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History of Unique Heliometric Observations of the Moon's Physical Libration

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Abstract: The research is devoted to the investigation history of the kinetic and dynamic parameters of the Moon. Today, the Moon is the subject of a comprehensive study in many space experiments. In this research, we proposed a historical analysis of unique Heliometric observations of the Moon's physical libration. The article described the history of the beginning of observations and study of the physical libration of the Moon in Engelhardt Astronomical Observatory (EAO) and the main results obtained by these studies. The programs of space missions consist of the subtle effects investigation of the rotational motion and the physical liberation, a study of the gravitational field of the Moon and planets crosslink tracking methods, creating a selenographic coordinate system and the standing the variety of the internal structure of the Moon. Unquestionably, the basis for all these studies are the classic Heliometric observations of lunar physical liberation started over 100 years ago. In 2015, it was the 100th anniversary of Banachiewicz's series of physical libration of the Moon creation. The values of the parameters of the lunar physical libration obtained from Heliometric observations are given. The study also describes Banachiewicz's observations on the meridian circle, participation in observations of a solar eclipse at the 1912 year and gravimetric expeditions.

Key words: History of unique Heliometer's observations, physical libration of the Moon, astronomical observations, kinetic and dynamic lunar parameters, Russia

INTRODUCTION

In the forest, the Engelhardt Astronomical Observatory of Kazan Imperial University was opened (Smith *et al*., 1997; Chin *et al*., 2007; Binder, 1988; Josset *et al*., 2006; Noda *et al*. 2008). It was constructed by donations of scientific equipment Engelhardt to Kazan University by a patron of art from the astronomical observatory in Dresden. The construction was managed under the direction of in the director of the City Astronomical Observatory managing faculty and the Rector of Kazan Imperial University. The new observatory received a name The Engelhardt Astronomical Observatory. In the observatory were established some telescopes: Engelhardt's 30.48 cm visual refractors manufactured by the Grubb company, the Repsold meridian circle, zenith Bamberg's telescope and in 1908 the Heliometer of Repsold (Fig. 1). On a refractor visual micrometric item observation of bodies of the Solar system were conducted, on the Heliometer were measured of Moesting A crater concerning points edge of the Moon with the purpose of its studying physical libration (Li *et al*., 2012; Kirk *et al*., 2015). These observations were started in the City Astronomical Observatory of Kazan University. The Heliometer was then transferred to the Engelhardt Observatory (Zuber *et al*., 2008; Yue *et al*., 2007). Who were an outstanding Polish astronomer, mathematician and geodesist? He was a professor at the Jagiellonian University in Cracow and director of the Astronomical Observatory and had a strong influence on Polish astronomy. His achievements led to honorary degrees at universities, fellowships in academies of sciences and the prestige of high positions in international organizations such as the International Astronomical Union and the Baltic Geodetic Commission. He is known from both his theoretical and observational studies, his famous motto being: "observer goes sum". In obtained the education in the Faculty of Mathematics at Warsaw University in 1900-1905. In came to Warsaw from Kazan in 1989. During work in Kazan in 1894-1898 in executed the first series of Heliometrical observations of the lunar craters Molesting A, Proclus and Aristarchus;

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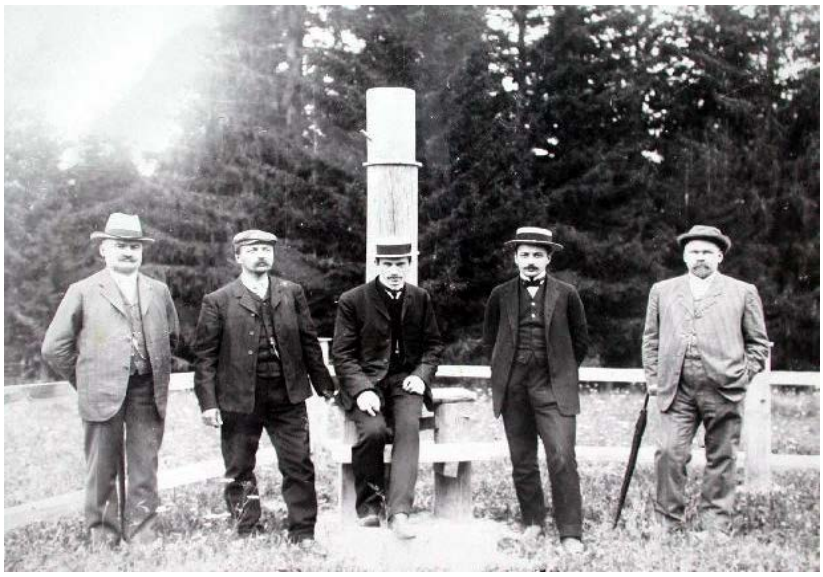

