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The Copernican Inspirations in Physics

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THE COPERNICAN INSPIRATIONS IN PHYSICS *

THE UNIQUE STATUS OF COPERNICUS IN THE EUROPEAN RENAISSANCE

One of the most characteristic features of the European Renaissance in the XVth and XVIth centuries is a strikingly large series of great, creative men of many gifts and much accomplishment. The spirit of genius was then lavished on an astounding number of individuals who did not waste their talents.

We admire not only their splendid works which remained till our times — e.g. beautiful paintings, sculptures and buildings, poems, books, treatises, or scientific, technical and geographical discoveries which contributed so much to the development of the European culture and civilisation. We admire also their strong personalities, the versatility of their education, interests and activities, the creative spirit, the humanistic attitude towards the surrounding world, the impressive courage and ambition of their deeds and plans.

The second half of the XVth and the whole of the XVIth century were in many respects a golden age for Poland too. The country was relatively strong, with quickly developing and growing wealth and culture. Our worst enemy since the XIVth century — the Teutonic Order — had been recently defeated in a decisive way. It was the time of the first really great poets and writers in Polish, great reformers, historians, thinkers and scientists. However, the most important contribution of XVIth century Poland to the world culture is without doubt the work of Copernicus.

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* This is the text of the lecture delivered on 19 February 1973 during a symposium in Tokio which was organized by the Science Council of Japan on the day of the 500th anniversary of Copernicus' birth.

He received a thorough and many-sided education at the Polish and Italian Universities in law, mathematics, astronomy and medicine. Apart from being a clergyman he practised with great success: medicine, economy, law, politics, mathematics, astronomy and even warfare — when he was organizing the defence of some Polish towns against the incursions of the Teutonic Order. Judging from the versatility and active style of life, he was one of the many great humanists of that period. And yet his main achievements and his immense influence on the development of science differ in nature from those of other great contemporaries. I should like to stress that just these differences and not the similarities made him not only great but also unique in his greatness.

In fact, the most admired and esteemed cultural activity of the period was that of a creative and successful artist (painter, sculptor, architect, etc.). With the help of the prominent poets, writers and scholars, as well as of the religious and political reformers and leaders, the great artists of the Renaissance were creating a new, anthropocentric type of culture. Their interests in natural sciences were limited by the desire of immediate applications of science in art or technology. The number of true scientists who wanted to go beyond that was rather small. Moreover, the scientists of that period were mostly off the main line of the cultural evolution as they were usually devoted to magic or mysticism or, at least, to purely rational speculations.

The most scientific among the great artists of the Renaissance was without doubt Leonardo da Vinci. He was deeply interested in geometry, anatomy and physiology as well as in all branches of physics. He left a large number of rather short and disconnected scientific and philosophical remarks and notes. They contained many interesting observations, ideas and discoveries. Unfortunately, Leonardo touched many problems but never did any systematic research on a large scale, never attempted to construct a more comprehensive theory. It seems that he was too much preoccupied by immediate applications of scientific knowledge to art (geometry, physiology of sight, anatomy) and to technology (mechanics, aero-and hydro-mechanics, optics, etc.). His technical ingenuity is testified by an astounding number of drawings and descriptions of many proposals of new inventions: engines, mechanisms, tools and gadgets. However, he did not implement his technical concepts so they can hardly be regarded as real inventions. He also never published his ideas so his influence on the development of technology was almost negligible although some of his concepts were realized several centuries later. In art he finished quite a few magnificent works but a vast number of paitings and drawings remained unfinished.

Copernicus, in striking contrast to Leonardo, worked persistently over 30 years on his heliocentric system and did not let himself be distracted for long by other activities.

The history of science shows that the initiation of the new science has not been done by making shrewd remarks, disconnected observations, or many ingenious technical proposals. Similarly ineffective were purely philosophical treatises on the scientific method like those of Roger Bacon or Francis Bacon. Certainly the most decisive for the development of science were the examples of successful applications of the new method in the form of a great and inspiring theory or a large series of important experimental discoveries. Thus it happened that neither R. Bacon, nor Leonardo, nor F. Bacon, but Copernicus, Galileo and Newton became the true fathers of the modern physical sciences.

