ON THE HISTORY OF METEOR RESEARCH AT THE TASHKENT ASTRONOMICAL OBSERVATORY

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Abstract: **This paper presents a historical overview of meteor research conducted at Tashkent Astronomical Observatory (TAO) from the second half of the nineteenth century to the mid-twentieth century. TAO was the first observatory within the Russian Empire, and subsequently the USSR, in which meteor studies were formally included in the institutional research program.**

Despite its geographical remoteness from major scientific centers, TAO developed a number of pioneering observational and analytical methods that made a significant contribution to the advancement of meteor astronomy. In particular, the technique of simultaneous photographic observations of meteor showers from three spatially separated stations—allowing improved determinations of meteor heights and velocities—was introduced well in advance of its later adoption in Europe. In addition, a statistical counting approach was proposed and subsequently developed by Öpik, enabling indirect estimation of the total number of meteor trails, including those not directly recorded by observers.

Special attention should also be given to the pioneering study by Maltzev, who analyzed the heights of maximum meteor luminosity that led to the prediction of an atmospheric layer above the stratosphere at altitudes of 85–90 km. This result, published in *Nature*, anticipated the later discovery of the mesosphere.

Keywords: **Tashkent Astronomical Observatory; meteor photography; meteor showers; meteor heights; meteor velocities; V.A. Maltzev.**

1 INTRODUCTION

Tashkent Astronomical Observatory, henceforth referred to as the TAO and now known as the Ulugh Beg Astronomical Institute of the Academy of Sciences of Uzbekistan, is the oldest scientific institution in Central Asia (see Figure 1). It was founded more than 150 years ago, in 1873 (Shcheglov, 1974).



Figure 1: The original Tashkent Astronomical Observatory building in 1885.

In the nineteenth century, the main astronomical centers in the Russian Empire were Pulkovo, Moscow (in Krasnaya Presnya), Dorpat (Yuryevsk, Tartu) and Nikolaev Observatories, which were located further North and were inferior to the TAO in terms of the number of clear observing nights. Tashkent Observatory, despite being located far from the scientific centers, had an important advantage: at 41° 19′ 30″ N latitude and 69° 17′ 37″ E longitude it was the only observatory located in the Asian part of the Russian Empire (Shcheglov, 1958).

In the initial period after the creation of TAO, Pulkovo Observatory (Struve, 1880; Zhilinskii, 1872) was the leading astronomical institution in the Russian Empire of the time, and it exerted a significant influence over the activities of TAO. For example, it was thanks to the support of Pulkovo Director, Otto Struve, that TAO was able to order its main optical instruments: a 6-inch Merz refractor and a Repsold meridian circle (Deich, 1945; Zhilinskii, 1872).

In the initial stages of TAO's development, its tasks focused on applied research, such as determining the geographic coordinates of sites in the Turkestan region, calibrating geodetic instruments, calculating clock corrections, and conducting magnetic and meteorological measurements (Anonymous, 1885; Shcheglov, 1974). However, fundamental astronomical fields gradually emerged at the Observatory. Thus, in 1884, systematic sunspot observations began using the 6-inch Merz refractor (Slonim, 1935). Ten years later, in 1894, a standard astrograph, manufactured by Paris Observatory opticians, the Henri brothers, was installed at TAO (Kozlov, 1935). Following this, regular work in the fields of photographic astrometry and stellar astronomy began. Thus, by the beginning of the twentieth century, Tashkent Astronomical Observatory had become a multidisciplinary scientific institution in the field of astronomy (Shcheglov, 1955).

In 1883, staff at TAO began studying meteors, which were included in the official research program and continued for more than half a century (Astapovich, 1958). The work of talented TAO astronomers such as Joseph Sykora, Ernst Julius Öpik, Nadezhda Sytinskaya, Vladimir Maltzev, and others contributed to the development of meteor research worldwide.

In this paper, we provide an historical overview of meteor research at TAO and the main results obtained by its staff over a fifty-year period, from the second half of the nineteenth century to the mid-twentieth century.

2 THE GLOBAL CONTEXT OF METEOR RESEARCH AT THE TURN OF THE NINETEENTH AND TWENTIETH CENTURIES

A meteor is a luminous phenomenon caused by the combustion of small fragments of comets and asteroids in the Earth's atmosphere (Wetherill and Alexander, 2024). Despite a long history of observations, dating back to ancient times, the systematic scientific study of meteors began only in the mid-nineteenth century. By this time, science had a fairly thorough understanding of the origin of meteoric phenomena, accumulated over previous centuries. For example, as early as the seventeenth century, thanks to the research of Montanari (1676), a geometric method for determining the altitudes of bright meteors (bolides) from visual observations was developed, and estimates of their velocities were also obtained. Thus, the atmospheric origin of this phenomenon was proven (Czegka, 1999; Hamel, 2014). And the discovery of annual and azimuthal variations in meteor showers by the German astronomer Heinrich Brandes in 1803 served as evidence of the cosmic origin of meteors (Romig, 1966).

A series of important discoveries and the introduction of new research methods in meteor astronomy occurred in the nineteenth century. For example, the famous American astronomer Olmsted (1834), studying sketches and descriptions of various observers of the Leonid shower, observed on the night of 12–13 November 1833, noted that meteor tracks have a common region of origin. He called this local region the radiant point (or radiant), introducing a new term into scientific circulation. The next important event can be considered the discovery of the connection between meteor showers and comets. In 1862, the famous Italian astronomer Giovanni Schiaparelli calculated the orbits of several meteors from the Perseid shower and noted that their orbits coincided with the orbit of Comet 109P/Swift-Tuttle (1862III), and in 1866 he confidently showed that the orbit of the new comet, 55P/Tempel-Tuttle (1866I), coincided with the orbits of meteors from the Leonid shower (Schiaparelli, 1871). Thus, Schiaparelli was one of the first to discover the nature of meteor showers (Astapovich, 1958).

