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G.A. KRASINSKY: FROM CLASSICAL CELESTIAL MECHANICS TO HIGH-PRECISION RELATIVISTIC NUMERICAL THEORIES OF THE ORBITAL MOTION OF BODIES IN THE SOLAR SYSTEM

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Abstract: Georgiy (George) Albertovich Krasinsky was one of the scientists who made Soviet and later Russian science both advanced and competitive by arousing interest in it with the leading researchers around the world. Having received his education in the Department of Mathematics and Mechanics at Leningrad State University, for a long time he was engaged in research in the field of classical celestial mechanics, where he performed a number of first-class studies whose results are still in demand at present. The onset of the Space Age, with its sharp jump in the accuracy of astronomical observations, caused by the rapid development of technology, made Krasinsky realize that the classical methods of celestial mechanics and astrometry could no longer cope with the processing of up-to-date measurements, as these were unable to provide the accuracy of the ephemerides of the Solar System bodies at a level demanded by the new requirements. As a result, under his expert guidance and with his active participation, the ERA (Ephemeris Research in Astronomy) software system was developed, which became the basis for all of the later work at the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) on processing modern high-precision measurements and formulating relativistic numerical theories of the orbital motion of the Solar System bodies. While working at the IAA RAS, George got deeply involved in such issues as the fundamental coordinate-time system, thus becoming one of those who were active in building up the quasar radio-interferometric network. During the last years of his life, George developed a numerical theory of the rotation of a deformable Earth with a liquid core, and theories of the evolution of both the rotational motion of the Earth and of the Moon's orbit.

Keywords: G.A. Krasinsky, history of astronomy, celestial mechanics, ephemeris astronomy, ephemeris of Solar System bodies, very long baseline radio interferometry (VLBI)

1 INTRODUCTION

Georgiy Albertovich Krasinsky (Figure 1) may rightly be considered one of the leading figures in the paper by Shor (2021), devoted to the history of the development and future progress of ephemeris astronomy in twenty-first century Russia. However, for various reasons, Krasinsky's contribution to Russian astronomy as described in this paper is rather schematic. So, the purpose of the present paper is to approach this issue in a logical and consistent way by analyzing the setting that shaped him as a scientist, and by placing him in a realistic historical context so that his scientific achievements can be fully appreciated.

Naturally, scientists of Krasinsky's standing are well known not only in Russia, but worldwide, within the scientific community dealing with ephemeris astronomy. During his lifetime, Krasinsky was elected President, Vice President and an Organising Committee Member of a number of Commissions of the International Astronomical Union (IAU).

George Krasinsky was in regular communication with scientists all over the world, examples being his friendly working-relations with Myles Standish and Jim Williams in the USA, and Jean Kovalevsky and Agnes Fienga in France.

Figure 1: G.A. Krasinsky during his postgraduate course (photograph: personal archives of the Krasinsky Family).

As current employees of the Laboratory of Ephemeris Astronomy at the Institute of Applied Astronomy of the Russian Academy of Sciences established by G.A. Krasinsky, we were honoured and highly privileged to have been able to work with him. As time passed, much personal information was lost, and in an attempt to slow down this process we would like to a pay a tribute and respect to the memory of our teacher, a scientist who through versatility and determination always seemed able to deal with any upcoming difficulties. His professional leadership and expert guidance made it very exciting and challenging to work with him. Although he died in 2011 we still miss him.

2 G.A. KRASINSKY: A BIOGRAPHICAL SKETCH

Georgiy Albertovich Krasinsky was born on 19 February 1939 in Leningrad (now St. Petersburg), in the USSR. During WWII, together with his mother and grandmother, George was evacuated to the Urals, while his father and his uncle were at the front. His grandfather died during the Leningrad Blockade. After the end of the war, the family returned to Leningrad. But his father, a surgeon who survived the war, did not join the family. Later, there were occasional contacts with his son, but these were irregular and lacking cordiality. Sadly, close relations were never established between George and his father.

