The International Meteor Organization held its annual meeting in Smolenice in the days immediately prior to the Symposium, allowing for enhanced cooperation to be fostered. The proceedings were published as a book by the Astronomy Institute of the Slovak Academy of sciences (Štohl & Williams, 1993).

Very sadly, Ján Štohl died in the interval between the symposium and the Proceedings appearing, while Ĺubor Kresák of the same Institute died in 1994. Commission 22 decided to hold a meeting after the IAU General Assembly in The Hague dedicated to the memories of Ján and Ĺubor. In consequence, 'Meteoroids' was then held at the Comenius University in Bratislava in summer 1994. The proceedings were published as a special volume of Earth Moon and Planets (vol 68, 1995 Edited by Porubčan, Williams & Vanýsek). The Commission also felt that it was good to organize a regular conference on Meteors, though not to coincide with the General Assembly. 'Meteoroids 1998' was held in Tatranská Lomnica again in Slovakia. The date and venue were chosen so that mutual participation at both the IAU Colloquium 173 'Evolution and Source Regions of Asteroids and Comets' and the annual conference of the International Meteor Organization would be possible. The proceedings were published as a book (Edited by Baggaley & Porubcan) and again published by the Slovak Academy of Sciences.

At this time, rather than deciding at the commission business meeting at the General Assembly, that invitations would be solicited from meteor groups and that the organizing committee of the commission would decide on the location. Thus 'Meteoroids 2001' was held north of the polar circle in Kiruna, Sweden and was dedicated to Bertil A. Lindblad. The proceedings were published as ESA SP- 495 (edited by Warmbeim). In 2004, the conference left Europe for the first time, with 'Meteoroids 2004' being held in London, Ontario, Canada. The proceedings were published as special issue of Earth Moon and Planets (Volume 95, 2004, edited by Mann, Brown & Hawkes).

At the 2006 IAU General Assembly in Prague, Commission 22 adopted nomenclature rules for meteor showers and established the first Task Group on Meteor Shower Nomenclature (Jenniskens, 2008). It's first president was Peter Jenniskens. The Task Group worked closely with a newly reformatted Meteor Data Center, headed by Jopek Tadeusz at the Adam Mickiewicz University in Poznań, which maintains an on-line Working List of Meteor Showers. Amateur astronomers are actively contributing to this, verify the existence of previously reported meteor showers as well as discovering new ones.

In 2007, the Meteoroids conference returned to Europe, being held in Barcelona, Spain and entitled Advances in Meteoroid and Meteor Science. The proceedings also appeared in Earth Moon and Planets (Volume 102, 2008, edited by Trigo- Rodríguez, Rietmeijer, Llorca & Jánchez). The IMO meeting was held prior to it, just over the border in France. The 2010 meeting returned to North America, and was held at Breckenridge, Colorado, USA and entitled 'Meteoroids: The Smallest Solar System Bodies' The proceedings were published by NASA as NASA/CP-2011- 216469. 'Meteoroids 2013', was held in Poznań, Poland with the IMO annual conference again being held in the same City. The proceedings appeared as a book (edited by Jopek, Rietmeijer, Watanabe & Williams) and published by the Adam Mickiewicz University Press. As for the future, commission 22 decided that a conference should be held at ESTEC, The Netherlands in 2016.

6. Concluding remarks

It is clear that since its formation in 1922 Commission 22 has been heavily involved in all aspects of meteor science through its working groups and by encouraging the organization of conferences and symposia held at regular intervals and, where the logistics allow, to hold these at a place and time that allows the International Meteor Organization to hold its annual conference in the vicinity. This allows a significant number of meteor scientists to attend both, and in the process sustain and encourage cooperation between amateur and professional meteor scientists. It should be stressed that such cooperation is vital in the days where networks have been established world wide and these in general can not be staffed and operated by professionals alone.

Acknowledgements

I thank Peter Jenniskens and Jiří Borovička for helpful comments.

