The Copernican System of the Universe

BY

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In the *Copernican System* of the Universe [1], the socalled *heliocentric system,* our common base the Earth, is moving with the other planets around the Sun with a period of one year, while at the same time rotating with a period of one day, the latter movement giving rise to the apparent diurnal rotation of the stars.

On this picture the line of sight to a star changes its direction corresponding to the motion of the Earth, i.e. an apparent annual motion of the star on the celestial sphere, the socalled *parallactic motion,* is expected. In the days of Copernicus this parallactic motion could not be detected, given the limited accuracy of naked-eye observation with rather crude instruments. It was only in 1838 that F. W. Bessel using highly refined observational methods measured a stellar parallax. Copernicus, however, gave the correct and obvious explanation that the distances of the fixed stars are enormously greater than the extent of the orbit of the Earth around the Sun.

We are all familiar with the Copernican picture of the world from our school days. We also know that the Copernican System replaced the *System of Ptolemy,* i.e. the *geocentric system* in which the Earth is assumed to be at rest while the Sun, the Moon, the planets and the stars are moving around the Earth in complicated fashion. In this system the stars are assumed to revolve with a period of one day around the Earth's axis, while their positions

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are not affected by an annual parallax since the observer on the Earth stands still.

In Antiqiuty the periodic motions of the Sun, the Moon and the planets were described by what today would be called mathematical models, geometrically elaborated, and serving the calculation of tables giving positions on the celestial spheres of Sun, Moon and planets. Historically, however, the use of the word "model" in this context is somewhat irrelevant. The fundamental

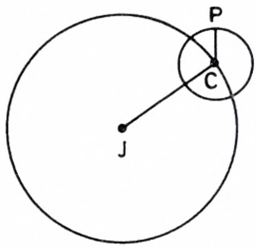

Fig. 1

feature in this mathematical description of the motions of the celestial bodies is *decomposition* into components consisting of *uniform circular motion*. Consider a simplified example in which a planet P moves with uniform speed on a circle (*the epicycle*) whose center C moves uniformly on a second circle (*the deferent*), while the composite motion is viewed from the Earth J which is stationary at the center of the deferent (fig. 1). Although the main features of apparent planetary motion on the celestial sphere can be described through this simplified picture, the picture is much too simplified for even a tolerably good reproduction of the observed motion. Correction in various ways is necessary, and in the System of Ptolemy devices such as placing the Earth excentrically with respect to the deferent and introducing additional epicycles (i.e. additional components of uniform circular motion) are utilized.

This mathematical description of planetary motion was introduced early in the history of Greek Astronomy, and in the perfected form of the *System of Ptolemy*, which achieved near agreement with the observations available in Antiquity, it was greatly admired during the following centuries—and in our times, too, as a highly impressive work of the mind.

As for COPERNICUS, he was intimately familiar with the tradition of Antiquity, in particular with Ptolemy's great book, ALMAGEST. Copernicus, in his famous work, published in 1543, entitled *De Revolutionibus Orbium Coelestium,* presents in book I a simplified description of his system, limiting himself here to a crude approximation in which the motions of the planets, including the Earth, around the Sun, and that of the Moon around the Earth are assumed to be uniform circular motions taking place in one plane. Copernicus shows how retrograde motions of the planets, as observed from Earth, can be explained in terms of the motion of the observer, with the Earth, around the Sun. In this way it is explained that the apparent motion of a planet exhibits loops although the planet moves all the time in the same direction around the Sun.

There is a close correspondence between the Copernican description of planetary motion and that given in the System of Ptolemy. Indeed, the retrograde motion had lead to the introduction in Antiquity of a double motion of the planet, i. e. motion on an epicycle the center of which moves on the deferent.

Obviously the two systems must lead to the same results with respect to the ultimate aim, namely, the calculation of needed tables of planetary motion as seen from an observer on the Earth. It shall now be shown, that a simplified description of planetary motion in the System of Ptolemy, in which it is assumed that all motions take place in one plane, will (given one further assumption to be discussed further on) lead to the same apparent motion of the planets across the celestial sphere, as that yielded by the simplified Copernican System as discussed in the first book of *De Revolutionibus.*

The further assumption, just referred to, pertains to a feature of the System of Ptolemy, namely, *that the motion of the Sun around the Earth must enter the description of motion for all planets.* For the socalled *inner* planets (Mercury and Venus) this occurs in that the direction from the Earth J to the center of the epicycle C is taken to be parallel to the direction JS from Earth to Sun (fig. 2a). For the *outer* planets (Mars, Jupiter and Saturn) it is the direction from the epicycle center C to the planet P that is always parallel to the direction JS or Earth-Sun (fig. 2b). This assumption is indeed a fundamental feature of the description of planetary motions in the System of Ptolemy, and it is, as now will be shown, kinematically equivalent to Copernicus' hypothesis.