Instead, the boy was brought up by his mother and partially paralyzed grandmother. Fortunately, there were two other men in the family who substituted for his father and took an active interest in the boy's life and personality. One was his mother's brother, Israel Yakoylevich Krasinsky, who after having graduated from university just before the war was immediately sent for military training and then to the front. Israel Yakovlevich fought with a rocket artillery Katyusha unit, went through the war as far as Berlin, and signed his name on the Reichstag as a symbol of the victory over the Nazis. Israel Yakovlevich was very close and dear to George. The other relative was George's great uncle, Georgiy Davidovich Krasinsky, a well-known polar explorer who had lost his son during the war and even offered to adopt George. Until the age of 16, George had used his father's surname, but after receiving his passport he adopted his mother's maiden name, and has been called G.A. Krasinsky ever since.

With his mother, Eddie Yakovlevna Krasinskaya, there was an extraordinary spiritual closeness, and mutual understanding and respect that stayed with him forever.

As a teenager, George grew up as an ordinary post-war schoolboy wearing trousers with patches on the knees, being a goalkeeper in a local football team, and reading a lot. He developed good literary taste and good language, and he loved history. His Mom, who strongly supported his interests, used to buy him theatre and philharmonic tickets. For many years George studied at the city Palace of Pioneers, where he received a good schooling and systematic training in the Arts (drawing and watercolour painting) and participated in exhibitions. At one of the city competitions, he took second prize for ornaments dating back to the time of Jan Hus. All of his childhood interests and hobbies remained with him forever. Theatre, music, exhibitions, books, and meetings with cultural and artistic figures were an integral part of his adult life. As a grown-up, he would sometimes pick up a pencil to make precise sketches or small portraits of family members. He loved Nature, small hikes in the forest, and kayaking. With his own family, he devoted a lot of his time to his daughters, Alexandra and Anna.

In 1956 he finished high school with excellent grades and was awarded a silver medal. In fact, he wanted to enter the Academy of Arts, but the idea that an artist's income was precarious and that he would not be able to support a family influenced his final decision. So in 1956 he enrolled in the Department of Mathematics and Mechanics at Leningrad State University, (which was named after A.A. Zhdanov).

George was not mistaken with this choice, as science also captivated him throughout his life. During his studies he received excellent results, the only 'good' mark during his 5-year study at the University being for the History of the Communist Party of the Soviet Union, and the only 'satisfactory' mark, was at the state examination on the same subject. When the State Commission saw his other grades, they invited him to come later and have another try, but he refused. Much later he explained to his family: "Why should I? The exams interesting for me have already been taken, so I didn't even begin to prepare for my last exam". The only thing George really regretted was that while still at the University he never had the opportunity to take an additional course in physics. So later, he would pick up physics by himself. Generally speaking, he was interested in science in a broad sense, followed the progress in its fields, and reading a lot on the history of science.

In his fifth year at the University, George wrote a paper and was rewarded with a sum of money called 'book money', which he spent buying books. The subject of his Diploma Paper was *Closed Trajectory Collisions in a Flat Boundary Three-Body Problem*. He passed the defence of his diploma thesis with honours. Figure 1 shows a photograph of George during his student years.

In 1961, George graduated from the University with a degree in mechanics. He was not focused on building a career, but it seemed to develop in a classic way: he entered the graduate school at the Institute of Theoretical Astronomy (ITA) of the USSR Academy of Sciences, in 1961–1964 as a Junior Researcher. In 1966 he defended his PhD thesis, which was titled *Optimal Transitions Between Close Keplerian Orbits*. Then from 1967 to 1987 he was a Senior Researcher at the ITA, and from 1988 the Leading Researcher at the IAA RAS.

Over the years, George received several Government awards: in 1981 the Order of the Badge of Honour; also in 1981, the State Prize of the USSR for a series of works on the creation of a unified relativistic theory of the motion of the inner planets of the Solar System; and in 2002 the Order of Honour.

In 1985, George defended his Doctoral thesis *Investigation of the Motion of the Major Planets and the Moon over the Interval 1715-2000 and Adjustment of Some Astronomical Constants*.

In 1997 the International Astronomical Union named minor planet 5714 ‘Krasinsky’. In 2000 he received the title of Professor, and in 2011 "Honoured Scientist of the Russian Federation".

From 2003 to 2006, he was President of Commission 4 “Ephemerides”, and a member of IAU Commissions 7 and 20, and working groups ILRS (International Laser Ranging Service) and IVS (International collaboration is a service of IAG and IAU).