Fig. 1: RLT: M.A. Grachev, Unknown person, A.A. Mikhailovsky, T.A. Banachiewicz, V.A. Baranov in 1914

in that way, he began in Kazan the Moon physical librations study and selenodetic researches. He also observed the positions Solar system bodies, the Minor, in particular, Planet 247 Eukrate and worked as gravimetric. In grasped the Krasnov's idea. On 22 April 1904, he was awarded the university's gold medal for his thesis on "An Investigation of the Reduction Constants for the Heliometer at Pulkovo Observatory". Then his scientific activity in the Engelhardt observatories can be conditionally subdivided into two parts.

The performance of scheduled works (an observation on the Heliometer, a processing of representation, the definitions of gravity in different areas of Russia, an observation of solar eclipses and so on) (Mietelski, 1968; Sivaramane, 2016). The initiative works on various sections of astronomy and geodesy.

MATERIALS AND METHODS

T.A. Banachiewicz's scientific work in Engelhardt Observatory

An observation on the Heliometer of Repsold: For further Heliometric observations in Engelhardt Observatory, a constant observer was required, as from 1905 there was no observer for the Heliometer. The graduate of Warsaw University was invited to take this position a professorial grant-aided student. After his magister's examination, from July 1910 he started to work as an assistant at Engelhardt Observatory. The Heliometer in Fig. 2 was transferred to him for the continuation of works on studying physical liberation. A skillful observer, in executed from 1910, 1915, 133 fine observations on accuracy (994 measurements concerning points of the

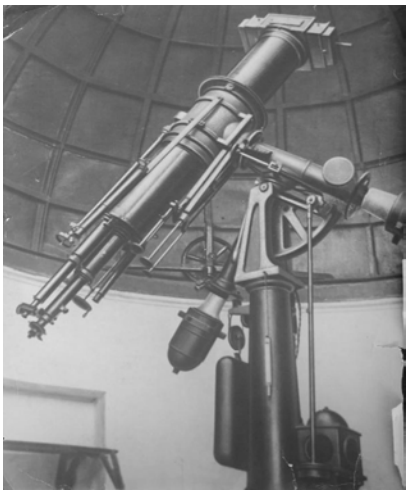

Fig. 2: The Heliometer (1910)

edge) crater Moesting in. This observation made 3rd Kazan series. This number has opened in Engelhardt Observatories >40 years continuous observation physical libration of the Moon. In total, at Kazan University and Engelhardt Observatory on Heliometer it has received eight rows of observation of crater Moesting A for studying physical libration. Thus in brought a considerable contribution to the theory of studying physical libration. In wrote about the observation on the Heliometer that: "In 5 year's observations are executed with greater art and with high accuracy; they make significant progress in so difficult and a delicate question as a question on indignations in

Table 1: Constants of the Moon's physical librations

Variables	Values
Yakovkin	
λ	-5010'19"±11"
β	-3010'56"±10"
h	15'35.5"±0.5"
I	1032'02"±17"
R	15'32.68"±0.040"
f	0.74±0.03
Belkovich	
λ_1	-5010'46"
λ_2	-5011'10"
β_1	-3011'15"
β_2	-3011'24"
h	15'32"
I	1038'51"
f	0.7
Mietelski	
λ	-5010'5"±6.2"
β	-3010"52"±6.3"
h	15'31.82"±0.281"
I	1032'37"±10.9"
R	15'32.834"±0.0193"
f	0.628±0.0191
f	0.70