The invention of photography in the first half of the nineteenth century, and its subsequent use for scientific purposes, gave a major boost to the development of meteor astronomy. Traditional visual methods were much less accurate than photographic techniques for determining meteor trail trajectories. The first photograph of a meteor was taken by the Austro-Hungarian astronomer Ladislav Weineck in

Prague on 27 November 1885, while observing the Andromedids meteor shower. On 25 Sep-tember 1892, the German astronomer Maxi-milian Wolf of Heidelberg obtained photographs of three meteors from a single shower in one night, allowing him to determine the location of the radiant using photographic methods for the first time (Hughes, 2012).

Despite the breakthrough discoveries in meteor astronomy made by the end of the nineteenth century, important questions still remained open, in particular: the connection between comets and the Perseid and Leonid streams discovered by Schiaparelli required confirmation for other observed meteor streams; also, the problem was the lack of data on the velocities and altitudes of meteors, and the question of the shift (drift) of radiant over time remained open (Romig, 1966).

3 THE ESTABLISHMENT OF METEOR RESEARCH INITIATIVES AT TAO

The first meteor observations at TAO took place in 1883 (Pomerantzeff, 1884a). It is interesting to see how the first work on meteor astronomy at TAO began. The American scientist Chandler (1883), analyzing meteors observed over many years in December, discovered that after excluding those clearly emanating from well-known and active radiants in the constellations Andromeda, Gemini, and Taurus, dozens of meteors remained, thus indicating the presence of another radiant (α = 90°, δ = +50°) in the constellation Draco. He hypothesized that this stream could be associated with what we now refer to as Comet 12P/ Pons-Brooks. To test his hypothesis, he asked Otto Wilhelm Struve, Director of Pulkovo Observatory, to organize observations of a meteor stream with a radiant near the star κ Dra (Pomerantzeff, 1884a). On 18 December 1883 Struve telegraphed the Director of TAO, Illiodor Pomerantzeff (Figure 2), with a request to conduct observations of a meteor shower with a radiant near κ Dra (*ibid.*).

The first meteor observations in the history of the TAO took place four days after receiving Struve's telegram (22 December) (Ivanov, 1935). The observations were carried out by



Figure 2: Illiodor Pomerantzeff, Director (1880–1888) and founder of meteor research at Tashkent Astronomical Observatory.

Pomerantzeff and his assistant, Pyotr Zalessky, a well-known Central Asian geodesist and astronomer. That night, over the course of 3 hours and 45 minutes, they managed to visually capture 50 meteors and plot their approximate tracks on a map. Subsequent processing of the obtained data using Tserassky's method allowed him, using Oppolzer's method, to obtain the approximate parameters of the stream's orbit (π = 9°.0, Ω = 254°.4, i = 53°.1, log q = 9.458) (Pomerantzeff, 1884a).

As can be seen from Table 1, the derived estimates of the orbital elements, as well as the calculated coordinates of the radiant (α = 198°, δ = +72°), obtained by Chandler (1883) and Pomerantzeff (α = 90°, δ = +50°) diverge significantly. Unfortunately, Pomerantzeff (1884a) does not draw any conclusions regarding these discrepancies. However, in a footnote to his paper, Pomerantzeff (*ibid.*) notes that 9 of the 50 meteors observed deviated from the main

Table 1: Results of determinations of the orbital elements of meteors and the orbit of Comet 12P/Brooks-Pons, carried out by Chandler (1883) based on long-term data from various authors, as well as determinations by Pomerantzeff (1884a).

Orbital Elements	Chandler			Pomerantzeff
	Meteors		Comet 12P/ Pons-Brooks	
	7 Dec. 1847	22 Dec. 1883		22 Dec. 1883
Longitude of perihelion (π)	44. 5°	55. 1°	93° 21'	9. 0°
Longitude of node (Ω)	256. 1°	256. 3°	254° 6'	254. 4°
Inclination (i)	68. 5°	72. 7°	74° 3'	53. 1°
Log. of perihelion distance (Log q)	9. 9600	9. 9784	9. 8894	9. 458

