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Wilfried Schröder

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MILUTIN MILANKOVIĆ (1879-1958) AND HIS CONTRIBUTION TO THE EUROPEAN ASTRONOMY

MILAN S. DIMITRIJEVIĆ
[1] *Astronomical Observatory, Volgina 7, 11160 Belgrade, Serbia, Yugoslavia*
E-mail mdimitrijevic@aob.bg.ac.yu

Abstract. The contribution to European astronomy of Milutin Milanković, the most distinguished Serbian astronomer, which name have a crater on the far side of the Moon (+170°, +77°), a crater on Mars (+147°, +55°) and asteroid 1605 Milanković is analyzed. He explained the phenomenon of the Ice Ages by astronomical reasons. Milanković elucidated also the history of the Earth's climate as well as that of planet Mars, being in addition the author of the mathematical theory of climate and of the Earth's pole motion. He did important contributions to the Celestial Mechanics and the History of Astronomy and was a great popularizator of science. At the Ortodox Church Council in 1923 in Istanbul, he submitted the proposal concerning the reform of the calendar, elaborated by him and Maksim Trpković, providing for a more exact calendar than the Gregorian one. The calendar of Milanković use now a part of Ortodox churches as for example Greek and Romanian.

1. MILUTIN MILANKOVIĆ'S WORK IN ASTRONOMY

Milutin Milanković (Dalj, May 28, 1879 - Belgrade, December 12, 1958) went down in the history of science as the man who explained the phenomenon of the Ice Ages by slow changes of the Earth insolation in consequence of changes of the Earth's axis inclination and of those of the parameters of the Earth's motion round the Sun. Milanković elucidated also the history of the Earth's climate as well as that of other planets, being in addition the author of the mathematical theory of climate and of the Earth's pole motion. He promoted the Celestial Mechanics by introducing into it the vector calculus, making besides several original contributions to the solution of the three-body problem, which are analyzed in detail in Popović (1979ab). At the Ortodox Church Council in 1923 in Istanbul a proposal concerning the reform of the calendar, elaborated by him and Maksim Trpković, was submitted, providing for a more exact calendar than the Gregorian one.

Since 1909 Milanković was teaching astronomical subjects at the Belgrade University (see e.g. Dimitrijević, 1997b). He authored university textbooks : "Celestial Mechanics" (Milanković, 1935), "History of Astronomical Science from its Beginnings up to 1727" (Milanković, 1948a) and "Astronomical Theory of Climatic Changes and its Application to Geophysics" (Milanković, 1948b), the last one being dedicated to the post-graduate students and doctoral candidates. Milanković made also important

contribution to the popularization of astronomy, his book "Through the Universe and Centuries" having gone through several editions (Milanković, 1926a, 1927, 1928ab, 1936, 1939a, 1943, 1944, 1952, 1979c, 1997c).

Milanković made a great contribution to the organization of astronomy in Yugoslavia (Indjić, 1997). From 1936 till 1939 he was the president of the first National Committee for Astronomy through which Yugoslavia became a member of the International Astronomical Union. He was a part-time Director of the Belgrade Astronomical Observatory up to January 27, 1951, when he became full-time Director, a post he held until June 26, 1951. His work as Belgrade Astronomical observatory director, has been analyzed in Popović and Dimitrijević (1999).

2. THE CANNON OF EARTH INSOLATION

Milanković began occupying himself with the astronomical origins of the climate changes and the mathematical theory of climate after settling in Belgrade, publishing in 1912 "A Contribution to the Mathematical Theory of Climate" (Milanković, 1912b), in 1913 "On the Application of the Mathematical Theory of Warmth Transmission to the Problems of Cosmic Physics" (Milanković, 1913) and in 1916 "Investigation on the Climate of Mars" (Milanković, 1916). In his "Théorie mathématique des phénomènes thérmiques produits par la radiation solaire" (Mathematical Theory of the Thermal Phenomena Caused by the Solar Radiation) (Milanković, 1920) Milanković develops a theory based on the principles of celestial mechanics and theoretical physics which explains the distribution of the solar radiation throughout the interplanetary space and over the planetary surfaces. He indicates also the connection between the insolation and the temperature of the planetary layers and brings out daily, annual and secular changes of the insolation.