rotary movement of the Moon". It is necessary to note detailed work (Mietelski, 1968), devoted to processing Heliometric in observation in Engelhardt observatories. The observations of in Engelhardt Observatories have been treated by Sivaramane (2016). Table 1 the constants of the Moon's physical libration are shown. They are accordingly received by at processing observation of in separately solved measurements of the east edge of a disk of the Moon (λ1, β1) and western (λ2, β2) with the purpose of estimating the influence of asymmetry of a lunar disk on conclusions of values the constants of the Moon's physical librations. In astronomers brought a big contribution to studying physical libration especially. He was an expert in the questions of the theory and methods of calculating the constants of the Moon's physical libration. During all his life he has been particularly interested in works in this area. Being long time the president of IAU Commission 17 (Movements and the Figure of the Moon), in reports of this commission in often acted with important and to pressing questions of rotation and figure of the Moon. His essential contribution was the introduction in practice of calculations the constants of the Moon's physical libration's matrix (cracovian) calculations. It is necessary to note, that in the great scientist and organizer of science, brought a big contribution to astronomy, geodesy and mathematics. Since, 1919 up to the end of his life he was director of the Krakow Astronomical Observatory. In 1925 he organized the scientific magazine "Acta Astronomica (Pitjeva and Pitjev, 2013; Witkowski, 1955; Zawada, 2004).

RESULTS AND DISCUSSION

An observation on a meridian circle and refraction constant: Besides observation on Heliometer in was engaged in some other research projects. For example, processing the view of 188 stars of in on a meridian circle. In finished the observation on a meridian circle of some from 188 stars with the purpose of defining the latitude of Engelhardt's observatory and a constant of refraction. Because of the shortage of qualified processing, he could not process these observations at once. It was only done by analyzing results of processing, in came to a conclusion about the existence of anomaly of refraction. It appeared owing to an inclination of the district to the south. They have also revealed big residual bend of a meridian circle. The refraction constant has appeared equal = 60.411", latitude = 55°50'20.52". This value of latitude practically corresponds to the modern standard value of latitude of the Engelhardt observatory.

Gravimetric expeditions: In gravimetric expeditions were started with the purpose of defining of gravity in points of observation the internet pendulum's oscillation. Originally they were conceived with a purely scientific purpose for setting a Figure of the Earth (Rambaux and Williams, 2011; Banachiewicz, 1912). Furthermore, these observations have appeared crucial as one kind of geophysical investigation. It has seemed that only astronomers are capable of such observations. Therefore, astronomers have brought up the numerous staff of geophysicists gravimetric.

An eclipse of the Sun on April, 17th in 1912. An observation of the Kazan expedition: The expedition sent by the Kazan University to station Leshchevo (= 2h 40 m 48.2s East longitude, = +600 3' 30.4"), consisted of in. At the disposal of the expedition, there were some telescopes, the universal tools for geodetic works and some auxiliary devices. The process of observation consisted of receptions of the moments of four contacts of edges of the Sun and the Moon, visual observation of chromosphere and a crown. After the third contact within 5 min, Venus was observed. Observations were made at three stations.

In executed other research in various fields of astronomy:

- Precalculations of coverings of stars by major planets (Banachiewicz, 1910)
- Calculation of visible places of satellites of planets
- Are received the amendment to a longitude of the Moon according to observation of coverings of stars of Galaxies of Banachiewicz (1914)
- Observation of zodiacal light
- Improvement of the Moon's declination as given American Ephemeris 1912 (Kirti, 2015) in the elements of the solar eclipse 1912, April 16-17 to read 1100' 53.1" (instead of 1100' 47.9")