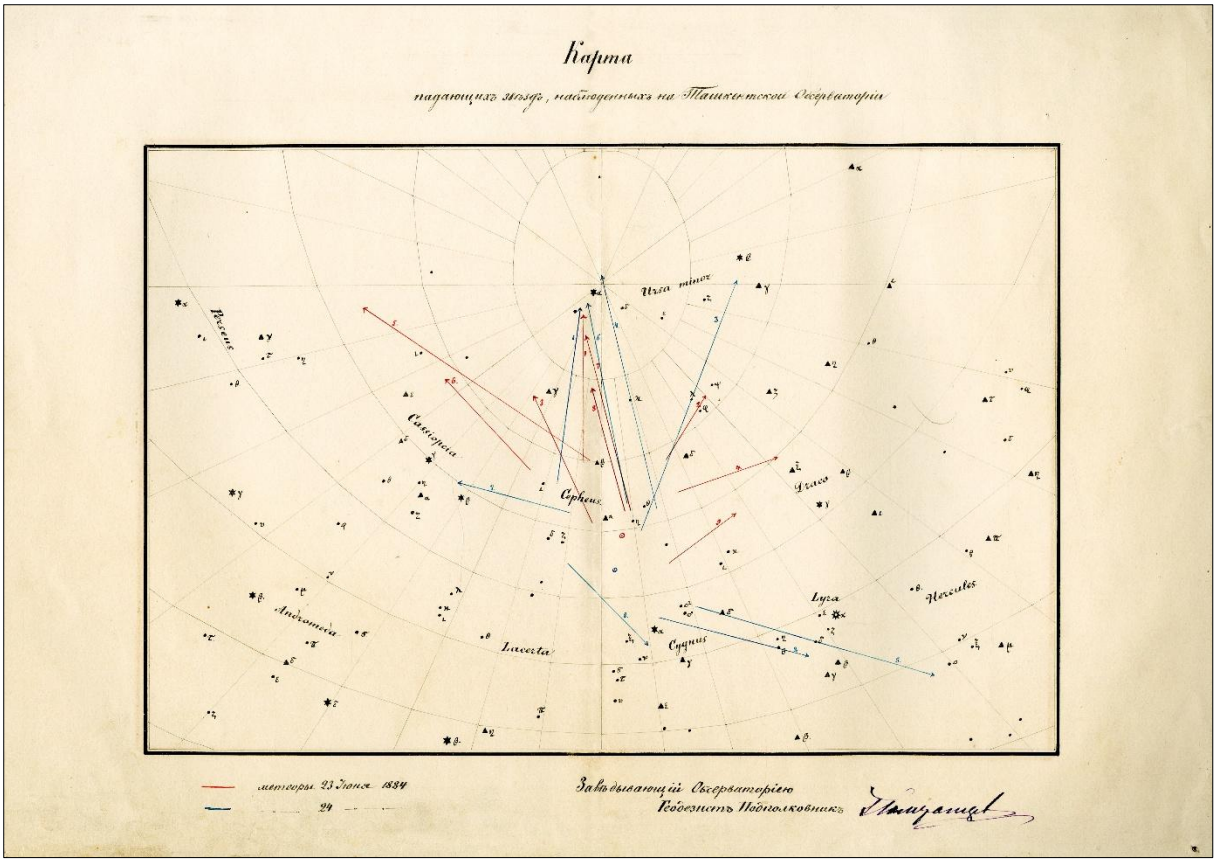


Figure 3: Map prepared by Pomerantzeff to show the shower meteors observed from TAO on 5 July (red lines) and 6 July (blue lines) in 1884. Since the Julian Calendar was used in Russia until 1918, these dates are shown on the map as 23 and 24 June respectively.

radiant. It is possible that these meteors were precisely what interested Chandler. It should be noted that Pomerantzeff had not previously been involved in meteor observations. However, he approached the task with great responsibility and, together with Zalessky, carried out the observations and processing with great care. Suffice it to mention the construction of a map of the region of the sky where they expected meteors to appear, using a gnomonic projection, as well as the development of previously unknown methods for constructing meteor orbits.

It is important to note that the observations by Pomerantzeff and Zalessky were not without consequences. These sparked their interest in meteor observation, and on 5 and 6 July they managed to 'catch' eight and nine meteors, respectively, in the Cassiopeia–Cepheus–Draco–Cygnus–Lizard region of the sky (Pomerantzeff, 1884b). These are plotted in Figure 3.

Upon completion of their observations, they not only determined the position of the radiant but also calculated the stream's parabolic orbit (Table 2). Their calculations were in excellent agreement with the elements of Comet C/1850 J1 Petersen (Ivanov, 1935).

Observations in 1883–1884 marked the beginning of meteorological research at the TAO. However, this was followed by an 11-year hiatus, because TAO staff were military surveyors and were busy with fieldwork mapping in the Turkestan region (*ibid.*).

A significant event in the life of TAO was the establishment of the position of astrophysicist in 1895. Vsevolod Stratonov was invited to accept this post, and he worked at TAO until 1904. Stratonov's biography deserves a separate research paper; here we will only note that interesting information, including about his life at TAO, is contained in his recently published autobiographical notes (Stratonov, 2019). His main activity at TAO from 1895 to 1899 was devoted to photographic astrometry. His interest in meteor astronomy was sporadic. He conducted observations of the Leonid shower and subsequently estimated the right ascensions and declinations of the origin and disappearance locations of the meteor trails. However, Stratonov did not analyze or interpret his observations. After a protracted conflict with the Director of TAO, Dmitriy Gedeonov, Stratonov (*ibid.*) left the Observatory and in the following year, 1905, his place was taken by another talented astrophysicist, Joseph Sykora, who would make a valuable contribution to meteor

Table 2: Results of observations of the meteor shower of 5-6 July 1884, conducted by Pomerantzeff and Zalessky at the Tashkent Observatory (after Pomerantzeff, 1884b).

Date (1884)	Number of Meteors	Radiant Position	Orbital Parameters of the Meteor Stream	Comet C/1850 J1 Petersen Orbital Parameters (after Carrington)
5 July	8	$\alpha = 314.2°$ $\delta = +59.2°$	$\pi = 273.5°$ $\Omega = 92.7°$ $i = 69.8°$ Log q = 0.007	$\pi = 273° 25.1'$ $\Omega = 92° 53.5'$ $i = 68° 11.4'$ Log q = 0.0341
6 July	9	$\alpha = 316.7°$ $\delta = +54.3°$	$\pi = 278.8°$ $\Omega = 93.6°$ $i = 64.1°$ Log q = 0.007	

research (Ivanov, 1935).

4 DEVELOPMENT OF THE METEOR RESEARCH IN TAO

4.1 Joseph Sykora

Joseph Sykora (Figure 4) was born on 16 January 1870, in Kharkov (present-day Ukraine), the son of a Czech educator invited to Russia to teach ancient languages at gymnasiums. After graduating from the Physics and Mathematics Department of Kharkov University in 1892 Sykora joined the University Observatory. At that time, the Observatory's Director, Professor Levitsky, organized solar observations using a 6-inch Merz telescope. He entrusted Sykora with systematic observations of sunspots and prominences. For his series of studies of sunspots and faculae, Sykora was awarded the Russian Astronomical Society Prize in March 1898 and a letter of thanks from the Czech Academy of Sciences, Letters, and Arts (Ehgamberdiev, 2017).

While working at Yuryev University (now the University of Tartu, Estonia), Sykora began to study photographic methods that could be used to research meteors. Experimenting with various instruments, he demonstrated that small, large-aperture cameras were far more effective for this purposes than large astrographs. Specifically, by mounting a camera with a 1:3.6 Planar lens of 110 mm focal length on the University's telescope, he managed to obtain seven meteor photographs between 10 and 12 August 1901 (Astapovich, 1958).

