The meteor work of Ernst Öpik at Armagh Observatory

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Ernst Öpik was one of the principal organizers of the Harvard-Cornell Arizona Expedition for the Study of Meteors in the early 1930s. Öpik took the lead in the analysis of the observations, first at Tartu Observatory and finally at Armagh Observatory. We present here details of the observational method employed, a summary of the main results on meteor radiants, velocities, heights and directions, a description of the Vibrating Meteor Camera devised later by Öpik at Armagh, and some personal recollections about Öpik by one of the authors.

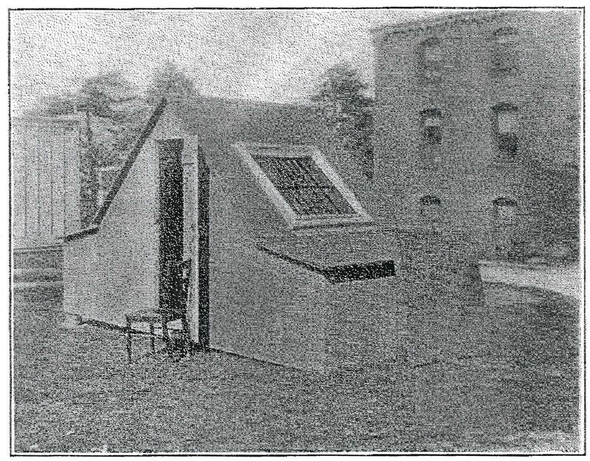
1 Introduction

It is almost exactly 150 years since Jonathan Homer Lane (1819–1880) published what was, arguably, the incipient paper on meteor photography (Lane, 1860). It concerned a method of using photography for the accurate measurement of a meteor's path and velocity in order to calculate an accurate orbit for the meteor. For timing purposes, he proposed: 1) placing a rotating prism, or an eccentric lens, in front of the camera's object glass, or 2) causing the object glass itself to revolve on a slightly eccentric axis. This second method is similar to the method employed by Öpik in his rocking mirror used in the Arizona Meteor Expedition for the determination of visual meteor velocities (Shapley et al., 1932).

Ernst Öpik was primarily a theoretician – many developments in understanding meteor physics originated with his papers – but his success additionally in devising meteor observing techniques and analysing the results demonstrated the range of his skills. Öpik's meteor work alone would rank him as a leading scientist. Together with his groundbreaking research on (inter alia) comets, collision probabilities, and stellar structure and evolution, it ensures his place as one of the twentieth century's great astronomers.

2 The Arizona Expedition for the Study of Meteors

Around 1930, Harvard College Observatory began the systematic study of visual observations of meteors. Öpik joined the staff of Harvard as a Research Associate and Visiting Lecturer from 1930 to 1934 (Lindsay, 1972). As well as general research and lecturing duties, Öpik played a leading role in organizing the Harvard-Cornell Arizona Expedition for the Study of Meteors. A seminal paper on meteor statistics had been published in 1930 by Öpik. This paper may have been the catalyst for the Arizona Expedition. The objective of this Expedition was to study meteors in a general way and, in particular, to determine their origin, e.g. a solar system origin as evidenced by elliptical orbits, gravitationally bound to the sun, versus unbound, hyperbolic orbits showing an interstellar origin. The paper (Öpik, 1930) had emphasized the need for information on the direction distribution of meteors. Öpik considered the chief objective of the Expedition to be the determination of the relative frequencies of meteors coming from different sky directions. The reduction of the observations was carried out under Öpik's supervision, first at Tartu Observatory, Estonia, and finally at Armagh Observatory.



One of the two meteor houses used for visual observations in Arizona. In the window is seen the reticule giving coördinates for positions of meteors.

Figure 1 – (Image courtesy National Academy of Sciences, USA).

Observing sites in Arizona were visited by Harlow Shapley in March 1930 and he selected Flagstaff as the Expedition headquarters. Vesto Slipher, then Director of the Lowell Observatory, allowed the Mars Hill site (located at 35°N, and about 2100 m above sea level) to be used, and he instructed his staff to give the meteor observers every assistance during their stay. During 1930, various pieces of equipment were built and tested at Cambridge, MA, such as the observers' 'reticule' house (Figure 1).