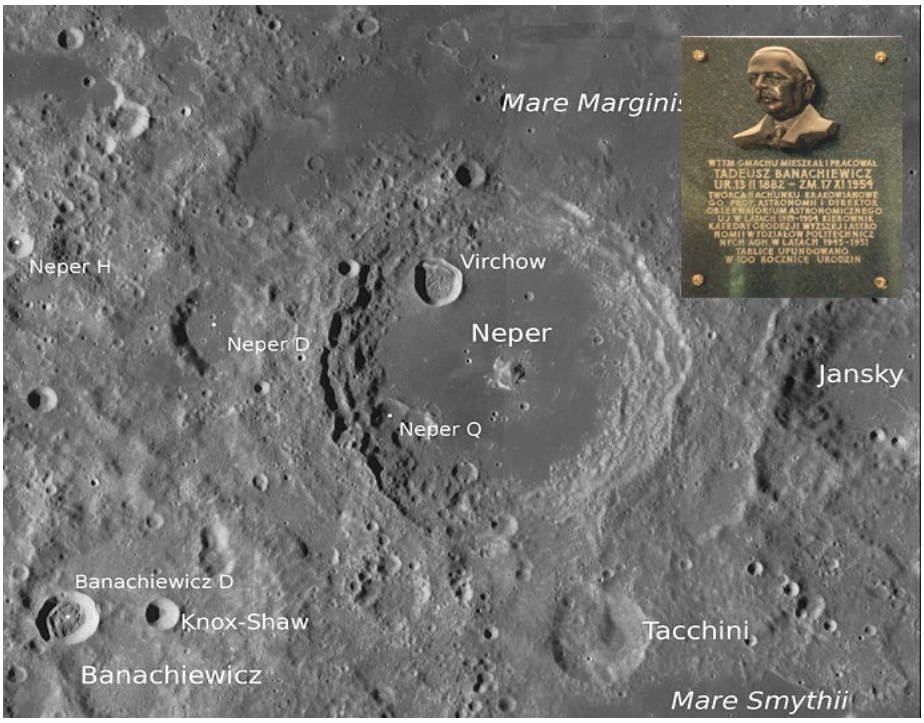

Fig. 3: T.A. Banachiewicz crater

- On heavenly mechanics and so forth, during his work in Engelhardt observatories, published over 25 articles and messages in Publication de l' Observatoire d'Engelhardt de l'Universite'de Kasan and other foreign editions

Magister thesis "About Longitude and Refraction": In regarded his work in Kazan both as a possibility to prepare and defend a master's work and as a chance to start teaching in University. His degree after Warsaw University was the "Candidate of physical and mathematical sciences of the Warsaw University" by the system of scientific degrees in Russia before 1917. This degree is like to modern Master of Science degree. At Moscow University (1909-1910) in passed, all examines required for partial fulfillment of regulations for the Magister degree of astronomy. This degree was similar to the Ph.D degree conferred in West Europe. In worked on the determination of the refraction's constants as well as studied the systematic errors variations formed due to anomalous refraction. During 1903-1909, Grachev made observations of 188-star pairs 22. Calculations were executed by in which derived a formula to account for the refractive error due to, as he believed, the slope of the terrain to the south. As it turned out half a century, the slope from North to South does exist but not area and air layers of equal density in the Earth's atmosphere. He also derived a formula to account for the effect of jitter on the follow-up. In Kazan, Banachiewicz prepared the dissertation for the magister degree entitled: "The constant of refraction and the geographical latitude of the Engelhardt Observatory by observations through the meridian circle. Unfortunately, some confusion has arisen in this matter: in insisted he has the exclusive right to use the results of their observations, in turn, believed that his original method of processing allows him to consider his calculated results his "Literary Property" as in those days called the Intellectual Property. In took a neutral stance in general but his mighty initial support Banachiewicz lost. It is evident from the Banachiewicz's correspondence. The magister thesis was not published then and accordingly, there were not the defense. Also, attempted to get privat-docent position of in the Kazan University with course "The Basis of Celestial Mechanics" in 1915. It had the formal objection associated with "omissions of work at the observatory." The objection was exactly formal because the academic course demanded only one lecture per week. All these circumstances formed Banachiewicz's idea to look for work elsewhere. And he found the new position of "younger assistant" in the Astronomical Observatory at Yuryev University in 1915 and never back to Kazan. In ended his work, in as professor. For position of privat-docent, giving him via legend, the right to lecturing, he presented the thesis prepared in Kazan "Three essays on refraction theory" (Fig. 3).

CONCLUSION

As written in his letters, his conditions for work and accommodations in Kazan were magnificent. Kazan years formed in as an astronomer. In his further research, he studies libration of the moon which became one of the subjects of Krakow Observatory under his directorship. His famous statement was: "observe ergo sum". In Krakow occultation of stars by the Moon were observed as well as a long running project of eclipsing variable stars observations. In the Bibliography the list of papers written during his stay in Kazan is surveyed. The comparison with all his published paper it is easily seen that in closely follows his scientific projects originated in Kazan. Therefore, when in some historical works is counted as Kazan astronomer, this can be regarded as a correct statement. For outstanding contribution to the study of the Moon in honor of his name on the lunar surface was named the lunar crater (Fig. 3). Selenographic coordinates of the crater's center are: 5.28° North latitude, 80.01° East longitude, the diameter is 100 km, depth is 1.68 km.

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