When Sykora arrived in Tashkent in 1905, he was already a well-known astronomer with extensive experience in photographic observations, including such complex ones as capturing the spectra of auroras in Spitsbergen (Chernouss and Sandahl, 2008).

His Tashkent period was characterized by a wide range of scientific problems, which demonstrated his talent as an observer, as well as his ability to design and improve instruments. However, his primary interest was in astronomy. Tashkent Observatory's equipment at that time was virtually identical to that of the observatories in Kharkov and Yuryev, where he had worked for many years before arriving in Tashkent. In particular, he continued sunspot observations with the 6-inch Merz telescope, which had begun his scientific career in Kharkov (Ehgamberdiev, 2017). However, perhaps Sykora's most significant contribution to the history of Tashkent Observatory was as a meteor researcher, and he proposed innovative methods for studying meteors.

4.1.1 Methods of Meteor Research Proposed by Sykora

In the summer of 1906 Joseph Sykora revived meteor research at TAO and, for the first time in its history, used photographic methods to record these phenomena. However, the initial Tashkent experiment was relatively modest: only three meteor trails from the Perseid stream were captured in five photographs. These observations yielded no new information (Ivanov, 1935). However, as early as the following year, 1907, Sykora succeeded in organizing photographic observations simultaneously from two sites—Iskander and Tashkent—which were separated by about 44 km. This long baseline al-

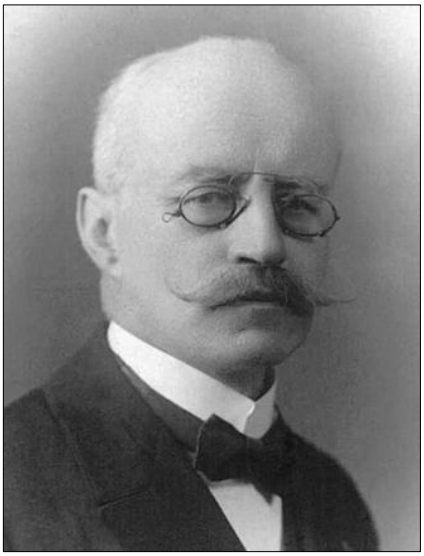


Figure 4: Joseph Sykora (after Ehgamberdiev, 2017: 31).

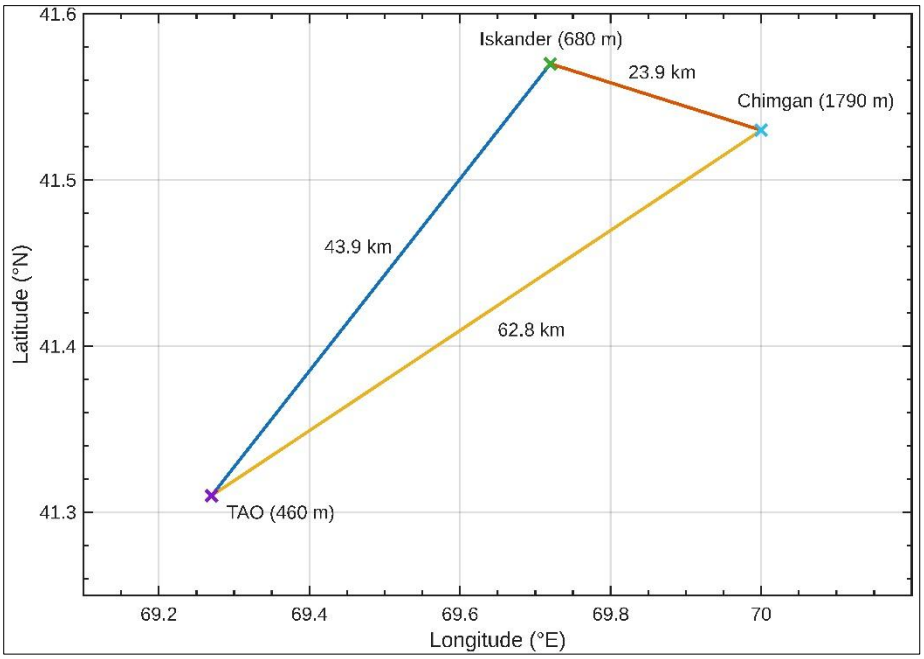


Figure 5: Layout of observation points organized by J. Sykora in 1908–1909 (diagram: the authors).

lowed him to calculate parallaxes with good accuracy and, accordingly, determine the average altitudes of the onset (~117 km) and end of the glow (~96 km) of Perseid shower meteors (Sykora, 1908; 1910a).

At that time, using simultaneous photography from two locations was no longer a new idea. As early as 31 July 1899 William Elkin, one of the pioneers of meteor astrophotography and Director of Yale Observatory (USA), organized simultaneous observations from two locations: Yale Observatory (S1) and Hamden Observatory (S2), located 3. 34 km apart. At that time, the same meteor was simultaneously captured on photographic plates from both locations (Elkin, 1900). Elkin then acquired a third meteor observation site at: Whitneyville (S3), 15.06 km from the Yale Observatory. Simultaneous photographic observations from S1-S2 or S1-S3 made it possible to determine the altitudes and velocities of meteor trails from various showers. Despite the importance of this work by Elkin and his team, the main results of the research were not published until 1937 (Olivier, 1937).