Copernicus took from the Renaissance humanism the antidogmatic and empirical, inquiring and searching, critical attitude, which was free from any mysticism and struggled openly against the bonds of tradition, with unreliable dogmas and authorities. From his scientific predecessors he inherited the character of his mind—rational and exact, but also very bold and profoundly theoretical, that made him search for a deeper understanding of Nature and was dissatisfied with qualitative sensual cognition and superficial description of the observed phenomena. The magnificent and fertile Copernican synthesis of these two hitherto rather separate trends gave birth to modern science. The heliocentric system of Copernicus was the first great, successful and promising result of the new scientific method and the most stimulating example of its powers. It was definitely a product of the Renaissance, but in many ways it was in contrast with the antropocentric culture of this period. Thus the Polish astronomer was an isolated forerunner and initiator of the modern physical sciences which gathered full momentum only in the XVIIth century. Because of the solitary character of his work and because of the otherwise slow development of science in the XVIth century, his work could bear full fruit only many decades later.

The unique status of Copernicus in the European Renaissance stems from the fact that being a true scientist he was different from other great humanists, and being a true humanist he was different from his scientific predecessors and contemporaries. He was a very rare individual, combining the two aforementioned traits in a novel, harmonious unity.

(In order to avoid possible confusion and misunderstanding I would like to stress the following: The difference between a scientist and a non-scientist does not necessarily lie in the objects of interest and methods of action but rather in the aims. One should, therefore, distinguish between the aims of a scientist and those of a technician. A scientist is interested in creating scientific knowledge, i.e. in discovering and investigating new phenomena and in finding the corresponding laws of Nature. On the other hand, a technician is interested in solving practical, technological problems with the help of scientific knowledge and methods or without them).

WAS *DE REVOLUTIONIBUS* A BESTSELLER?

Of course the claim of Copernicus for fame and immortality lies in the book *De Revolutionibus Orbium Coelestium.* To several historians and laymen, who do not understand the ways science is developing, it is a strange and apparently a hardly justifiable claim. For their excuse one may point out that many important rules of the growth and structure of science have been discovered only in the XXth century. Let us suppose for the moment, that we do not know anything about these rules and about the influence of Copernicus on the later development of science and want to evaluate his book taking into account only its form, popularity and acceptance by the readers. If we restrict our judgements to these static and narrow points of view the result of our analysis will be rather confusing.

In fact, the book is a dry geometrical treatise on the kinematics of our planetarny system, full of figures, calculations, tables and highly technical expressions, with a forbidding motto on the front page. It was neither a widely read and popular bestseller of that time, nor is it one now. Somebody called the book mockingly the "worstseller" of all times. However, I would like to stress that the basic ideas of the Copernican system were simple enough to be explained and understood without going through all the technicalities or even without reading the book. On the other hand, already during the lifetime of Copernicus, and quite frequently at later times, several less technical and more popular presentations of his heliocentric system were published. Moreover, because of various straightforward philosophical and religious implications the book of Copernicus was soon hailed by many people as highly stimulating, revolutionary and progressive. In other circles it was regarded as a shocking and regrettable scientific or religious blasphemy. Such a strong polarization of opinions aroused the curiosity and contributed very much to the quick spreading of Copernican ideas and to their wide popularity. We can say that in this sense *De Revolutionibus* was a strange bestseller that was rarely read, but was much discussed and talked about.

THE ASTRONOMICAL ACHIEVEMENTS OF COPERNICUS

Copernicus is famous as the astronomer who "stopped the Sun and set the Earth in motion". This sentence is indeed very appealing, but many critics point out that strictly speaking Copernicus was not the first person trying to do it. In fact, some ideas of the heliocentric system have been expressed by several ancient Greek astronomers and philosophers and Copernicus knew it. However, he did not stop at a superficial and vaguely speculative discussion of this possibility but spent more than 30 years on a comprehensive mathematical and empirical elaboration and verification of his heliocentric system. He was rather what we call now a theoretical astronomer, but with a deep understanding and appreciation of the value observation and measurement. He used mainly the observational results of others but performed also about 60 observations of his own in order to verify some consequences of his theory. It is true that he neither invented any new measuring devices nor improved old ones and that his equipment for making observations was rather primitive. His knowledge of contemporary mathematics — especially geometry — was excellent, but he did not contribute here anything of importance, did not create any new mathematical methods.