In 1926 he published the research paper "Investigation in the Thermic Constitution of the Planetary Atmospheres" (Milanković 1926). In all of these works he devoted particular attention to the climate of the planet Mars, establishing beyond doubt the mean annual temperature on this planet's surface to be about minus 17°C. His researches in the Mars climate as well as his prediction of the non-existence on this planet of any highly developed life, have been verified by the modern cosmic investigations. As for the exploration of Mars, Milanković's scientific works have been made use of in the studies and discussion on the liquid water on Mars (Hoffert *et al.*, 1981), on its crust and atmosphere (Miyamoto, 1966), surface temperature and climate (Gifford, 1956) as well as on the astronomical theory of climate changes on that planet (Toon *et al.*, 1980).

In his "Canon" Milanković collected the results of his longstanding researches, demonstrating the long-period cyclical changes in the Earth climate and the occurence of Ice Ages as being a consequence of the following causes:

(a) Changes of Earth's axis inclination between 22° and 24.5° with a 41 000 year period, owing to which the insolation on any particular point on the Earth's surface undergoes changes too;

(b) Changes of the eccentricity of the Earth's orbit about the Sun, with a 100 000 year period, bringing about changes in the Earth's distance from the Sun, which in turn gives rise to changes in the duration of seasons;

(c) Precession, causing the point of the winter solstice being shifted along the Sun's annual apparent path, affecting the duration of the seasons with a 22 000 year period.

In order to solve the problem of the occurence of the Ice Ages in Quartenar, Milanković in 1932 arrived at his famous differential equation of the Earth's poles motion. He found that some 300 million years ago, the Earth's North pole was in the Pacific ocean at +20° latitude and 168°E longitude. At present also the North pole is moving towards its equilibrium point in Siberia, near the location of Pechora river flowing into the Arctic ocean (Milanković, 1933a-d; 1934ab).

The most important Milanković's work is "Kanon der Erdbestrahlung und seine Anwendung auf das Eiszaitenproblem" (The Cannon of the Earth's Insolation and its Application to the Ice Ages Problem) (Milanković, 1941). It is his capital scientific work, a monograph, comprising results of his researches previously published in 28 research works. In this monograph these results are assembled in one whole, together with new analyses and supplements, including numerous examples and applications of his theory. In this capital work Milanković presents mathematical theory of Earth's climate (applicable also to other planets), explaining the origin of the Ice Ages and exposing his theory of the Earth's poles motion. The writing of the Cannon Milanković began on March 30, 1939, finishing it in the first half of february 1941 (Indjić, 1997).

Dimitrijević (1997a) analyzed the citations of Milutin Milanković in Science Citation Index for 1946 - 1996 period. It has been found that the Canon of Earth's Insolation and its Application to the Ice-Age Problem is a unique work with citability which is not decreasing with time, but increasing or constant. Canon and articles closely connected with the mathematical theory of climate and their results are used and cited for a number of astronomical problems as for example climat changes in cosmical perspective (Opik, 1965, 1966; van den Heuve, 1966), mass spectrometry in cosmochemistry (Delaeter, 1990), secular variations in stellar structure and ice ages (Opik, 1950), Solar neutrinos and variation of Solar luminosity (Ulrich, 1975), fundamental astronomical system (Fleckenstein, 1953), stability of Solar system (Kopal, 1980)... Among cited articles, intersting is his article from egineering praxis "On membrans with equal resistance" published in 1908 (Milanković, 1908), in which he describes the project of an one million liter water tower and finds its optimal shape.

3. CELESTIAL MECHANICS

The Minister of Education and Church Affair Ljub. Stojanović signed on September 9, 1909, the decree of appointment of Milutin Milanković, working as senior engineer at the Betonbau Unternehmung Pittel und Brausewetter in Vienna, associate professor of Applied Mathematics, that comprised Rational Mechanics, Celestial Mechanics and Theoretical Physics. Thus Milanković came to Serbia and Belgrade, setting on the university career. He held lectures by six semester cycles, the Celestial Mechanics being accorded a not full semester. Conjointly, Milanković pursued scientific researches in the field of Celestial Mechanics, publishing the results obtained in the papers : "The Characteristics of Motion in a Specialized Three - Body Problem" (Milanković, 1910), "On the General Integrals of the n-Body Problem" (Milanković, 1911). "On the Kinematic Symmetry and its Application to the Qualitative Solutions of the Problems of Dynamics" (Milanković, 1912a). He was elected full professor of the Applied