Ten years before his death, doctors provided him with a fatal diagnosis, and told him that he had no more than three years left to live. He did not tell anybody about it at the time but continued his work and obtained excellent new results—which only made him eager to work further. It was probably science that gave him strength and extended his life. A couple of years before his death, he said in a private talk (paraphrased here):

> I have a feeling that I am standing on the top of a mountain. I see everything clearly, I understand how things work. And I'm so happy to be able to show it to people.

The last book that he had in his hands, when already very weak from his illness, was *The Art of Drawing*. To an onlooker, he seemed to be sleeping, but in fact he was carefully examining every detail while quietly turning the pages. Those were the drawings of one of his favourite artists—Valentin Serov.

G.A. Krasinsky died peacefully on 17 March 2011 at the age of 72 and was buried at the Cemetery of Astronomers at the Pulkovo Observatory in St. Petersburg.

3 CLASSICAL CELESTIAL MECHANICS AND TRANSITION TO NUMERICAL METHODS

Having entered the ITA of the USSR Academy of Sciences, Georgiy Albertovich Krasinsky was first engaged mainly in the theoretical methods of celestial mechanics. He improved the trigonometric theory of secular perturbations of major planets, introduced new effective methods for expanding the perturbing function in planetary and satellite problems, and also studied the resonant structure of the asteroid belt. He presented these results in the following three chapters in the monograph *Minor Planets* (Krasinsky, 1973):

1. “Basic Equations of Planetary Theory”;
2. “Asymptotic Methods of Planetary Theory”;
3. “Quasi-periodic and Periodic Motions”.

In the works of that time, he revealed himself as an excellent celestial mechanic (Krasinsky, 1970; Krasinsky and Pius, 1972; Krasinsky, 1975), and his results were used in practice to process the observations of small planets. Subsequently, G.A. Krasinsky abandoned analytical methods in favour of numerical ones. He came to the conclusion that numerical methods were much more accurate in processing observations and required much less time to be implemented.

Throughout his work, G.A. Krasinsky consistently studied and used new programming methods to solve astronomical problems. His first significant result in this area was the system for automating ephemeris calculations MAMONT-1981 (Krasinsky, 1982). In this work, he noted that:

> At present, the need for ephemeris service for high-precision astrometric and radio engineering measurements cannot be satisfied by the traditional use of astronomical yearbooks …

and argued that the time had come to create an automated computing system for quickly and conveniently obtaining various ephemeris high precision data. And here, he described his own experience of building such a system. The system was designed to calculate the observed values, and either an observer or a specialist in astrometry/dynamic astronomy acted as a user. Each request to the system was formulated in terms of some specialized language using astrometric terminology. The system was built in such a way that it was easy to organize its interaction with the astrometric database. It is also necessary to note that the system could be expanded by introducing new objects. Such a system was implemented in the DUBNA monitor system of the BESM-6 computer, written as a mixture of FORTRAN and ALGOL-GDR languages, and contained about 5000 lines of program code. The ephemerides used in the system covered the time interval 1945–1985 and were more accurate than the data in astronomical yearbooks.

Gradually, mathematical models describing the dynamics of all the main objects of the Solar System were included in the system, the time interval was extended to the eighteenth and nineteenth centuries, and a connection with the database of astrometric measurements was implemented. The ephemerides of the Sun, Moon, and planets were based on numerical theories of the motion of these objects (Krasinsky, 1988). The parameters of the theories were adjusted using radio engineering and laser measurements. For convenient reference, the system was named MAMONT-1981 (Mathematical Modelling of Celestial Mechanics Theories, version 1981). A detailed description, complete with examples of the processing and instructions for the user, is presented in Krasinsky et al. (1982).

4 THE ERA SOFTWARE SYSTEM AND THE OBJECT-ORIENTED LANGUAGE SLON

The development of the MAMONT-81 system went in parallel with the SPORA project (Babaev and Lavrov, 1987) which was being developed at that time under the leadership of S.S. Lavrov in the ITA of the USSR Academy of Sciences. In particular, within the framework of this project, I.R. Agamirzyan created a convenient tool for developing the language processor SHAG (Agamirzyan, 1986). It seemed then that using the results of the SPORA project would make it possible to create a new software system devoid of the shortcomings of the MAMONT-81 system. The disadvantages of the MAMONT-81 system included its lack of flexibility, since it was impossible to solve an arbitrary astronomical problem using the MAMONT-81 system. The system could only solve those tasks for which the built-in scheduler was designed, al-though the means of functional filling made it possible to do much more. In addition, MAMONT-81 did not have sufficiently developed tools for manipulating large data arrays necessary in this subject area (observations, catalogs, etc.).