However the Copernican description of the planetary motions was much simpler than that of Ptolemy, although he used essentially the some mathematical technique of epicycles. But in the heliocentric system the old technique of epicycles could be largely simplified, purified and generalized. In fact in the Copernican system the period of motion of a planet is a much simpler and more transparent physical quantity than in the Ptolemaic system. The basic period has there the simple meaning of the time of one complete revolution around the Sun. The periods of different planets are different but they grow with increasing sizes of the orbits. In the Ptolemaic system this specific period of each planet was obscured by the motion of the Earth with its own periods. In his letter to the Pope Paul III, Copernicus pointed out the advantages of the heliocentric system and those of referring the motion of each planet to its specific time of revolution around the Sun.

From the point of view of modern mathematics the use of pure epicycles with uniform motion on each cycle constitutes in the system of Copernicus the geometrical (two-dimensional) counterpart of the XIXth-century method of Fourier expansions which applies to any periodic functions. The method of epicycles was open for improvements in the sense that it allowed an unlimited increase of accuracy by addition of more and more epicycles. This corresponds to taking more and more terms of the Fourier expansion. Thus the rigorous method of epicycles can be rearded as a good, and, at least in principle, self-consistent method of successive approximations. The objections of Copernicus against the use of non-uniform motions on some cycles, introduced in the Ptolemaic system, can be regarded as a sign of his anxiety to remove the unnecessary inconsistencies in the application of this method. Obviously, Copernicus could not be fully aware of the situation, he might, however, have had some inklings. About 80 years later the discoveries of Kepler allowed to describe exactly all the motions of planets and thus made redundant the use of epicycles.

The main task of scientific research is the discovery of a simple order or symmetry in the seemingly chaotic or at least very complicated and obscure world of observed events. The next task consists in finding a reasonable explanation of this order in terms of some suitable structure or dynamics. Having constructed a theory which describes and explains quantitatively all the observational facts, one looks for predictions of new facts. Notwithstanding all the shortcomings and inconsistencies of his work (removed only later), Copernicus was able to show that just by simply changing the frame of reference (or point of view) one can see some simple order and regularities in the planetary system and that this must have some deeper meaning. The Ptolemaic system was too involved to display these symmetries. The Copernican heliocentric system explained the observed motions of the Sun, the Moon, the planets and the stars in a relatively simple manner. The motion of the Earth was correctly described as a superposition of theree independent motions: the daily rotation around the axis going through the centre of the Earth, the yearly motion of the centre around the Sun, and the small precession of the rotation axis. Many peculiarities of the observed motions of the celestial bodies, which were quite mysterious in the Ptolemaic system, found a simple geometrical or kinematic explanation in the Copernican system. For example in the Ptolemaic system the orbits of Mercury and Venus differed qualitatively from those of Mars, Jupiter and Saturn. Copernicus explained all such effects very simply by showing that in the heliocentric system they result from the fact that, compared with the Earth, Mercury and Venus are closer to the Sun, whereas Mars, Jupiter and Saturn are farther from the Sun. There were too many such successes of the Copernican system to be quoted and discussed here. One of the most important conclusions drawn by Copernicus referred to the distance from the Sun to the stars and had the form of a very interesting and inspiring prediction. The fact that he could not see the annual paralaxes of the stars was explained by Copernicus by conjecturing very great distancies from the Sun to the stars. In this way the Copernican system suggested immediately that the Universe may be much larger than ever dreamed before, if not infinite.

THE PRINCIPLES OF THE SCIENTIFIC METHOD

The book of Copernicus was devoted entirely to astronomy and cosmology but it had an enormous impact on physics as well. Of course, from the modern point of view, astronomy is just a branch of physics. It seems quite natural that the methods of discovering and investigating the laws of Nature were first developed for the solar system. The accuracy of the astronomical measurements was relatively high and could be still very much increased by taking into account the quantitative observational results accumulated through many centuries. Furthermore, the motions of planets and the forces involved were not obscured by complicated secondary effects (e.g. resistance of the medium, friction) and thus appeared in their purest form requiring the least amount of abstraction and idealization. For these and several other reasons the situation in astronomy in the XVIth and XVIIth centuries was most favourable. The general concepts and methods developed in the studies of astronomical problems could then be applied successively to more and more involved physical problems. Astronomy played therefore the important role of a testing ground for the new ideas and methods of physical research. The heliocentric system of Copernicus was the first serious attempt since antiquity to construct a theory of the Universe, so the general principles and the scientific methods used by the author were of utmost importance.