In the Ptolemaic System the aim is the reproduction of motion on the celestial sphere, i.e. the determination of lines of sight to

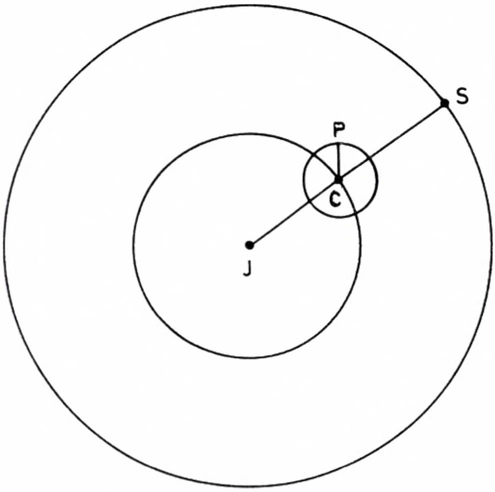

Fig. 2a

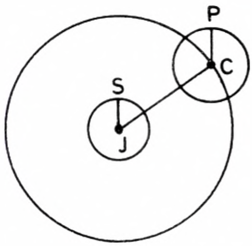

Fig. 2b

the planets. Therefore, only the *ratio* between the radii of deferent and epicycle is relevant, hence it is possible to *choose* the value of one of these quantities arbitrarily. If, in the simplified Ptolemaic description of the motion of an *inner* planet we choose one radius in such a way that the center of the epicycle coincides with the Sun S, then we see that the inner planet P moves uniformly on a circle around the Sun, while the Sun in this simplified description moves uniformly on a circle around the Earth J (fig. 3a).

In the case of an *outer* planet, suppose the radius CP of the epicycle is chosen to be equal to the radius JS of the solar orbit, then the line from the center C of the epicycle to the planet P is at all times parallel to and of the same length as the line from the Earth J to the Sun S. It then follows that the line SP from the Sun to the Planet is at all times parallel to and of the same length as the line JC from the Earth J to the center C of the epicycle, i.e. the length is equal to the radius of the deferent. This means, however, that the planet, in this case also, moves uniformly on a circle, the center of which coincides with the Sun (fig. 3b).

Thus it holds, for an inner as well as for an outer planet, that in the simplified Ptolemaic System considered the planetary motion can be described as a uniform circular motion around the Sun, which in turn has uniform circular motion around the Earth.

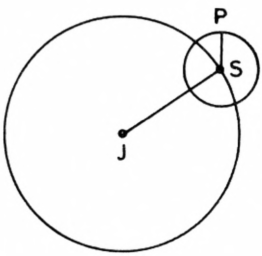

Fig. 3a

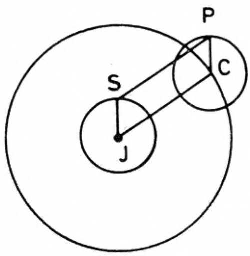

Fig. 3b

In fact, this is the System of the Universe that TYCHO BRAHE adopted, after he rejected the Copernican System, because he had not detected any annual parallax of the fixed stars. In the Tychonic System—already known in Antiquity—the Earth is at rest, and the phenomenon of annual parallax does not occur.

Consider further the planetary motions in the simplified Ptolemaic System, keeping in mind that as far as the prediction of the planetary motions across the celestial sphere is concerned it is equivalent to the Tychonic System. Here the Earth, *as seen from the Sun*, moves in a circle the same way as the planets, and the step to the Copernican System of planetary motion can immediately be taken. As for the Moon, there is no problem in the simplified system since motion around the Earth is assumed in all cases. For the fixed stars, the predictions differ, the Copernican System leading to the occurrence of an annual parallax.