Based on the experience of using the MAMONT-81 system, a group of authors led by G.A. Krasinsky began working on a new software package for solving problems of dynamic and ephemeris astronomy—ERA (Ephemeris Research in Astronomy), including the problem-oriented programming language SLON (System of Logical Observation processing). In December 1985, this team, with G.A. Krasinsky F.A Novikov and V.I. Skripnichenko as the main workers, put into operation the first experimental version of the ERA-1 system on the BESM-6 computer (Agamirzian et al., 1986; Novikov, 1990). Subsequently, the program code of the system was rewritten with improvements based on the practice of operating the experimental version. The last working version of the system in this configuration, ERA-3 (Agamirzian et al., 1986), was already implemented on personal computers in the DOS operating system.

Unfortunately, the ERA-3 system turned out to be practically useless for serious scientific work due to many reasons: a large number of errors in the program code, insufficient functional content, meagre capabilities of the SLON language, etc. So G.A. Krasinsky decided to create a special team in his newly formed Laboratory of Ephemeris Astronomy, which for several years would be engaged in the development of such a system that could meet his requirements for software intended for scientific research. A group of researchers involved in the research and, in fact, taking part in its testing, also worked with the new versions of the system. The results obtained later showed that in addition to being an outstanding researcher, Krasinsky was a very good organizer, and he managed to bring the process of developing a software system into accordance with the most rigorous standards in this area.

As a result of the work of this team, the ERA-5 system was developed (Vasilyev and Krasinsky, 1997). This was an integrated programming environment for solving problems of ephemeris astronomy and included:

(1) A description of the system configuration, containing a list of supported astronomical objects, types of observations, coordinate systems, time scales, a set of actions and functions for processing observations, calculating ephemerides, etc. The description of the configuration could be changed and supplemented using a special JACC language.

(2) An integrated development environment that includes text editors for programs in the SLON language with a detailed description and a system of hints, as well as an editor for tables of the ERA system.

Figure 2: A presentation by G.A. Krasinsky to the Academic Council of the Institute of Applied Astronomy of the Russian Academy of Sciences (photograph: personal archive of Eleonora Yagudina).

(3) The processor of the high-level problem-oriented language SLON, which made it possible to solve almost all traditional tasks of ephemeris astronomy at the present-day level of accuracy.
(4) Programs for calculating model measurement values and their derivatives for almost all types of astronomical observations.
(5) Programs for constructing high-precision dynamical theories of orbital motion for almost all the natural and artificial bodies of the Solar System.
(6) A graphic system for constructing scientific graphs, visible circumstances of eclipses, occultations, etc.
(7) The processor of the LSM (Least Square Method) language, which made it possible to describe and solve, using the least squares method, the problem of estimating the parameters of models used in ephemeris astronomy, space geodesy, etc.

When the first version of the ERA-5 system appeared, G.A. Krasinsky told us, the employees of his laboratory, something like this: “Finally, we got the tool we need. Now it's time for science." Indeed, over the following years, he himself, his students and his followers carried out a number of scientific works and defended several theses in the field of ephemeris astronomy and space geodesy. Observations of the planets, their satellites, small bodies of the Solar System, the Moon, artificial satellites of the Earth, spacecraft, VLBI observations of quasars, pulsar timing, etc. were processed using programs in the high-level languages SLON and LSM. Based on the processing of observations, high-precision numerical theories of the planets of the Solar System, the Sun and the Moon, theories of the motion of satellites of planets, minor planets and comets, numerical ephemeris of navigation satellites and series of parameters of the Earth's rotation were constructed. Many of these works were pioneering, not only in Russia but were also among the first in the world.