In my opinion the discovery of the successful method of scientific research is the greatest achievement of the human mind. The scientific method was founded in its almost mature form in physics in the XVIIth century, mainly by Galileo, Descartes and Newton. However, the beginnings of the new method and the real breakthrongh were the work of Copernicus. We can trace in his work most of the basic principles of the scientific method of physics. He believed in the reality of physical phenomena and the cognizability of the external world with the help of sensual observation and reasoning. His method was quantitative (based on measurement) and rational, simultaneously empirical and mathematical. He believed that a true theory should be not only in full quantitative agreement with all the observed phenomena, but should also agree with the nature of things. It is not quite clear what exactly he meant. Judging from his own applications of this principle, he believed that a good theory should display some simple natural order, or perhaps have a still deeper, e.g. dynamical justification. In fact he was looking for such a justification of his heliocentric system and made some suggestions in this direction.

Of great importance in the whole book of Copernicus are aesthetic arguments. He speaks very often about perfect shapes, perfect motions, beautiful natural order, beautiful symmetry, beauty of Nature. Such arguments may seem improper and inadequate for exact sciences; nevertheless, I would like to stress that similar arguments are being frequently used in XXth century physics as well, and play quite an important role. The use of aesthetical arguments in science is no more regarded as something improper or as a sign of ignorance, but rather as the expression of a new sense possessed only by exact scientists: the sense of the mathematical beauty of Nature.

In the Aristotelian cosmology accepted by Ptolemy the Earth was different from the other planets and the Sun. Copernicus treated all the celestial bodies in the same manner both from the kinematic and cosmological point of view. E.g. in contrast to the Ancients, he assumed that all the celestial bodies should have their own gravities like the Earth. In this way he actually made use of the principles of the unity of matter and of the universality of physical phenomena and physical laws, though in a not quite consistent manner.

Copernicus was a realistic thinker and a scientist with many modern traits. He avoided any irrational and idealistic interpretations of the observed phenomena. Although some of his ideas and arguments may be regarded as unfounded and metaphyscal, they were much less metaphysical than those of almost all his contemporaries. He was also completely free of magic, mysticism and superstition, e.g. he was not interested in astrology, which was quite unusual for an astronomer of that time. Even much later Kepler and other astronomers spent large portions of their lifes on preparing astrological calendars and horoscopes.

Copernicus was method-conscious and criticized the arbitrariness, qualitative character, lack of justification and the a priori assumptions made by his predecessors. He rejected indignantly all the arguments based on the Scriptures and other authorities and believed that the scientific truth should be searched and verified in another way. It required a great courage to write about it openly to the pope.

THE PROBLEM OF RELATIVITY AND OF PHYSICALLY DISTINGUISHED FRAMES OF REFERENCE

The great achievements of Copernicus in astronomy and cosmology consisted in: (a) proposing a new, exact and simpler description of the solar system which displayed its beautiful natural order, (b) providing a simple explanation of many otherwise mysterious phenomena, (c) creating a quantitative cosmology of completely new type, (d) predicting several hitherto unexpected properties of the Universe. Those were all rather immediate, tangible and perceptible achievements which could be understood and appreciated already during the life time of Copernicus or shortly afterwards.

This does not apply to the immense influence of Copernicus on the development of phycics. Here the merit of Copernicus lies not in the solutions he found, but in the problems implied by his theory which he left unsolved, or only partially solved.

One of the most important problems put forward by Copernicus was the problem of the relativity of motion and of preferred frames of reference. The principle of relativity was stated and discussed by Copernicus in a very explicit manner. He wrote: "Every observed change of position is the result of either the motion of the observed object, or the motion of the observer, or of the motion of both, provided that these two motions are different. Because if the observed object and the observer move in the same manner, the observer will see no motion of the observed object."