Thus, in the simplified case, the two Systems lead to equivalent results for the motions of Sun, Moon and planets on the celestial sphere. The question then arose, Which System is the true system that corresponds to reality?

The answer to this question is *not* that the two systems can be regarded as representing reality equally well. Although the systems (at least in the simplified case) are equivalent in their description of directions of lines of sights to the planets, they are not equivalent in an extended context, when motion according to the *laws of physics*, in particular the *laws of dynamics*, is considered. According to the ideas of Antiquity the socalled *natural motions*, including the motions of celestial bodies, are intrinsic properties of bodies. And in Aristotelian dynamics as well as in the later Newtonian dynamics it makes a difference whether one or the other of the two systems is adapted.

In the first book of *De Revolutionibus* Copernicus argues courageously and very cleverly for the point of view that it is possible to regard his system as corresponding to reality without giving up the most essential fundamentals of Aristotelian dynamics. Once Newtonian dynamics is adopted, it is clear that the Copernican System must be preferred to the System of Ptolemy, because the former is an *inertial system*, i.e. a system in which the law of inertia is valid. A system in which the Earth is assumed to be at rest is not strictly an inertial system, and only in such systems does Newtonian mechanics hold. However, this whole problem was only slowly and gradually clarified. In this context it should be remembered as an essential feature that if following the ideas of Antiquity—and even NEWTON, but not HUYGENS—in which, more or less consciously, the existence of a socalled *absolute space* was assumed, there must be a clear answer to the question whether it is the Earth or the Sun that is at rest.

Up till now we have only dealt with what could be called the kinematical equivalence of the two systems in the *simplified case* treated in the first book of *De Revolutionibus*. Let us consider next the problem to which the rest of *De Revolutionibus* is devoted, namely, *the detailed description* of planetary motion. In this effort Copernicus is forced to depart from the assumption of uniform circular motion introduced in the simplified description in the first book of the work. Here we note that Copernicus follows Ptolemy closely in his geometric description, and we see how deeply he was rooted in the traditions of Antiquity. In these further efforts the assumption of a planet's uniform circular motion around the Sun no longer sufficed, and Copernicus with great perseverance tries to develop a heliocentric system that leads to agreement with the observations, using the same mathematical methods as Ptolemy, in particular superposition of uniform circular motions. We encounter the epicycles of the Ptolemaic description, now adapted to the heliocentric system. Even as in the System of Ptolemy it is necessary to take into account that motion in the planetary system takes place not in one plane but in several planes, and this complicates the description in both systems. Here, too, Copernicus closely follows the mathematical pattern of Ptolemy.

For Copernicus it was absolutely essential to follow the tradition describing the motion of celestial bodies through superposition of uniform circular motions. He even felt that Ptolemy had been wrong when in one case considered in ALMAGEST he introduced a nonuniform circular motion, namely, when in the description he makes use of a ray emerging from a point a little off the deferent center (the socalled *equant*) and makes it move with constant angular velocity, thus producing a non-uniform motion of the point of intersection of the ray with the deferent, i. e. of the center of the epicycle. Copernicus' attempts at saving the situation were not particularly successful—he introduced one additional uniform circular motion—however he felt that this was a very important contribution. In fact, E. J. DIJKSTERHUIS compares this passage with the incident when GOETHE, in his conversations with ECKERMANN, claimed that his science of colours was his most important contribution [2].

To a man of the renaissance the strong tie to the tradition of Antiquity was most natural, and in the case in question this means the tie to Ptolemy's method of geometrical description. However, it may have meant that many readers, having experienced the excitement of the first part—the first book— of *De Revolutionibus* with its exposition of the simplified Copernican System, were disappointed when they tackled the five following books of *De Revolutionibus*, where the detailed theory of planetary motion is developed using mathematical methods in the Ptolemaic style. Here the same complicated picture was encountered as in the Almagest.

Even within the framework of Ptolemaic geometrical description further simplifications might have been possible for Copernicus, for instance as a consequence of referring the motion of the planets to the actual Sun rather than to the mean Sun defined by the center of the orbit of the Earth, a procedure that set off the Earth. And it is not yet made clear that the orbital planes of the planets all pass through the actual Sun. *He did not know how rich he was,* said KEPLER of Copernicus.