In addition, based on the ERA system, the Astronomical Yearbook on a personal computer (PersAY) was implemented, intended both for use by professional astronomers and amateurs. All ephemeris editions of the IAA RAS are prepared on the basis of the ERA system: "Astronomical Yearbook", "Marine Astronomical Yearbook" and "Marine Astronomical Almanac". Since 1990, the ERA system has been used for ephemeris calculations in the control and data processing centre of the Quasar network (Finkelshtein et al., 2004). The ERA software package has not lost its significance up to the present day and continues to be intensively used to solve fundamental and applied problems. The results of the work done were presented at the Academic Council of the IAA RAS (e.g., see Figure 2).

5 THE SCIENTIFIC INTERESTS AND WORK OF G.A. KRASINSKY

Undoubtedly, the ERA system was the most beloved brainchild of G.A. Krasinsky, and the creation and development of which he devoted a significant part of his time. Moreover, the capabilities of the system also made it possible to quickly and at a high level conduct research in the field of ephemeris astronomy and space geodesy. Everyone who knew Krasinsky noted the wide range of his interests and the scientific range of the problems that he solved. The work done by Krasinsky in his last years can be divided into several groups:

Figure 3: G.A. Krasinsky and Myles Standish discussing ephemeris astronomy at the 26th General Assembly of the IAU in Prague (photograph: personal archive of Eleonora Yagudina).

(1) Processing the classical ground-based observations to refine the Jupiter ephemeris, to determine the relative orientation of the HIPPARCOS catalogue and the DE ephemeris, to adjust the selenodesic coordinate system;
(2) Construction of a high-precision relativistic theory of planetary motion and a theory of the orbital motion of the Moon based on the processing all the available observations;
(3) Determination of the masses of small bodies of the Solar System;
(4) Construction of the theory of the Earth's rotation and determination of geodynamic parameters based on the analysis of laser and VLBI measurements;
(5) Organization and processing of one of the world's first VLBI observations of satellites—geo-stationaries and navigation satellites;
(6) Joint work within the framework of the IAU commissions to update a system of fundamental astronomical constants, determine the rotation parameters of planets, their satellites, minor planets and comets, as well as to develop theories of planetary motion and theories of the orbital motion of the Moon (Archinal et al., 2011; Fukushima et al., 2010; Luzum, 2009; Luzum et al., 2011).

At the 26th General Assembly of the International Astronomical Union, issues surrounding construction and accuracy of modern ephemerides of Solar System bodies were actively discussed (e.g. see Figure 3).

Under the leadership and with the most active participation of G.A. Krasinsky, a high-precision numerical theory of the motion of the planets of the Solar System and the orbital motion of the Moon EPM (Ephemerides of the Planets and the Moon) was advanced, which is on a par with the DE series ephemerides of the Jet Propulsion Laboratory (USA) and INPOP (Institute for Celestial Mechanics and Ephemeris Calculation, France). Currently, the EPM ephemeris is used for ephemeris support of the GLONASS system and for the preparation of the Astronomical Yearbook. And the construction of these ephemerides is entirely based on the ERA software package.

The last years of Krasinsky's life were mainly devoted to his scientific interests in the field of radio astrometry. He made a great contribution to the theoretical substantiation and practical implementation of the Russian Quasar VLBI Network. At the first stage of the construction of the VLBI network, much attention was paid to testing the observations of satellites in the radio interferometric mode using mobile stations equipped with small fast-rotating antennas. After the VLBI observations of the GPS and GLONASS navigation satellites, it turned out that the available means of correlation processing did not provide the accuracy of measuring the interferometric delay, comparable to the measurement accuracy of the then existing GNSS receivers. Krasinsky solved the problem in the shortest possible time by developing the first software correlator in the history of the IAA RAS. In addition to high-precision delay measurements, the correlator made it possible to process observations in the single-telescope mode and obtain pseudo-range measurements, as well as phase measurements. The Krasinsky correlator was subsequently modified in terms of the user interface, translated into C language and became a standard tool for processing satellite VLBI observations.