This principle of kinematic relativity is always true, independently of any particular dynamics. However, if we use only this principle we come to the conclusion that all the possible frames of reference are mathematically equivalent in the sense, that any of them can be used for a mathematical description of the moving objects. From such a purely mathematical point of view, the transition from the Pholemaic system to the Copernican or heliocentric system meant simply a change of the frame of reference. Both frames should give certainly mathematically equivalent descriptions of all motions, provided that we know the formulae relating the respective coordinates. However, Copernicus was sure that the frame of reference connected with the Sun was better than that connected with the rotating Earth. His justification of this preference with the help of centrifugal effects can be now regarded as quite convincing. However, it did not look very convincing in the XVIth century because the argumentation had then many physical gaps that were filled only later. Nevertheless, the arguments of Copernicus turned out to be correct. He was also able to show that the heliocentric system was much simpler and displayed better some simple order and symmetry of the motion of planets and stars. He regarded accordingly the motions of the planets in the heliocentric system as true, real motions, and those seen from the rotating Earth as seeming motions. We know now that the physical distinction between mathematically equivalent frames can be done only if we know the forces, i.e. by using dynamical arguments. Copernicus could not give a completely convincing solution of this problem because he knew too little about dynamics.

The problem of relativity and of physically distinguished frames occupied many generations of physicists, however, in spite of many great successes in this field, all its successive solutions are only partial and approximate, although they are getting better and better. The first comprehensive solution was proposed by Newton who introduced the concept of an inertial frame which is characterized by the condition that a mass point on which no forces are acting (we must know it beforehand) moves in such a frame with constant velocity. If we use only inertial frames, then not all characteristics of motion are relative. E.g. the velocity of a mass point is relative, but the value of the acceleration is not. Newton still believed in the existence of one distinguished absolute inertial frame. This belief was shared by most physicists in the XVIIIth and XIXth centuries. Absolute frame was then connected with the problem of ether, i.e. of a universal, homogeneous medium responsible for the propagation of light and, later, of the electromagnetic waves. The Maxwell's equations of electrodynamics seemed first to require an absolute frame of reference, which was the condition of their compatibility with the laws of Newton's mechanics. At the end of the XIXth century Michelson showed that the velocity of light is the same in different moving inertial frames. In the beginning of the XXth century Einstein made the explicit assumption that there is no absolute frame of reference and that all the inertial frames are physically completely equivalent. However, the coordinates of an event measured in two uniformly moving inertial frames had to be related by the Lorentz transformations which involved both space and time. The special theory of relativity of Einstein is a theory of space and time and of inertial systems, but with very strong dynamical implications. In fact, the Lorentz transformations relating two moving inertial frames required some substantial changes of Newton's mechanics. The most important of these changes consisted in replacing the constant inertial mass by a definite function of velocity. If the velocities of the mass points are very small in comparison with the velocity of light, the difference between the old mechanics of Newton and the new mechanics of Einstein becomes negligible. So we can say that the range of validity of the old mechanics of Newton is restricted to small velocities. If the velocities reach the order of the velocity of light one must use the relativistic formulae. The special theory of relativity is again only a partial and approximate solution of the problem, though it is much better and more accurate than the solution of Newton.

In his general theory of relativity, which is in fact a geometrical theory of gravitation, Einstein introduced curved space-time and connected its metric with the gravitational field and the distribution of masses. This caused another revision of the problem of equivalent frames and started a new wave of works on the structure of the Universe. On the other hand the advent of quantum mechanics and in particular Dirac's theory of the so-called physical vacuum, which appears also in quantum field theories, opened completely new possibilities of approach to this problem. In my opinion, quantum theory has not been properly exploited as yet, and I believe that the most interesting discoveries concernig the structure of space and time and of the physical universe are still before us.