Returning to Sykora's work, we note that in 1908 he managed to establish another observation point. In addition to Tashkent and Iskander, the Chimgan mountain point was added, located at an altitude of 1,790 meters above sea level in the foothills of the Chatkal Mountains (see Figure 5), approximately 63 km from Tashkent. That year, plans were already underway to conduct photographic observations of the Perseid shower simultaneously from the three sites. However, on the observation days, from 9 to 13 August, the Moon was at its maximum phase (Full Moon occurred on 12 August), preventing the acquisition of images of the relatively faint meteors, so the observations were purely visual. As a result of this work, traces of 380 meteors were recorded, the vast majority of which were obtained from Iskander (286 meteors). Despite its high altitude, the weather at Chimgan was cloudy, and only 36 of the 380 meteors were recorded, while in Tashkent only 58 of the meteors were seen. Due to a malfunctioning clock at Iskander and the inaccuracy of the clocks on the Chimgan expedition, it was impossible to synchronize the appearances of meteors recorded simultaneously at the different locations. As a result, it was impossible to estimate the altitudes of the different meteor trails that were recorded (Sykora, 1910b).

However, the following year, 1909, proved more fruitful. Considering all the previous difficulties, the team led by J. Sykora thoroughly prepared for photographic observations of the Perseids. This time, the observing teams were divided as follows: J. Sykora himself chose Chimgan, as the most difficult point in terms of comfort; his wife, N. Sykora, and N. Zinchenko conducted observations from Tashkent; and E. Volkov and V. Spiridonov monitored the sky from Iskander. Observations were conducted as in the previous year, from 9 to 13 August, but this time their team was fortunate to have a clear, moonless sky. For photographic recording, fixed cameras with lenses were used: 'Tessar' (A = 1:3.5) in Tashkent, and 'Planar' (A = 1:3.6) in Iskander and Chimgan. Altogether, 22 photographic negatives were obtained with exposures ranging from 1.5 to 2 hours, and meteor trails were captured on 8 frames. Three of the photographic negatives (No. 1 from Tashkent, No. 4 from Iskander and No. 6 from Chimgan) captured the trail of the same meteor (Sykora, 1910c; 1910d). We could not find any information in the literature about earlier observations like this, so these would appear to be the first photographic observations of a meteor in the history of astronomy made from three different observing sites (see Figure 6). The ad-

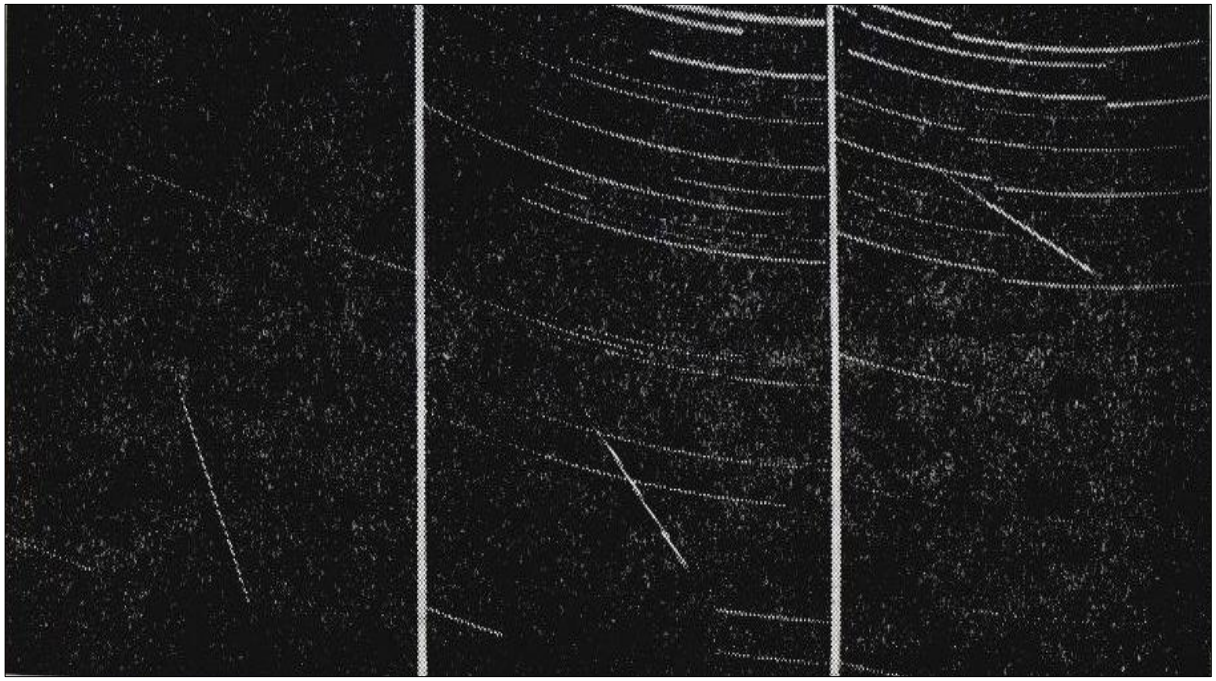


Figure 6: Photographs of the same meteor taken from Tashkent, Iskander and Chimgan on 11 August 1909 by Sykora's team (after Astapovich, 1958: 134).

vantage of this method is that simultaneous photographic observations from three distant points allows us to obtain three parallax estimates, which provides a higher accuracy in determining altitudes, while observations from two points provide only one estimate. The results of their calculations are presented in Table 3.

The meteor photographed on 11 August 1909 was notable for producing two bright flashes, recorded in all three images. Similar flashes had already been recorded in photographs taken by J. Sykora in 1901 from Yuryev. He particularly noted the asymmetry of the brightening traces and their repetition (see Figure 7), explaining this not by the meteoroid's disintegration into individual particles, but by the ejection of combustion products from its nucleus (Sykora, 1910c).

Photographic observations from the three locations conducted by J. Sykora's team in 1910 unfortunately were not as successful: the resulting images failed to capture a single trace, although 132 meteors were observed visually. The quality of photographic emulsions during that era only allowed the recording of bright objects. Meanwhile, observations of the 1911 Perseids were purely visual, due to the Full Moon.