It would take a lot of time to list Krasinsky's works on the application of VLBI and other methods of space geodesy. Even when it was difficult to imagine that something completely new could be done in this area, Krasinsky used to find novel ideas and to work them out producing interesting results. For example, in Krasinsky (1999), the amplitude and phases of the eight harmonics of the Universal Time variations due to ocean tides were adjusted. The variability of these parameters from year to year was studied. Subsequently, progress in the technique of VLBI observations allowed him to obtain a high-precision series of corrections to the theoretical position of the celestial pole and the universal time scale for the interval 1984–2005. His paper presents the weighted root-mean-square errors of residuals in the nutation angle and in the precession angle, equal to 0.136 mas and 0.129 mas, respectively. These errors were noticeably smaller than the similar errors (0.172 mas and 0.165 mas) in the IAU 2000 standard theory.

Along with up-to-date methods of space geodesy, Krasinsky also used the data of classical ground-based astrometry. So, in the work of Vasilyev et al. (2000), the ephemeris of Jupiter was refined, on the basis of the Nikolayev observations of the Galilean satellites in 1962–1997. In addition to the refinement of the ephemeris, some angles of mutual orientation of the HIPPARCOS catalogue and the DE ephemeris were determined.

In some other work, where 439 CCD observations of the relative position of the Galilean satellites of Jupiter and the star 104297 Hipparcos on 12–14 November 1997 were used, normal positions of four Galilean satellites were derived. A normal place for the position of Jupiter on the average date of observations was constructed (Casas et al., 1998).

One more innovative project by Krasinsky, carried out jointly with a group of employees of the IAA RAS, was the refinement of the parameters of the selenodesic coordinate system based on processing the large-scale images of the Moon. The fact is that for some time the use of accurate positional observations of the Moon had been a complex astrometric task, since the significant apparent diameter and irregularities of the limb made it difficult to reduce measurements to the lunar center. There were no other observations than optical ones, and the observations of 1970–1975 of the Ordubad Observatory were used to solve the problem. From the analysis of photographic observations of lunar craters against the background stars, corrections to the crater coordinates were found, to refine the selenodesic coordinate system. All this was done on the basis of the ideas proposed by Krasinsky (Aleshkina et al., 1998).

From an analysis of laser ranging of the LAGEOS-1 and LAGEOS-2 satellites Krasinsky (2012) studied the secular and seasonal variations of the potential coefficient. It was established that in addition to the well-known annual variations, there were also significant semi-annual variations of comparable amplitude. The theoretical value of the dynamical Love number, a scaling factor for near-diurnal variations induced by the liquid core of the Earth in the geopotential coefficients, was refined.

Several papers by Krasinsky deal with the determination of the masses of small bodies in the Solar System. He was the first to propose taking into account, when constructing the ephemeris of the planets of the Solar System, not only the masses of individual asteroids, but also the average mass of asteroid belts in the form of a ring located in the ecliptic plane, with a uniform distribution of matter in it. In Krasinsky et al. (2001) a comparison is made of asteroid mass estimates obtained by dynamical and astrophysical methods. Based on the derived masses of 300 largest asteroids and on the basis of the fragmentation theory, the parameters of the theoretical distribution of asteroids were found under the assumption that there was no observational selection effect in that set. This distribution is extrapolated to low-mass asteroids and an estimate for the total mass of the asteroid belt is obtained, which is in good agreement with the dynamic estimate. These results made it possible to derive an expression for estimating the total number of minor planets in any single interval of absolute stellar magnitudes. The comparison with the observed distribution showed that at that time about 10% of asteroids with an absolute magnitude less than 14 were discovered (according to the distribution derived, there should be more than 100,000 such asteroids).

In his next work Krasinsky (2002), the total mass of the asteroid belt was estimated from the analysis of the motion of major planets as the result of processing high-precision radio measurements of the distances to the landers Viking-1, Viking-2, and Pathfinder (1976–1997). Modelling the perturbing accelerations of the major planets took into account the individual contributions of 300 selected minor planets. The total contribution of all the other small asteroids was modelled as a perturbing acceleration in the motion of the planets caused by a solid ring in the ecliptic plane. The mass of the ring and its radius were adjusted parameters. The masses of 300 disturbing asteroids were derived from their published radii and taxonomic classes assigned to the asteroids. The average density corrections for each class were estimated. In this way, estimates were obtained for the total mass of the main asteroid belt (including 300 asteroids mentioned) and the hidden mass in the asteroid belt estimated from the dynamic influence of the asteroid belt on planetary motion. The results obtained in the work showed once again that it was possible to predict the number of minor planets in any unit interval of absolute stellar magnitude.