Mathematics on September 29, 1919. Since the school year 1920/21 he lectured only on Theoretical Physics and Celestial Mechanics, ceding the Rational Mechanics to Anton Bilimović, former professor of the Odessa University. Thanks to his introduction of vector methods these lectures of his were more modern than those at some western universities. After our country's occupation by Germans in 1941, Milanković remained at the University until the last session of the Faculty Council on October 19, 1941, following which he, together with the complete University personel, was "put at disposal". As from March 6, 1942, he was appointed full professor of the Philosophy Faculty of the Belgrade University at the Department of Theoretical and Applied Mathematics for the subjects Astronomy and Celestial Mechanics. After the World War II he continued lecturing on Celestial Mechanics. In addition, he dedicated one semester of the course in Celestial Mechanics to the History of Astronomy so that the students of these two disciplines took one single examination in these subjects (Andjelić, 1977).

The writing of "Celestial Mechanics" (Milanković, 1935), Milanković began, according to his pedantic notes he was keeping, on July 20, 1934, completing it on January 14, 1935 (Indjić, 1993). Thanks to his having been among the first in the world to use the vector calculus in treating the problems of Celestial Mechanics he "at least three times condensed, abriged, simplified and made more perspicuous presentation, which earned him recognition from abroad too" (Ševarlić, 1979; B. Š. (Ševarlić), 1980; Popović, 1979ab). Instead of six numerical elements serving until then for specifying the elliptic orbits of celestial bodies in the solar system, he introduced two vectors, "wherewith all the solutions in this field were substantially simplified and made more elegant" (Ševarlić, 1979).

The prewar edition of "Celestial Mechanics" Milanković condensed and published as a textbook in 1947 under the title "Fundamentals of Celestial Mechanics" (Milanković, 1947). In this abridged edition that part of the Celestial Mechanics is exposed which deals with the motion of the planets and their secular perturbations. Besides, using the results of his work "On the Use of Vector Elements in the Calculus of Planetary Perturbations" (Milanković, 1939bc) and those of "Canon" (Milanković, 1941), he arrived at the "principal propositions of the presented theory in a shorter and more perspicuous way than has been done elsewhere" (Milanković, 1947, Foreword). This work has been used in astronomy and cited several times (Musen, 1947, 1948, 1961, 1966; Fleckenstein, 1952; Allan and Ward, 1963; Deprit, 1975; Hestenes, 1983; Bartnik *et al.* 1988) concerning the three body problem in the case of planets and stars, examination of planetary trajectories and investigation of the motion of artificial Earth's satellites. The second edition was published in 1955 (Milanković, 1955a), the third in 1980 (Milanković, 1980), on the occasion of centenery of his birth (in 1979) and the fourth in 1988 (Milanković, 1988). In addition, in 1977 was published the complete prewar edition (Milanković, 1997b).

4. HISTORY AND POPULARIZATION OF ASTRONOMY

The interest for astronomy manifested itself in Milanković as early as during his sojourn in Vienna. In his "Memories, Experiences, Insights" (Milanković, 1979b) he

points out "Any science may be comprehended in its fulness only after one gets acquainted with its origins and its gradual development", describing how "in him grew the idea of the history of sciences being the most magnificent part of the entire history of humanity" (Mužijević, 1979) as well as his love for such history. Milanković read, studied and collected works on the history of science and technics systematically with a collector's passion. As an university professor he took care to make the libraries of both Mathematical Seminar and Astronomical Observatory being capable "to offer a clear survey of the historical development of these sciences" (Milanković, 1979b). In his book "Technics During the Remote Centuries" (Milanković, 1955b) he stated with regret that "while the works on the world history migt fill a large library, the most important works on the history of Mathematics, Astronomy and Physics might be well stored in any personal library". In contrast to the world history, according to Milanković, in the history of science instead of hereditary rulers the main roles are played by those who their places in the history of science acquired by the force of their mind, remarking that "it was worth-while getting acquainted closely with them.! That is why my library was getting richer year by year by works on the history of exact sciences and their applications" (Milanković, 1953, Introduction).