4.1.2 The Ultimate Fate of J. Sykora

On 1 September 1911 Joseph Sykora left TAO and switched to teaching. Initially, he was the Director of the Tashkent Girls' Gymnasium. At

Table 3: Estimates of meteor trail heights from parallax estimates obtained from three photographs taken on 11 August 1909 (after Sykora, 1910c: 141).

Meteor 'Evolution'	Altitude (km)
The beginning of the glow	112. 1
Weak brightness enhancement	108. 3
A sharp increase in brightness	97. 7
Weak brightness enhancement	94
First flash	88. 1
Second flash	85. 3
Weakening	83. 3
Short-term increase in brightness	81
The end of the glow	80. 7

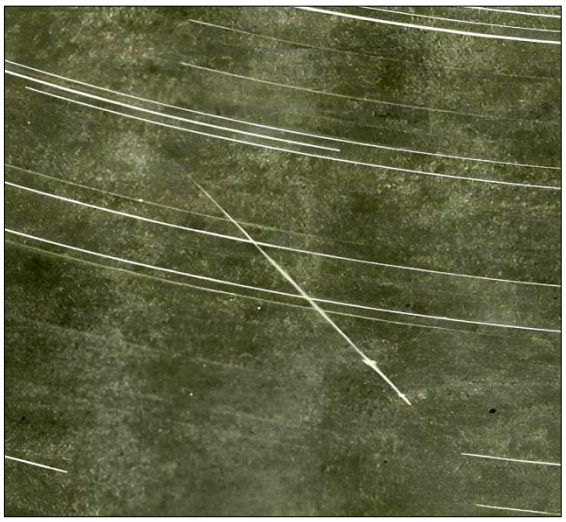


Figure 7: Photograph of a meteor taken from Iskander on 11 August 1909. The traces of two flashes are clearly visible on the meteor track (after Ivanov, 1935: 109).

the same time, his first academic advisor, Professor Levitsky of Kharkov University, was appointed a trustee of the Vilnius Educational District. He invited Joseph Sykora to serve under him, promising rapid advancement in teaching. In the fall of 1911, Sykora received a teaching position at the Šiauliai Gymnasium in Šiauliai, Lithuania (Bulaevskiy, 1987). He took his duties very seriously and worked diligently, which is why he constantly changed jobs, taking on increasingly more prestigious positions. Over the course of ten years, he worked at a number of educational institutions. His academic record includes the Sandomierz Gymnasium, the Lodz Industrial School, the Ivanovo-Voznesensk Polytechnic Institute, Perm University, the People's University of Yekaterinburg, the Astronomy Department at Kharkov University, and others (Bronshten,1993).



Figure 8. Ernst Julius Öpik photographed in the 1920s.

In his historical homeland he found work at Ondřejov Observatory and returned to the scientific problems he had successfully addressed in Tashkent, particularly the determination of meteor altitudes. Sykora was a member of the Czech Astronomical Society and initiated the founding of its Meteor Section. At the General Assembly of the International Astronomical Union in Leiden, the Netherlands, in 1928, he was elected to Commission No. 22, 'Meteors, Meteorites, and Interplanetary Dust', and was recognized as one of the world's foremost meteor photographers (Drbal, 2012). Joseph Sykora would live another 16 years, dying in an increasingly politically unstable Czechoslovakia in 1944, during WWII.

4.2 At the Crossroads of History. Meteor Research at TAO During 1911–1921

After J. Sykora's departure from Tashkent, interest in meteor research at TAO began to wane, and simultaneous observations of meteors from three different sites were no longer conducted.

However, during 10–13 August 1912 joint observations of the Perseids were organized from Tashkent (observers, N.F. and V. Bulaevskiy) and Iskander (observers, the Volkov couple), and on the same dates in 1913 observations were conducted from Tashkent (A. Auzan and V. Bulaevskiy) and Chimgan (N. Bulaevskiy). All of these observers used visual methods, and it was only in 1926 that their results were published (Sawicky, 1926). Attempts to use cameras to photograph meteors were unsuccessful (Ivanov, 1935).

No detailed information is available about meteor research during the period 1914–1919, and although it is known that joint observations of the Perseids were conducted from Tashkent and Chimgan in 1917, the results were not preserved (Ivanov, 1935). This is understandable given that the period from 1914 to 1919 was extremely unstable in the Russian Empire: WWI, two revolutions in 1917, and then the Civil War, which led to a financial crisis, food shortages, and, especially, a shortage of consumables for scientific work (photographic plates, paper, expeditionary equipment, etc.). Inevitably, this affected the quality of research at TAO, so it is not surprising that meteor observing practically ceased.

But in early 1919, when the Civil War was still raging in the western part of the new Soviet Russia and famine was prevalent, more than a hundred professors and their families moved from Moscow and St. Petersburg to Tashkent to found the city's first university. Among the settlers was a young 25 year old astronomer of Estonian descent, Ernst Julius Öpik (Bronshten and Pustil'nik, 2002), who would breathe new life into meteor research at TAO.

4.2.1 Ernst Julius Öpik: A Short Biography

Ernst Öpik (Figure 8) was born on 22 October 1893 in Kunda, Estland Governorate, Russian Empire (now modern-day Estonia), to the family of the head of the local Customs Service. While still in school, thanks to the influence of his older sister, Anna Öpik, he developed a passion for astronomy. Although he graduated with honors from the prestigious Nikolaev Gymnasium in Tallinn in 1911, he was unable to immediately continue his studies at university due to the family's financial situation. After earning a small amount of money for a year as a tutor Ernst

went to Moscow in 1912, where he enrolled in the Astronomy Department within the Physics and Mathematics Faculty at Moscow University (Bronshten and Pustil'nik, 2002). Already in his first year, he actively engaged in scientific work, with a wide range of interests: from visual binary stars and solar physics to planetary and meteorological research. This is confirmed by his publications in leading journals (Öpik, 1914; 1916).