At the end of September 1931, Öpik and Samuel Boothroyd with their assistants went to Arizona, beginning systematic observations in early October, and following some preliminary adjustments to the equipment the full programme began in November. The duration of the Expedition was from 3 October 1931 to 31 July 1933 (i.e., 23 lunations). Approximately 26,000 observations were made of 22,000 meteors on a total of 366 observing nights. Observations were carried out on up to 23 nights of each lunation, with between 4 and 8 hours of observation per night. There was a rest period for the observers: 3 to 4 nights spanning either side of the full moon. The members of the Expedition were: Öpik, Samuel Boothroyd (Cornell), George Mussen (Cornell), Helmut Haendler (Harvard), Roger Wilson (Caltech), Donald Hargrave (Flagstaff), Robert Harris (University of New Mexico), and George Peters (University of Arizona). Second stations were located at Platten Ranch (37.7 km NW of Flagstaff, first 4 lunations) and Canyon Padre (35.3 km SE of Flagstaff, remaining 19 lunations). Four observers, two at each station, monitored an area of sky about 60° in diameter centred at 45° zenith distance on the meridian north and south.

Iron reticules forming a rectangular grid projected on the sky were used to obtain reference coordinates in 10° intervals to help delineate the paths of the meteors and to determine the declination and right ascension. The reticules were mounted on the two opposite slopes of the observing house. The observer looked through one eye-hole placed 50 cm from the reticule and moved only his eye. Celestial coordinates could be found to an accuracy of one tenth of a degree. The wires of the reticule (widths $0\overset{\circ}{.}5$ and $0\overset{\circ}{.}8$) allowed them to be seen easily against the sky. Although the wires obscured 10% of the area, the loss in meteor counts was less than 2% because the meteor trails were much longer than the width of the wires. The time of appearance of the meteor was determined to the nearest second; the magnitude and duration were also recorded. The parallactic displacement was small compared with the diameter of the field of view, thus for very low or very high meteors it was estimated that less than 30% fell outside the region of the other observer.

Visual and telescopic observations of meteor velocities supplemented the visual reticule observations. What Öpik and Boothroyd termed a 'Double Pendulum' device was used for angular velocity observations. This consisted of a square mirror which was given an oscillatory motion such that the normal to its surface was made to move in a conical fashion, so that a star would describe a circle (or ellipse). A meteor would thus have an epicycloidal, i.e. a looped, trajectory (cf. Sec. 4 below). The angular speed of the meteor was obtained by dividing the length of a full loop by the period of rotation of the mirror. A field of view of 30° to a magnitude limit of 5 was achievable for the velocity observations of meteors (Shapley et al., 1932).

The telescopic observations supplemented the visual observations, but also they had a separate value. The statistical information was different for meteors of different luminosity and the telescopic observations allowed a wider range of luminosity to be studied. Simultaneous observations using two 4-inch telescopes of magnifying power 17× and field of view of about 4° were made from two stations separated by about 3 km.

3 Main results of the Expedition

Although not the primary purpose of the Expedition, group radiants (shower radiants) were investigated first. Experiments by V.A. Maltzev (1928) had indicated that more stringent criteria for deducing radiants than Charles Olivier's (1918) definitions should be applied. Most radiants published up until that time were spurious, as confirmed by Maltzev and then the Arizona Expedition. The Expedition results showed that the number of meteors belonging to real radiants of sufficient concentration was 26% (in autumn) and 15% (during rest of year), overall a roughly 80:20 ratio of sporadic to shower meteors. A final list of 279 radiants with over 5,000 probable members was compiled (Öpik, 1934a).

A series of papers followed addressing meteor velocities. Whereas the association of shower radiants with elliptical streams had been established in the nineteenth century, at the time of the Expedition the possibility of sporadic meteors being hyperbolic was a key issue in meteor astronomy. In fact, 'in 1932 the majority of meteoritic astronomers still believed that hyperbolic meteors were indeed abundant' (Whipple, 1972).

For visual meteor velocities (Öpik's 1436 observations in October and November 1931), Öpik's rocking mirror was given a vibration of period one-tenth of a second and amplitude $0\overset{\circ}{.}5$. Apparently the majority of the naked-eye meteors had hyperbolic velocities, viz. greater than 42 km s^{-1} (Öpik, 1934b).

Telescopic velocities (by Boothroyd) were based on observations from 14 November 1931 to 8 April 1932. (See Figures 2 and 3.) The horizontal mirror was given a conical vibration of one-thirtieth of a second around its vertical axis. The telescope (4-inch aperture, 17× magnification, field $3\overset{\circ}{.}65$) pointed down on the mirror such that a field at 45° zenith distance could be observed (alternately N and S on the meridian). The majority of telescopic meteors too had (apparently) hyperbolic velocities, and the frequency of high velocities was greater for faint rather than bright meteors (Boothroyd, 1934).