The book "History of Astronomical Science from its very Beginningsa until 1727" (Milanković, 1948a) as a universitary textbook Milanković began writing in late November 1946, its manuscript being ready for press on September 19, 1947, the book having been printed in 1948, its second edition in 1954 (Milanković, 1954) and the third in 1979 on the occasion of centenary of Milanković's birth (Milanković, 1979a). In addition the book was translated into Slovenian and published in Ljubljana in 1951 (Milanković, 1951). This book was published also in Belgrade in 1997 (Milanković, 1997b). In this interesting and well documented book Milanković covered the entire period from the earliest beginnings of astronomy up to Newton's death in 1727. Moreover, Milanković gives in it some original scientific contributions "such for instance as the clearing up of the Aristarchus' role in the development of the heliocentric idea of the proof of the Apollonius having created his important epicycle theory proceeding from the heliocentrism and not from the geocentrism as was held before him" (Ševarlić, 1979).

By its qualities this book is a veritable masterpiece, a true monument to Milanković's teaching and scientific work, studied with great interest by the students. But the book surpasses by far a textbook's scope, being a veritable delicacy to all lovers of astronomy. Milanković's wish, expressed in the preface "to encompase in a later work on a larger scale the complete history of astronomy" remained, unfortunately, unfulfilled.

His masterpiece in the domain of popularization of astronomy, the book "Through Universe and Centuries" (Milanković, 1928b) Milanković began writing in summer 1925 in Austria. He published it by instalments in the period 1926 - 1928 in "Letopis Matice Srpske" (Annal of the Serbian Headquarters) (Milanković, 1926a, 1927, 1928a), being published as a book in 1928 (Milanković, 1928b). He translated it into German in 1936, whereat he recast and considerably enlarged its text (Milanković, 1936), the second German edition being issued in 1939 in Leipzig (Milanković, 1939a). A considerably enlarged Serbian edition was published in 1943 (Milanković, 1943), the book

having thereafter four more printings (Milanković, 1944, 1952, 1979c, 1997c). Particular letters from the book "Through Universe and centuries" Milanković published in "Politika" (19. XII 1928), "Deutsche Algemeine Zeitung" (2. XII 1936), "Aachener Anzeiger u. Politisches Tageblatt" (20. X 1936), "Wolfenbütteler Zeitung" (9. X 1936), "Das Weltall" (1936, Vol. 37, No 4), "Berwardsblatt" (1937, No 22), "Kasseler Post" (1. VI 1937), "Mitteldeutsche National Zeitung" (23. V 1937), "Osteroder Zeitung" (25. V 1937), "Saarbrücker Landes Zeitung" (21. V 1937), "Scwerter Zeitung" (7 VI 1937), "Sonntagsbeilage der Nordhäuser Zeitung" (5. VI 1937), "Der Westen" (13. VI 1937), "Altonaer Nachrichten" (17. III 1937), as well as in Yugoslav journals "Saturn" (1938, Vol. IV, Nos. 1, 2 i 3), "Proteus" (Ljubljana, 1940, VII, Nos. 2/3, 4/5, 1941, VIII, No 9) and in Science Fiction Almanach "Andromeda" (1978, No 3). This very interestingly written book in the form of letters, containing a wealth of data on the history of astronomy and on problems of this science is probably our most published book in the domain of science popularization.

5. CALENDAR

At the Ortodox Church Council in 1923 in Istanbul a proposal concerning the reform of the calendar, elaborated by the Serbian astronomer Milutin Milanković (Milanković, 1997d) together with professor Maksim Trpković, was submitted, providing for a more exact calendar than the Gregorian one. Instead of three days in 4 centuries one should omit 7 days in 9 centuries or 0.0077 days per year. This means that only 2 years out of 9 ending the centuries, would be leap years. The rule is that those years whose ordinal number ends with two zeros are leap years only provided that the number of centuries they belong to, divided by 9, yields the remainder 2 or 6. For instance the year 2000, ending the 20th century, is a leap year since $20 : 9 = 2 +$ the remainder 2. Milanković's proposal implies a much smaller difference, with respect to the true tropical year, than Gregorian calendar. Further improvements concerning the approaching to the duration of the tropical year are not necessary since that duration itself undergoes changes over longer periods.

Milutin Milanković is the most distinguished Serbian astronomer. In honour to his scientific achievements in astronomy a crater on the far side of the Moon (coordinates $+170^o$, $+77^o$) was given his name at the 14th IAU General Assembly in Brighton in 1970. His name is given also to a crater on Mars (coordinates $+147^o$, $+55^o$) at the 15th IAU General Assembly in Sidney in 1973. In 1982 a small planet, provisorily designated 1936 GA, discovered in 1930 by M. Protić and P. Djurković, received its permanent name : 1605 Milanković.

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