In 1916 Öpik graduated with honors from Moscow University and, on the recommendation of the Dean of the Faculty, was accepted as an Assistant at the University Observatory. However, a year later, in 1917, the country was shaken by two revolutions (February and October), which brought chaos to everyday life and, in addition, gave rise to the Civil War. Fleeing financial difficulties and hunger, Öpik accepted Stratonov's offer to move to Tashkent to head the Astronomy Department at the newly established Turkestan University (now the Ulugh Beg National University of Uzbekistan). Having moved to a new position in April 1919, in addition to teaching, he became involved in scientific work at TAO, and in particular in meteor research (Öpik, 1977).

4.2.2 Öpik's Meteoric Research at TAO and His Proposed Method of Statistical Counting

Öpik proposed an interesting method for counting meteors, allowing one to indirectly estimate the total number of meteor trails, even those not observed by observers. This method, called 'statistical counting', was developed based on the Perseid observations he organized in Tashkent and Chimgan in 1920–1921 and published in Tartu in 1922 (Öpik, 1922a; 1922b).

The essence of the method is as follows (Öpik, 1922a): suppose we have two observers, A and B, who, during a time interval t, visually recorded n_a and n_b meteors, respectively, with m meteors being common (recorded by both observers). Then, based on probability theory, the following expressions are valid:

$$m = p_a n_a = p_b n_b \quad (1)$$

Here p_a and p_b are dimensionless coefficients of perception for the first and the second observers. From the Equation 1 we have:

$$p_a = \frac{m}{n_b}; p_b = \frac{m}{n_a} \quad (2)$$

Then the total number of meteors, N, during time t (including even those that were not recorded by any of the observers), can be estimated as:

$$N = \frac{n_a}{p_a} = \frac{n_b}{p_b} = \frac{n_a n_b}{m} \quad (3)$$

This method can be scaled up to a larger number of observers. Thus, Öpik's method allows one to estimate the *a priori* number of meteors based on *a posteriori* data.

As an example, let us consider the following situation: suppose the first observer saw 10 meteors during a time interval t, and the second observed 16 during the same interval, with 8 meteors from their samples shared. Then, using formula 3, it is easy to calculate that the total number of meteors N passing during time t equals 20. It is important to note that this approach assumes that the observer's perception coefficient is a constant value that does not change over the time-interval t.

4.2.3 Öpik's Subsequent Fate

In 1920, the Treaty of Tartu was signed between the Republic of Estonia and Soviet Russia regarding the independence of Estonia, and Öpik decided to return to his historical homeland. He received an invitation from the Director, Taavet Rootsmäe, to take a position as a staff astronomer at Tartu Observatory. Having moved in 1921 first to Moscow and from there to Tartu, he continued his scientific work (Bronshten and Pustil'nik, 2002).

The life of Ernst Öpik, rich in adventures and discoveries, is beyond the scope of this paper. He had to endure the hardships of World War II, then new migrations, which eventually led him to Northern Ireland, where he lived until his death in 1985. It is also not possible to describe all of Öpik's scientific contributions, which extended from stellar evolution to planetary studies. We can recommend the following sources for those interested in his biography (Öpik, 1977; Bronshten and Pustil'nik; 2002). We will focus only on the achievements that were realized based on the experience of working at TAO.

Analyzing the data from the 1920–1921 Perseids, Öpik introduced the concept of the meteor luminosity function and calculated the index of this function, allowing one to obtain the distribution of meteors in the stream by stellar magnitude. He also discovered a functional dependence of the length of a meteor trail on its brightness and a dependence of the number of meteors from a single radiant on their zenith distance. All of this subsequently helped Öpik make an important discovery: that meteor brightness was dependent on velocity (Öpik, 1930).

5 THE FINAL STAGE OF METEOR RESEARCH AT TAO: 1921–1934

After Öpik's departure from Tashkent in 1921, meteor research at the Observatory again paused for several years. However, in the mid-1920s,



Figure 9: Nadezhda Sytinskaya (a still from the film “The Moon”, 1965).

new personnel arrived at TAO and began regular meteor observations.

From 1925 to 1934, meteor observations were actively conducted. In 1926, P. Savitsky (1926) published a paper in which he presented the results of processing the observations in the form of a catalog of 386 meteors from the Perseid stream, observed in Tashkent and its environs in 1907, 1909, 1910, 1912, 1913, 1920, and 1925. This work noted the importance of simultaneous observations from several sites spaced over large distances, which allowed for highly reliable parallax measurements. At the same time, this work noted that the large distances between observation points sometimes made it difficult to confidently identify the same individual meteors.

The work of observatory staff members such as P. Savitsky (Sawicky, 1926), M.F. Subbotin (1928), and V. Maltzev (1928) was aimed at obtaining and processing observational data on meteors, including estimating their velocities, and determining the coordinates of radiants and analyzing their spatial distributions. These studies were conducted as part of comprehensive programs of visual and photographic observations, and were distinguished by their high accuracy for their time.



Figure 10: Vladimir Maltzev (after Ivanov, 1935: 112).

5.1 Nadezhda Sytinskaya and the Problem of Radiant Drift

In 1926 Leningrad University graduate Nadezhda Sytinskaya (Figure 9) joined TAO, primarily devoting her scientific work to meteor research. During her time at TAO, she expand-ed the scope of meteor observations. In addition to the Perseids, she began a program of observing the Lyrids, Orionids, Leonids, Cassiopeids, and other meteor showers. During this era, almost the entire TAO staff was involved in observing major showers (Ivanov, 1935). Analyzing long-term observation series, Sytinskaya became interested in the shift (drift) of radiants. In particular, she demonstrated that meteor shower radiants are not stationary but systematically drift across the celestial sphere while a shower is active. This was one of the first demonstrations of the dynamic nature of meteor showers (*ibid.*).

Sytinskaya’s work established that a radiant’s temporal shift was related to the geometry of the meteor shower’s orbit and the Earth’s orbital motion (Sytinskaja, 1928; 1948; 1954). Quantitative estimates of drift of the order of 1° per day were obtained, which was subsequently confirmed by later observers (Jenniskens, 2006). Thus, the TAO took an important step from descriptive observations to the physical interpretation of meteor phenomena.