In constructing the sequence of better and better approximations to the ideal inertial frame Copernicus made the first and the most decisive step which was crucial for the future development of physics, for the discovery and verification of the dynamical laws of motion. In fact, for everyday's practice, with its very limited accuracy, the frame of reference connected rigidly with the Earth may be good enough in the sense that the deviations from the inertial frame may then be neglected. If we increase the accuracy of our measurements or extend the scope of our observations, e.g. on the motions of the celestial bodies, the Copernican frame, located in the centre of the Sun and with fixed orientation provided by very distant stars, is a much better approximation of the ideal inertial frame. Still better (i.e. "more inertial") is the frame located in the centre of mass of the whole solar system. However, the second improvement is very small in comparison to the first.

DYNAMICAL PROBLEMS OF THE COPERNICAN SYSTEM

The Copernican system implied many questions of purely dynamical nature. E.g. it was at that time unclear what forces were responsible for the constant velocity of rotation of the Earth around its axis. Copernicus dismissed the problem by regarding the rotation around a fixed axis as a perfect circular motion which does not require any causes. This is usually regarded as an explanation in the Aristotelian spirit, but we should remember that in fact the rotation of a rigid body with constant angular velocity is an inertial motion which persists without any external forces, with constant angular momentum.

Copernicus knew too little about the forces and dynamical laws to use them as arguments in the modern sense. Instead he speaks of perfect natural motions, natural positions, etc., very often in cases where from the modern point of view we have to do with a balance of forces.

The next question referred to the forces responsible for the motions of the heavy Earth and other planets around the Sun. This was a new problem which did not exist in the Ptolemaic system, because there the havy Earth was supposed not to move at all and the celestial bodies were believed to be made of a weightless or at least very light substance. In the first case no forces were necessary, in the latter case the required forces were small and thus could be provided by... human-like deities. Furthermore, in the Ptolemaic system only the heavy matter on the Earth was subjected to gravity but the weightless or very light celestial bodies were not. This was an explanation why the celestial bodies do not fall on the Earth. In the Copernican system the Sun and all the planets were treated in the same way as heavy bodies, which required a new explanation of the fact that neither the Moon is falling on the Earth nor the Earth and the other planets are falling on the Sun. Copernicus gave a partial, and as it turned out later, not a quite satisfactory solution of this very profound problem. Namely he assumed that all the celestial bodies and the Earth have independent gravities of their own. In this way there was apparently no reason for them to be falling on each other. With the help of this multigravity concept, Copernicus explained the spherical shapes of the Earth, Sun, Moon and all other celesial bodies. Thus he was already very close to the concept of the universal gravity. Obviously the truly universal gravitational attraction could be seriously proposed only much later, after the discovery of the laws of dynamics. This was done by Newton 150 years later. However, again the first step towards the theory of the universal gravitation was made by Copernicus.

These and other dynamical problems implied by the Copernican theory were violently discussed and occuppied many generations of physicists. Galileo removed many objections against the Copernican system, e.g.

against the daily rotation of the Earth. After the discovery of the satellites of Jupiter, phases of Venus and other phenomena with the help of his self-made telescope, Galileo fully supported the Copernican system. Copernicus knew already that a falling body moves with increasing velocity but did not know the law of this increase which was discovered by Galileo. Galileo was also the first who related force with acceleration and not with velocity. The next break with Ptolemy and with Aristotelian physics was provided by Kepler who discovered that the planets are moving on elliptic orbits with one focus in the centre of the Sun.

All the principal dynamical problems of the Copernican system were solved at the end of the XVIIth century by Newton, who found the general laws of dynamics. In order to have a rigorous mathematical formulation of these laws and the exact methods of solving the equations involved, new branches of mathematics had to be created. This was done by Descartes, Newton, Leibniz and many others. Newton also introduced the concept of inertial mass and postulated a universal gravitational attraction between any two massive bodies. He has showed that not only Kepler's laws but also a definite time dependence of the position vectors of all the planets follow simply from his equations of motion. Newton's theory secured a total victory of the Copernican system, which he supplemented with a profound and comprehensive knowledge of dynamics and with more adequate, exact mathematical tools that made the old method of epicycles completely redundant. Newton's theory of universal gravitation, as well as his dynamical theory of the motions of planets and of the structure of the Universe, remained unsurpassed for more than 200 years till the construction of Einstein's theory of gravitation.