References

Adams, J. C., 1867, *MNRAS*, 27, 247-252

Appleton, E. V. & Naismith, R., 1947, *Proc. Roy. Soc.* A 59 461-472

Babadzhanov, P. B. & Obrubov, Y. Y., 1980, In: *Solid particles in the Solar System Eds Halliday I McIntosh B A D.Reidel Dordrecht* 157-162

Babadzhanov, P. B. & Obrubov, Y. Y., 1983, In: Highlights in Astronomy Ed West R M D Reidel Dordrecht 411-419

Borovička, J., Spurný, P., Brown, P., Wiegert, P., Kalenda, P., Clark, D., & Shrbený, L., 2013, *Nature*, 503, 235-237

Brown P. G. Revelle D. O. Tagliaferri E. & Hildebrand A. R., 2002, Meteoritics & Planetary Science, 37, 661-675

Brown P. G., Assink J. D., Astiz L., *et al.*, 2013, *Nature* 503, 238-241

Brouwer D., 1947, *AJ*, 52, 190-198

Browning J., 1867, *MNRAS*, 27, 77-79

Cabannes J. Dufay J. & Gauzit J., 1935, *ApJ*, 88, 164-172

Ceplecha Z., 1961 *Bull. Astron. Inst. Czechoslovakia*, 12, 21-47

Ceplecha Z., Rajchl J., 1965. *Bull. Astron. Inst. Czechoslovakia*, 16, 15-22

Chladni E. F. F., 1794, Ueber den ursprung der von Pallas gefundnen und andern ahnlichen eisenmassen, J F Hartknoch, Riga

Clegg J. A. Hughes V. A. Lovell A. C. B., 1947, *MNRAS*, 107, 369-378

Davidson M., 1915, *J. Brit. Astron. Assoc.* 25, 292-293

Denning, W. F., 1921, *Nature*, 107, 15-16

Denning, W. F., 1926, *MNRAS*, 87, 104-107

Denning, W. F., 1928, *J. Brit. Astron. Assoc.* 38, 302

Draper, J. W., 1864, *A history of the intellectual development of Europe*, Harper Brothers, New York