The next paper (Öpik, 1934c) elegantly showed how the distribution of true (heliocentric) velocities in space can be statistically obtained from the sky-plane projected velocities of Öpik (1934b) and Boothroyd (1934). Visual and telescopic observations of meteor velocities indicated positively the existence of hyperbolic meteors, the percentage of high velocity meteors increasing with decreasing brightness. For October and November 1931, almost all solar (i.e. elliptical) naked-eye meteors were members of real radiants, and almost all members of real radiants were solar meteors. In contrast almost all of the sporadic meteors were of extra-solar origin, though Öpik (1934c) noted the important dis-

Figure 2 – Samuel Boothroyd with the conical-motion mirror devised for the Arizona Expedition. (Image courtesy of The Irish Astronomical Journal).

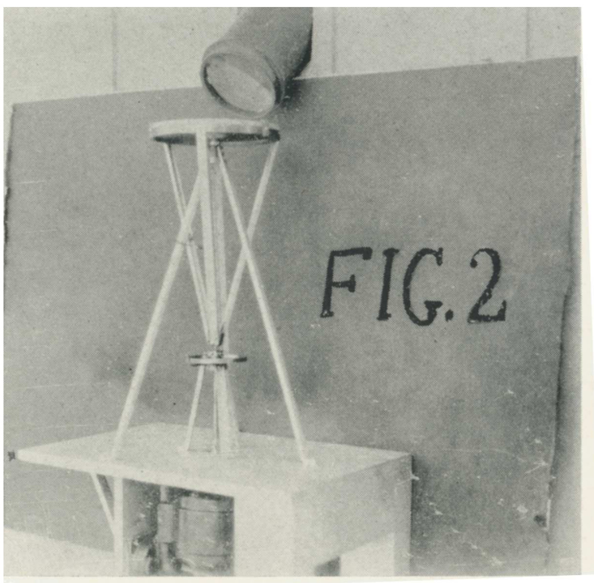


Figure 3 – Arrangement used by Boothroyd for telescopically viewing the meteors during the Arizona Expedition. Notice the objective end of the telescope above the rocking mirror near the top of the figure. (Image courtesy of The Irish Astronomical Journal).

tinction between the number of observable meteors and the density in space, since hyperbolic particles tend to produce brighter meteors owing to their higher speeds. Since by the end of the following decade the double station Harvard Photographic Meteor Program and radio studies at Jodrell Bank had proved that virtually all meteors were on elliptical orbits, hindsight tells us that velocity determinations were the least successful part of the Arizona Expedition, despite the very neat and in principle valid idea of the rocking mirror.

Results on meteor heights were an important achievement of the Expedition. Öpik statistically discussed the heights of 3,540 meteors, determined by simultaneous observations at two stations. Meteors coming from the apex (the fastest ones) appeared 23 km higher than those coming from the antapex. A 'night effect' was found which showed a decrease in the average height by 0.3 km/hr. A 'seasonal effect', corresponding to the annual temperature curve of the upper atmosphere, was also indicated. A general range in heights amounting to ± 8 km was noted (as the main causes, Öpik suspected that this was possibly due to variations in chemical composition, shape, and luminous efficiency). The relatively great heights found for the major shower meteors (Leonids, Perseids, Orionids) are possibly due to their chemical composition (Öpik, 1937).

In view of the high number of meteors coming from the antapex Öpik revised his former views regarding the dependence of luminosity on velocity. Instead of a cube law of velocity (in his notation, $s = 3$), a more appropriate value should be $s = 1.3$, which was more in line with Schiaparelli's and Hoffmeister's theory with $s = 0$. This change of view was related to the quantity of ionization of the meteor atoms (Öpik, 1940, p. 317).

Before the publication of the Arizona Expedition results there had never been an attempt to check the random distribution hypothesis of meteor motions. The results (Öpik, 1956) showed strongly preferred directions. Another first for the Arizona data were measurements of the quantity we now term the population index. This varied between between 2.80 and 3.63 for different components of the meteor influx. Öpik's (1956) paper also reviewed his previously devised 'Double Count' method to reliably (statistically) estimate the fraction of meteors of a given magnitude that a visual observer misses, foreshadowing later authors' work on perception coefficients.

4 Öpik's Vibrating Meteor Camera

Öpik continued meteor observations when he came to Armagh Observatory. He used a system rather similar to the conical-motion mirror arrangement used in the Arizona Expedition. This time, Öpik dispensed with the mirror, and applied a conical motion to the camera.