At one time, Krasinsky also did a purely theoretical work on the construction of theories of the rotational motion of the Earth and the Moon (Krasinsky, 1998; 1999). It contained a detailed derivation of the equations of rotational motion of an elastic-plastic body, which would take into account tidal effects and were suitable for both numerical integration and analytical study. In the second part of this work, Krasinsky considered the joint evolution of the Earth's rotation and the Moon's orbital motion under the influence of dissipation caused by the action of the lunar tidal force on the inelastic Earth. Numerical integration over an interval of 2 billion years was used to track changes in the semi-major axis, eccentricity and inclination of the lunar orbit, as well as the inclination of the equator to the ecliptic and the angular velocity of the Earth's rotation. A characteristic feature of the evolution was a sharp change in its nature at a critical date about 1.46 billion years ago, when the length of the day decreased to 16 hours, the lunar semi-axis to 69,000 km, and the length of the month to 0.8 current days.

Among the theoretical works by Krasinsky, one should also note the work Krasinsky and Brumberg (2004) in which a significant secular trend in the change of the value of the astronomical unit was obtained. In this paper, the authors attempted to explain this discrepancy with various assumptions. An analysis of these assumptions led to the conclusion that, within the framework of modern models of the Universe, there were no absolutely exact explanations of this effect.

6 CONCLUDING REMARKS

G.A. Krasinsky was a scientist of the broadest erudition, who possessed vast knowledge not only in his field, but in science in general. In addition, he was an inexhaustible generator of ideas, the depth of which we, the staff of his laboratory, his scientific colleagues and opponents, are only now beginning to realize. Krasinsky had an undoubted organizational and pedagogical talent. He knew how to select scientific tasks for his employees so that not only did they correspond to the scientific level of a particular researcher but were near the limit of the researcher’s capabilities. This made our work extremely interesting, and it forced us to constantly improve our professional level.

Professor Krasinsky rose head and shoulders above all of us in the scope of his knowledge. When he explained a certain task, scratching with a pen something on a piece of paper, we nodded, and then tried to take those pieces of paper home so that at our leisure we could understand what was required of us. For quite a long time, we would be looking for information, reading literature, asking colleagues, until we realized that those scratched symbols in his explanations were the only possible way to solve the problem. Inevitably, there were a lot of hot disputes and controversial episodes, but Krasinsky was always right.

Krasinsky was always distinguished by his adherence to principles, rejection of lies and high demands on himself and his employees. Faced with something that seemed wrong to him, or appeared to be dishonourable or false, Krasinsky would express his opinion without regard to authorities or superiors. At the same time, he was very fair and generous to his colleagues, always taking into account any small contribution that a worker had made to a project. Thus, he always tried to include as the coauthors of a publication all those who participated.

Lunchtime tea parties occupied a special place in the life of the Laboratory. We were often visited by interesting employees of other Laboratories, and tea drinking would turn into scientific debates, poetry reading, talks about painting, Russian and world science. Communication with some colleagues continued outside the Laboratory, for example, during small hiking or kayaking trips.

Krasinsky was greatly appreciated by some of our foreign colleagues. One of the leading experts in the field of ephemeris astronomy was Myles Standish (JPL, USA), who wrote:

> It was an honour for me to know George Krasinsky as a professional and as a person. I met George when he formed a first-class group of colleagues who subsequently created lunar and planetary ephemerides at the IAA RAS. I was very impressed with the result, knowing that the bulk of the work on creating the ephemeris was done by him. I was always happy to share my observational data with George, a friend of mine who could be admired and trusted.

Georgiy Albertovich Krasinsky died somewhat unexpectedly, just as it seemed that he would overcome his disease, as he usually did in solving complex scientific problems. But this time the disease was stronger … In Figure 4 we show a photograph of George a few years before his death in March 2011.

Figure 4 (left): G.A. Krasinsky in the last years of his life (photograph: personal archive of Eleonora Yagudina).

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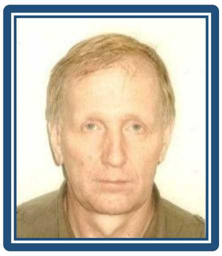

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