Ellicot A., 1804, *Trans. American Philosophical Soc.*, 6, 28-29
Elkin W. J., 1899, *American Jl. Of Science and Arts*, 8, 473-474
Ellyett C. D., 1949, *MNRAS*, 109, 359-364
Ellyett C. D. Davies J. G., 1948, *Nature*, 161, 596-597
Guth V., 1934, *the Realms of the stars*, 15 (in Czech)
Hagihara Y., 1972, *Celestial Mechanics*, MIT Cambridge Mass
Halley Edmund, 1688, *Phil. Trans. Roy. Soc.* 16 402-406
Halley Edmund, 1714, *Phil Trans. Roy. Soc.* 29 159-164
Halliday I., Blackwell A. T., Griffin A. A., 1978 *JRASC* 72, 15-39
Hasegawa I., 1993, in *Meteors and their parent bodies*, Eds Stohl J. Williams I. P. Astronomical Institute Slovak Academy of Sciences, Bratislava 209-223.
Hey J. S. Stewart G. S., 1947, *Proc. Phys. Soc.*, 59, 858-883
Herrick E. C., 1837, *American Jl Sci. and Arts* 33 176-180
Herrick E. C., 1838, *American Jl Sci. and Arts* 33 354-364
Herrick E. C. Bradley F., 1846, *American Jl of Science and Arts* 1 446- 447
Howard E., 1802, *Phil.Trans Roy Soc.*, 92, 168-212
Hunt J. Williams I. P. Fox K., 1985, *MNRAS*, 217, 533-538
Jenniskens P. Butow S. J. Fonda, M., 2000, *EM&P*, 82, 1-26
Jenniskens P., 2006, *Meteor Showers and their Parent Bodies.* Cambridge University Press,
Jenniskens P. Vaubailllon J., 2008, *AJ*, 136:725-730
Jenniskens P., 2008, *Earth, Moon and Planets* 102, 5-9
Jenniskens P. Vaubaillion J., 2010, *AJ*, 139, 1822-1830
Jones J.,1985, *MNRAS*, 217, 523-532
Jopek T. J., Jenniskens P, 2011, In: *Meteoroids: The smallest solar system bodies.* W. J. Cooke, D. E. Moser, B. F. Hardin, D. Janches, eds., NASA Marshall Space Flight Center, NASA/CP-2011-216469, p. 7-13
Kirkwood D., 1861, *Danville Quarterly Review*, 1 614-618
Kirkwood D., 1867, *Meteoric Astronomy: a treatise on Shooting Stars*, Fireballs and Aerolites, J B Lippencott &Co. Philadelphia
LeVerrier U. J. J., 1867, *Comptes rendus*, 64, 94-99
Lyttleton R. A., 1951, *MNRAS*, 111, 268-277
Littman M., 1998, *The Heavens on Fire*, Cambridge University Press,.
Lock, J, 1834, *Letter to the Cincinnati Daily Gazzette*, August 11
Lovell A. C. B. Banwell C. J. Clegg J. A., 1947 *MNRAS* 107 164-175.
McCrosky R. E. and Boeschenstein H., Jr., 1965 *SAO Special Report*, #173
McCrosky R. E., Posen A., Schwartz G., Shao C.-Y., 1971, *JGR* 76, 4090-4108
McKinley D. W. R. Millman P. M., 1949, *Proc Inst Radio Eng.*, 37, 364-375
Millman P. M., 1961, *JRASC* 55, 265-267
Newton H. A., 1863, *American J. of Science and Arts*, series 2, 36, 145-149
Olivier, C. P., 1925, Meteors, The Williams & Wilkins Pub Co, Baltimore
Olmstead D., 1834, *American Journal of Science and Arts*, 25, 363-411
Olmstead D., 1835, *American Journal of Science and Arts*, 26, 132-174
Öpik, E. J., 1934, *Harv. Coll.Obs. Circ.*, 391
Öpik E. J., 1940, *Analysis of 1436 meteor velocities*, Pub. Tartu Obs, 30, 86
Peters C. F. W., 1867 Astronomische nachrichten 68 287-288
Popova O. P., Jenniskens P., Emel'yanenko V., *et al.*, 2013, *Science* 342, 1069- 1073
Porter J. G., 1943, *MNRAS*, 103, 134-153
Pringle J., 1759, *Phil Trans Roy. Soc.*, 51, 259-274
Proctor M. Crommelin A. C. D., 1937, *Comets, their nature Origin and Place in the science of Astronomy*, The Technical Press, London
Rittenhouse D., 1786, *Trans. American Phil. Soc.*, 2, 173-176
Schiaparelli G. V., 1867a, *Comptes rendus*, 64, 598-599
Schiaparelli G. V., 1867b, *Astronomische Nachrichten*, 68, 331-332
Shapley H. Öpik E. J. Boothroyd S. L., 1932, *Proc. Nat. Acad. Sci.*, 18, 16-23

https://doi.org/10.1017/S1743921316000843 Published online by Cambridge University Press