In 1951, two conical-motion cameras, were constructed by the Senior Assistant of Armagh Observatory, Dr E.B. Armstrong (to Öpik's design). Observations commenced in August 1951. (See Figures 4 and 5). One of the cameras was operated by Öpik at Armagh Observatory and the other by Capt. W.S. Wright from his home at Aghalee some 32 km NE of Armagh. The camera pointed towards 10° zenith distance (NE), equal to half the average parallactic displacement relative to the other station.

The trajectory of the meteor is an epicycloid – a superposition of the conical vibration of the camera on the linear motion of the meteor. The angular velocity of the meteor is determined from the spacing between the loops. Figure 6 is an enlarged portion of a one-hour ex-

Figure 4 – Öpik's vibrating meteor camera in the grounds of Armagh Observatory. Dr E.J. Öpik (right) with Dr E.B. Armstrong who constructed the camera to Öpik's design. (Image courtesy of The Irish Times).

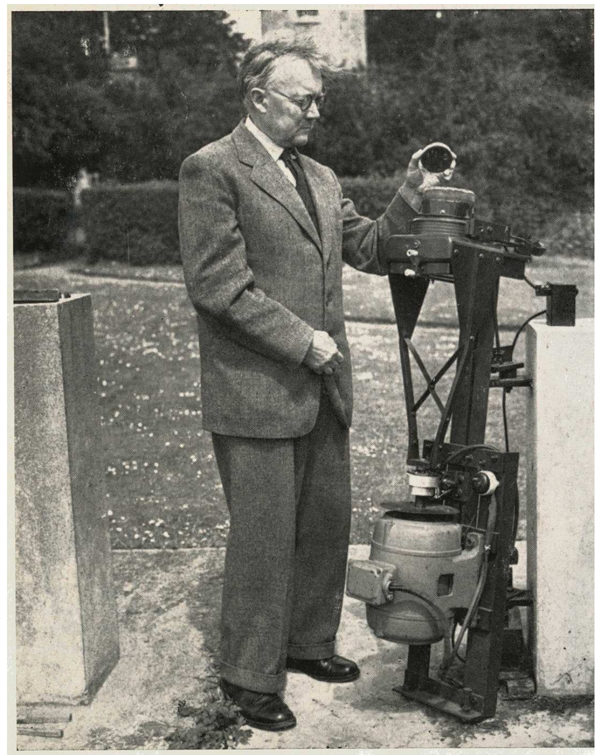


Figure 5 – Dr E.J. Öpik and his vibrating meteor camera. The camera specification was: 7 cm aperture, 20.6 cm focal length. The vibration was controlled by a synchronous motor operating at 1000 rev/min. An attached camera dew-cap was electrically heated by a 12V current. (Image courtesy of Patrick Corvan).

posure with the vibrating camera. This particular meteor (23/24 November 1952, average visual magnitude –3.0) occurred near the centre of the plate where the vibrations were almost circular. The star trails crossing the image have a width that, as with the meteor's epicycles, results from the camera's vibration.

Öpik (1953) computed various heights for the meteor along its track: a, H=108.3 km; d, H=101.1 km; e, H=98.7 km; and mid-trail, H=104.7 km. According to Öpik, this was rather high for a meteor of this magnitude, e.g., from the Arizona Expedition, H=94.5 km (mid-trail). This meteor was probably a late Leonid of the 'dustball' type vaporizing at a greater height.

The measured angular velocities were:

	a – b	b – c	c – d	d – e
ω (deg/sec)	28.64	29.93	31.23	32.4

The change in angular velocity was due mainly to perspective rather than deceleration.

With the Vibrating Meteor Camera (VMC), the epicyclic image of a meteor (Figure 6) is enhanced at the cusps, or loops, where the camera motion most nearly cancels the meteor's sky motion. Öpik (1953) estimated the gain in intensity amounted to two or three magnitudes compared to the meteors found by using a non-vibrating camera. The fainter meteors could be detected as a series of dots (or short sections) at these