5.2 Vladimir Maltzev and the Determination of Heliocentric and Geocentric Velocities of Meteors

In 1931 a talented young researcher named Vladimir Maltzev (Figure 10) joined TAO. He was a native of Odessa and longtime Secretary of the Astronomical Section of the Russian Society of Amateurs of Universe Science ‘Mirovedenie’. Unlike his predecessors, he lacked a higher education but possessed a wealth of knowledge and skills, as evidenced by his publications (e.g., see Maltzev, 1928; 1930).

Maltsev’s primary focus at TAO was variable star research, which he conducted using a regular astrograph. However, in his spare time, he pursued meteor research, a field in which he made significant progress. In particular, he was interested in determining the heliocentric velocities of meteors, a problem of crucial importance for answering the question of their origin. Maltzev (1930) developed his own method of determining geocentric velocities (heliocentric velocity can be calculated from geocentric velocity and flow elongation parameters), which

he published in 1933 (Maltzev, 1933b). His approach was based on Schiaparelli's formulas (and known as the zenithal attraction method):

$$\tan\frac{\Delta Z}{2} = \frac{v'_g - v_g}{v'_g + v_g}\tan\frac{Z_r}{2} \quad (4)$$

$$v'_g = \sqrt{v_g^2 + 2gr} \quad (5)$$

Here, v_g is the true geocentric velocity of a meteor, $v'_g the$ velocity distorted by gravity, *g* the acceleration of gravity, *r* the radius vector of the meteor, Z_r the true zenith distance of the radiant, and ΔZ the zenith distance correction due to the Earth's gravity. To find v_g it is necessary to find Z_r and ΔZ from observations. The difficulty of the problem lies in the fact that it is very difficult to determine the true radiant point. Maltsev's idea was to observe meteor showers from different hemispheres over a certain period to find the change in ΔZ over time Δt, and then calculate the true geocentric velocity using successive approximations. This method was rediscovered several years later by the New Zealand astronomer Ronald McIntosh (1936).[1]

The geocentric velocities obtained by Maltzev (1933b) for the major streams, such as the Perseids, Leonids, and Taurids, turned out to be close to modern data, despite the limited capabilities of the observational technology of that time (Ceplecha, 1988; Whipple, 1954). This demonstrates the high level of observational and data processing techniques developed at TAO.

Another important contribution by V. Maltzev was his study of the upper atmosphere through meteor observations. In 1933, his work (Maltzev, 1933a) was published in *Nature*, one of the most prestigious scientific journals. In this paper, he noted that the maximum brightness of most meteors was reached at altitudes of 85–90 km. His results provided indirect evidence for the existence of a layer above the stratosphere where meteor-related processes occur. Thus, it can be said that Maltsev anticipated the discovery of the mesosphere, which occurred only several decades later (in the 1950s) thanks to rocket-based research.

Unfortunately, Vladimir Maltzev's life was cut short on 1 April 1934, and with his death, meteor research at the TAO ended (Ivanov, 1935).

6 CONCLUSIONS

Over its half-century of existence the Tashkent Meteor School made a significant international contribution to the study of meteors. The following are some of the TAO's most important achievements:

(1) Photographic methods for simultaneously observing meteor showers from three remote locations, allowing for more accurate estimation of meteor altitudes and velocities (J. Sykora).
(2) A statistical counting method allowing for an indirect estimate of the total number of meteor trails, even those not observed by observers (E. Öpik).
(3) Based on Tashkent observations, a functional relationship between meteor luminosity and their number was determined (E. Öpik).
(4) Proof of the dynamic structure of meteor showers based on a study of the drifts of meteor shower radiants during the shower's period of activity (N. Sytinskaya).
(5) A method for estimating the heliocentric and geocentric velocities of meteoroids based on observations from different hemispheres (V. Maltzev).
(6) The hypothesis of the existence of an atmospheric layer above the stratosphere, 85–90 km (anticipating the discovery of the mesosphere), based on an analysis of the altitudes of maximum meteor brightness (V. Maltzev).

Thus, the research by TAO staff played a significant role in the development of meteor astronomy as a precise science. They not only ensured the accumulation of extensive observational data but also contributed to the development of methods for interpreting it, many of which remain relevant today.

7 NOTES

1. Auckland amateur astronomer Ronald Alexander McIntosh (1904–1977) made a major multi-facetted contribution to New Zealand astronomy (Orchiston, 2016), but his main observational interest was in meteors. His research in this field was of international importance and was reviewed some years ago in a paper published in this journal (see Orchiston et al., 2021).

8 ACKNOWLEDGMENTS

In meteor research, unlike other branches of astronomy, there is sometimes a fierce rivalry between professionals and amateur astronomers. Indeed, when meteor showers occur, thousands of amateur astronomers travel to locations far from urban light pollution to admire this beautiful natural phenomenon! It is the amateurs who often provide professional astronomers with information on the intensity of the showers, i.e., the number of meteors appearing per hour. They can also determine how the shower's intensity changes during the night,

from day to day, or even from year to year.

However, more complex tasks, such as constructing maps and plotting meteor paths, determining the altitude of their atmospheric entry, not to mention constructing the orbit of a meteor shower for comparison with the orbit of a particular comet, are only possible for professionals. And not just any professionals, but astronomers with a gift for observation! The TAO astronomers, whose work we described above, were precisely such extraordinary researchers. With a feeling of deepest appreciation and gratitude for their titanic work, we dedicate this research paper to their blessed memory.

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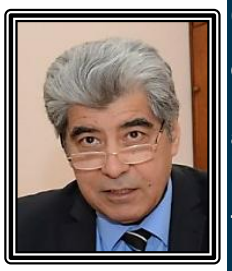
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