Štohl J. Williams I. P., 1993, *Meteors and their Parent Bodies*, Slovak Academy of Sciences
Twining A. C., 1834, *American J. Sci. and Arts*, 26, 320-352
Van Humbolt A. Bonpland A., 1852, A Personal Narrative of travels in the equinoctial regions of America during the years 1799-1804, London
Vaubaillon J., Koten P., Margonis A. *et al.*, 2015, *EM&P* 114, 137-157
Von Niessl G. Hoffmeister C., 1925, *Katalog der Bestimmungsgroßen für* 611 Bahnen großer Meteore, Denksch. d'Akad. d'Wiss. Wien, 10
Weinek L., 1888, Astronomische Beobachtungen an der K.K.Sternwarte zu Prag, in den Jahren 1885, 1886, und 1887
Weiss E., 1867, *Astronomische Nachrichten*, 68, 381-384
Weiss E., 1868, *Astronomische Nachrichten*, 72, 81-102
Whipple, F. L., 1938, *Proc. Am. Phil. Soc.*, 79, 499-548
Whipple, F. L., 1940, *Proc. Am. Phil. Soc.*, 82, 275-290
Whipple F. L., 1950, *Ap. J*, 111, 375-394
Whipple F. L., 1951, *Ap. J*, 113, 464-474
Whipple F. L. Hamid S. E., 1950, *AJ*, 55, 185-186
Williams I. P., 2002, *The evolution of meteoroid streams*, in Meteors in the Earth's Atmosphere, Murad E Williams I. P., eds., Cambridge Univ. Press, Cambridge, 13-32
Williams I. P., 2004, *JIMO*, 32, 11-20
Williams I. P., 2011, *A&G*, 52, 2.20-2.26
Williams I. P. Murray C. D. Hughes D. W., 1979, *MNRAS*, 189, 483-492

II. MINUTES OF THE BUSINESS MEETING HELD IN HONOLULU, USA, ON AUGUST 12, 2015 (DURING THE XXIXTH IAU GENERAL ASSEMBLY)

Peter Jenniskens
President of the Commission

The president of the Commission Peter Jenniskens presented the report on Commission activities and current status. During the 2012–2015 triennium, the C22 organizing committee included J. Borovička (vice president), T. Jopek (secretary), S. Abe, G. Consolmagno, M. Ishiguro, D. Janches, G. Ryabova, J. Vaubaillon, and J. Zhu.

(*a*) Following the IAU Commission reform, C22 (and all other current commissions) will cease to exist on August 13, 2015. C22 will be replaced by newly formed Commission F1 with the same name Meteors, Meteorites, and Interplanetary Dust. The president of C.F1 will be Jiří Borovička. So far, 104 members have registered to become a member of C.F1, including 45% of the 129 former C22 members. Many of the remaining are active C22 members who are expected to register once the registration process opens up again.

(*b*) The activities of C22 in the last triennium included the co-organization on the Chelyabinsk airburst field investigation and outreach during a field study of the Chatman Island bolide (both performed by the Commission president), the co-organization of the Meteoroids 2013 conference in Poznań, Poland (chair of the local organizing committee was T. Jopek), the Commission business meeting at the ACM conference in Helsinki, Finland, an effort to rewrite definition of terms in meteor astronomy, and the work of two Working Groups (see below).

(*c*) The participants paid tribute to the members and other people that contributed to our field, who deceased in the last triennium: B. McIntosh, W.T. Hally, S.E. Dwornik, and J. Kleczek.

https://doi.org/10.1017/S1743921316000843 Published online by Cambridge University Press

(*d*) The next Meteoroids 2016 meeting will be held at ESTEC, Noordwijk, The Netherlands on June 6–10, 2016. The chair of the LOC will be D. Koschny, the chair of the SOC will be the C.F1 president J. Borovička.

(*e*) Following a proposal by the IAU General Secretary T. Montmerle, the usual triennial report to the Transaction of the IAU will be replaced by an article about the history of Commission 22 and its role in meteor science and related fields. The main author will be I. Williams. The report is due October 31.

(*f*) The current status on creating new definitions of terms related to meteor astronomy was presented earlier today during the Division meeting by J. Borovička. Objections were raised against establishing arbitrary boundaries in otherwise continuous distributions. Based on this discussion at the IAU General Assembly, the proposed definitions will be further discussed within Commission F1 with the aim to arrive at a set of new definitions that can be approved by electronic vote including all C.F1 members during the next triennium.

(*g*) The working group on collaboration with amateur astronomers was led in the last triennium by D. Koschny. Since the collaboration and contacts with amateur astronomers are now well established (especially with IMO and in the field of meteor shower research), there is no need for continuation of this working group under C.F1.