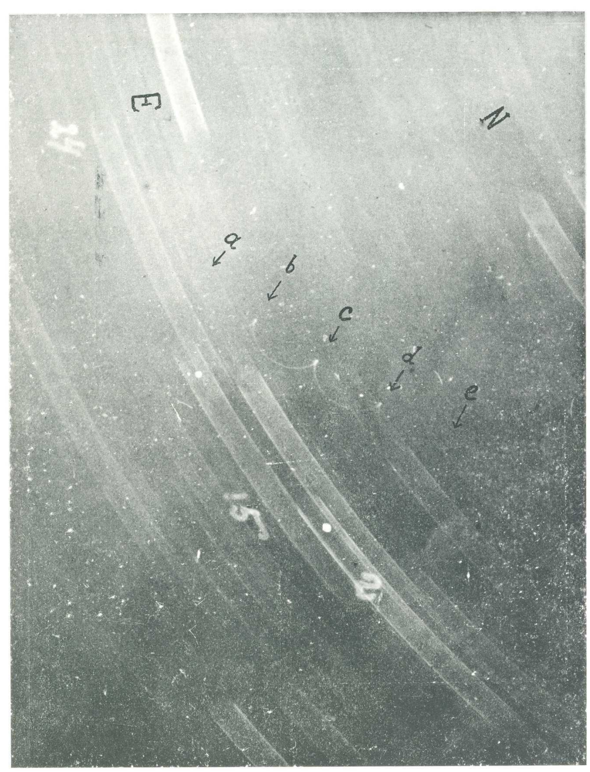


Figure 6 – The meteor of the night of 23/24 November 1952 as photographed with Öpik's vibrating meteor camera. (Image courtesy of The Irish Astronomical Journal).

enhanced points. For shower meteors and medium- to high-velocity sporadic meteors, by having the camera motion set to a suitable rate the VMC could record 4 to 5 times more meteors than an identical stationary camera. Also, useful information about the meteor wake could be gained from VMC photographs of bright meteors.

Ernst Julius Öpik: some personal recollections (JMF)

2010 September 10th was the 25th anniversary of the death of Ernst Öpik (Figure 7). He died about six weeks prior to his 92nd birthday in Bangor, Co. Down. Ernst was born in Port Kunda, Estonia in 1893. He came to the Armagh Observatory as a Research Associate on 11th June 1948, signing the Observatory visitors' book on 30th June. As a Physics and Mathematics undergraduate at The Queen's University of Belfast in my fresher year in the late 1960s, Ernst's son, the late Uno Öpik, was appointed as my Advisor of Studies and during some of our sessions together we had brief conversations about his father. I first came to meet Ernst in 1969 when I came to the Armagh Observatory to work as a vacation student with Eric Lindsay on some Magellanic Cloud projects. I am grateful for the encouragement which both Ernst and Eric gave me.

Ernst and I shared the same birthday, October 23rd, but separated by 55 years. During the mid- to late-1970s when we were both present, whenever the staff gathered for Ernst's birthday party in the Observatory, Ernst and I would perform our customary handshake across the Boardroom table.

Ernst was fluent in many languages and was also a composer of some difficult-to-play piano compositions. He would sometimes perform, to small audiences, on the baby grand piano now in the Observatory Boardroom.

I remember on one occasion while travelling by bus with him to Belfast, I was quizzed by him on various aspects of physics and astronomy. As an example, he asked me completely out of the blue what is the value of Boltzmann's constant. I'm not sure of what I stuttered out, but, at least, he did not rebuke me. I was rather relieved though when we reached our destination! So ended my oral examination with Ernst Öpik. I did, however, gain some knowledge of his great genius and his success in science. He was constantly revising the values of the physical constants in his head and told me once that his mind was continuously thinking about problems, even while asleep.

One evening in 1975, I believe, Robert Scott (Armagh Observatory's meteorological observer), and I were pondering over a game of chess. It was my turn to make the next move. I made the move and Ernst, looking over my shoulder, commented: 'I haven't played chess since I was twelve, but I wouldn't have made that move'. Eventually, needless to say, I went on to lose the game!

Figure 7 – Ernst Julius Öpik, Research Associate at Armagh Observatory from 1948 to 1981.

On another occasion, Robert and I were struggling with a word in a cryptic crossword when Ernst came by. We told him the clue but he couldn't solve it either. He went on his way saying that he would continue to think about it.

I seem to remember that Ernst took up jogging at the age of about 83. Around that same time, I have a vivid recollection of him chasing the group of hunting dogs that would occasionally cross the Observatory grounds. Through my office window, I saw Ernst with a closed umbrella raised aloft pursuing the pack along the path immediately south of the Observatory.

We had arranged to meet each other in Bangor on 11th September, 1985 to hand over the last volume of his collected works which I had been compiling over the previous two to three years, when we received news that he had passed away on 10th. His mind had been fully alert earlier that year when I had passed most of the bound volumes to him.

Ernst was always of a friendly and courteous disposition, always asking about the welfare of the staff and their families. However, he could be quite abrupt with those who 'should know better' whenever they showed an error of judgment, scientific or otherwise.

I knew Ernst for 16 years. I am glad to recall him as a good friend and a stimulating mentor.

Acknowledgements

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