I should like to mention here another type of inspiration of the Copernican system which consists in a straightforward imitation of this system in completely different situations. The best known example is the Bohr model of the hydrogen atom, where the atomic nucleus (proton) played the role of the Sun and the electron was supposed to move on elliptic orbits under the influence of Coulomb's force, like a planet. The semiclassical model of Bohr was soon replaced by quantum mechanics, but it had definite successes and played a very important role in the development of quantum physics.

THE COPERNICAN SYSTEM AS A SOURCE OF PROBLEMS

Most people, including many historians of science, appreciate only the tangible and immediate achievements of individual scientists. This attitude can be more or less justified with respect to the experimental discoveries and technical constructions but is rather misleading with respect to scientific theories.

It is a fact that we can understand Nature only with the help of dynamical and causal theories and not with the help of purely descriptive catalogues of facts. Therefore the theories are really top achievements of the whole scientific work. However, we know that our theories of Nature are never faultless, perfect and ultimate, but only approximate and partial. Therefore, the principal aim of scientific research consists not in finding the ideal of "absolute and ultimate truth" which cannot be grasped in one jump, but in constructing a progressing series of more and more accurate theories with increasing ranges of validity. None of the older theories was able to remain unchanged and to withstand serious revisions resulting either in complete refutation of some theories or in some changes and improvements of other. Even the most modern and accurate physical theories do not claim to be exact, complete or ultimate.

Consider, for example, Newton's mechanics of massive bodies. For 200 years the classical theory of Newton was regarded to be exact and ultimate. With the advent of Maxwell's electrodynamics more and more doubts concerning the accuracy and general validity of Newton's mechanics emerged. In the first quarter of the XXth century the physicists finally realized that Newton's mechanics is only approximate and that in many cases it fails completely. It cannot be applied to atoms, molecules and other microsystems, where it must be replaced by quantum mechanics. Also in the case of large velocities in the considered system, Newton's mechanics must be replaced by Einstein's relativistic mechanics, which takes into account the velocity dependence of the masses, retardation effects of all the interactions, etc. Moreover, many of the most fundamental concepts and principles of Newton's mechanics turned out to be wrong. In fact the concepts of time and space, which are fundamental for all of physics, have been constructed by Newton with little reference to actual or possible measurements. Thus, from the modern standpoint, his constructions of these concepts were definitely metaphysical. The same applies to many derived concepts like those of instantaneous interactions, time and space interval between two events, time ordering of physical events, etc. However, neither these nor many other profound mistakes made by Newton would justify to denounce his greatness and his merits for the development of physics. It is true that he did not discover absolute truth and did not construct an exact and ultimate theory as it was believed in the XVIIIth and XIXth centuries. He constructed a theory which is only approximate and in many points is definitely wrong, but which has still quite an impressive range of validity. This is the lot of all good theories. (The lot of wrong hypotheses is much worse). However, his mechanics inspired all the future development of physics, astronomy and philosophy and had an immense influence on all sciences.

Bearing in mind these laws of the scientific progress, we are not afraid nowadays of open problems and of a multiplication of questions. Neither are we despising theories that are only approximate and partial and require still more work and investigation. The progress of science depends on the ability of scientists to ask profound, relevant and stimulating questions. A right question or the right way of stating a problem often implies the way of looking for the answer. Thus we cannot naively blame Copernicus for not having found ultimate solutions of so many observational, mathematical and dynamical problems of his heliocentric system. We should instead highly appreciate the undeniable, historical fact that his work was a rich source of the most fundamental and inspiring questions referring to: (a) the basic principles of the scientific method, (b) the philosophical problems of human cognition of the physical world, (c) the structure of the Universe, (d) the general principles and dynamical laws of physics, (e) many more detailed and specific problems of astronomy and physics. Some of these problems were explicitly formulated and discussed by Copernicus, some appeared in his book in an implicit form, some could be clearly seen only later, after some further progress in science was made.

In spite of the fact that physics and astronomy have developed enormously since the time of Copernicus, very many scientific problems of our century are just continuations or extensions of the fundamental problems put forward by him. Not denying his great immediate achievements in astronomy, I would like to stress the even greater merits of Copernicus as the man who laid the first foundations of the modern physical sciences as a whole, and stimulated and inspired their development up to our times.