(*h*) The working group on meteor shower nomenclature was led in the last triennium by T. Jopek. T. Jopek also maintained the Meteor Data Center. In 2012–2015, 263 new meteor showers were added to the working list, which now contains 526 showers. The Meteor Data Center worked to include all available data records for each shower from various literature sources, make corrections, and add literature references through hyper links. The working group tackled nomenclature issues and prepared the proposal for the amendment of the list of established showers (see below). There is obviously the need to continue this working group under Commission F1. N. Haghighipour, the forthcoming president of Division F, nevertheless, stressed that all working groups in the next triennium must be approved by the steering committee of Division F. The proposals will be due in the next few months. In between, the working group can continue its work.

(*i*) Within C.F1, meteor shower nomenclature issues will be taken on by the following members: D. Janches (president), T. Jopek (lead Meteor Data Center), M. Koseki (IMO representative), Z. Kaňuchová, J. Trigo, R. Rudawska, J. Watanabe, P. Brown, P. Jenniskens, and G. Kokhirova. The new membership was approved by voting. Pending the re-establisment of the C.F1 Working Group on Meteor Shower Nomenclature by Division F, this will be the new WG membership.

(*j*) At the C22 business meeting in Helsinki, a change in meteor shower naming rules was adopted that was still in need to be confirmed by a vote at the IAU General Assembly. T. Jopek proposed to replace the current wording in the nomenclature rules reading: "The general rule is that a meteor shower (and a meteoroid stream) should be named after the then current constellation that contains the radiant, specifically using the possessive Latin form." with a new text reading: "The general rule is that a meteor shower (and a meteoroid stram) should be named after the constellation that contains the nearest star to the radiant point, using the possessive Latin form." In the discussion it was clarified that the nearest star with a Bayer designation, a Greek or Roman letter, or (in exceptional cases) Flamsteed number is meant. The change was then approved by voting.

(*k*) The Working Group on Meteor Shower Nomenclature prepared a short list of 7 meteor showers to be moved to the list of established showers. These were the 96/NCC Northern delta Cancrids, the 97/SCC Southern delta Cancrids, the 362/JMC June mu Cassiopeiids, the 506/FEV February epsilon Virginids, the 529/EHY eta Hydrids, the 530/ECV eta Corvids, and the 533/JXA July xi Arietids. Some 100 other showers are in the pipeline, but verified in papers that are still in various stages of review. At the day of the meeting, the news came that one such paper was now accepted for publication. After consultation with WG president T. Jopek, the following showers were added to the list: 21/AVI alpha Virginids, the 69/SSG Southern mu Sagittariids, 343/HVI h-Virginids, 428/DSV December Virginids, 431/JIP June iota Pegasids, 510/JRC June rho Cygnids, 512/RPU rho Puppids, 524/LUM lamda Ursae Majorids, 526/SLD Southern lambda Draconids, 549/FAN 49-Andromedids, 569/OHY omicron Hydrids. The name of 49-Andromedids (the only shower named according a numbered star) was discussed. The use of Flamsteed numbers came as a result of the old nomenclature rule wording discussed before, and is discouraged with the new nomenclature rule wording now accepted. However, since the name is already in use in the literature, it is not desirable to change it. A vote of approval moved all 18 showers to the list of established showers.

(*l*) At the request of P. Jenniskens, the Working Group proposed to move meteor shower 3/SIA, the Southern iota Aquariids, from the list of established showers back to the working list for more study. Although the shower was repeatedly extracted from small collections of photographed orbits in the past, and therefore included in the list of established showers when it was first created, it is not present in modern (video) data. Past photographic observations do not hint to this being a periodic shower. Instead, meteors attributed to the shower in the past were probably a random selection from the antihelion source (a case similarly to the 55/SCO alpha Scorpiids, which have remained in the working list). After a discussion the proposal was accepted by voting (most people absented). After adding 18 showers and removing one for more study, this brings the tally of established showers to 112.

https://doi.org/10.1017/S1743921316000843 Published online by Cambridge University Press