Through the centuries we find some criticism of the work of Copernicus, based on such considerations, and this kind of criticism has persisted into our times, formulated in particular by the leading modern historian of Mathematics and Astronomy, OTTO NEUGEBAUER. I shall mention a few examples, but would like to say right away that I do not regard the criticism as fully relevant. The criticism does, however, serve a justified purpose, in view of naive and unrealistic judgements of the relation of Copernicus to Ptolemaios that is found in certain works in the history of science. The attitude toward Ptolemy that is found in Copernicus' own writings can never support the unrealistic judgements referred to, and in fact we do not find them in the works of such outstanding historians of Astronomy as J. L. E. DREYER [3], whose books to a great extent are as pertinent today as when they were written, or E. J. DIJKSTERHUIS [4].

In one place Neugebauer says with a reference to festive occasions, such as we celebrate here tonight, that *the Copernican theory is by no means so different from or superior to the Ptolemaic theory as is customarily asserted in anniversary celebrations* [5]. And in a later article on the planetary theory of Copernicus in which however Neugebauer emphasizes by way of introduction that he is not considering the alternatives, geocentric or heliocentric system, he summarizes his criticism of the mathematical methods of Copernicus as follows:

If one reads Copernicus only superficially and with the conviction that he had abolished, or at least greatly simplified the Ptolemaic system, one will not be tempted to study the Almagest in any detail. Vieta) of course, still knew better. He must have been fully aware of the fact that there was not a single proof or mathematical procedure in the De Revolutionibus which did not have its exact replica in Almagest. To Vieta as one of the leaders in the new trend of mathematics it must have appeared rather antiquated when Co-*

* French mathematician (1540–1603).

pernicus again and again demonstrated that his model agreed with Ptolemy's.

Modern historians, making ample use of the advantage of hindsight, stress the revolutionary significance of the heliocentric system and the simplifications it had introduced. In fact, the actual computation of planetary positions follows exactly the ancient pattern and the results are the same.

And Neugebauer concludes with the following statement:

Had it not been for Tycho Brahe and Kepler, the Copernican system would have contributed to the perpetuation of the Ptolemaic system in a slightly more complicated form but more pleasing to philosophical minds [6].

We have already referred to the point of reality on which such criticism is based: In his attempts to carry over the results of the Ptolemaic descriptions into the new system Copernicus was not completely successful. What made Copernicus' *De Revolutionibus* such an important contribution was the general putting forward and explanation in the first book of the new heliocentric system, rather than the concrete contributions to the detailed description of planetary motion contained in the other books. With regard to TYCHO BRAHE's lifework in the realm of observational Astronomy, and JOHANNES KEPLER's derivation of the laws of planetary motion, the situation is different. Here, concentration with the aim of comprehension of important, concrete details led to the great new results.

We have dwelt on criticism of *one side* of Copernicus' efforts, but it would be unreasonable to let this diminish appreciation of the *enormous advantage* gained by Astronomy through the introduction of the Copernican system. *Immediately*, through Copernicus' own work, and then through the *development* that followed, culminating with the derivation of the Keplerian laws of planetary motion and Newton's interpretation of these laws, a development through which it became possible to formulate a comprehensive description of the motions of terrestrial as well as celestial bodies: classical mechanics.

With regard to the insight, that was gained *immediately* upon the publication of *De Revolutionibus*, let us emphasize the importance of the general feature that the Copernican System is a *simpler* one than the Ptolemaic, even though decisive simplification as far as details are concerned was not yet achieved. Suffice it to point here to the explanation of the retrograde motions of the planets as developed in the first book of *De Revolutionibus*. More than that, the Copernican System is capable of explaining the fact, referred to before, that the annual motion of the Sun is reflected in the description of the motions of *all* the planets according to Ptolemy, albeit in different fashion for inner and outer planets. Thus, in this respect the Copernican System is the expression of a more comprehensive theory than that of Ptolemy. In other words, we can better understand the Ptolemaic description, once we are familiar with the Copernican. Finally, let us point to the fact that the development of the Copernican System led to a determination of the distances of the planets from the Sun, expressed in units of the radius of the orbit of the Earth around the Sun, based on the approximation of circular planetary orbits. It is possible to derive numbers corresponding to the relative distances just referred to within the framework of the Ptolemaic System, but here the meaning of these numbers in terms of relative distances from the sun is not obvious. Furthermore, while the order of the planets can be arbitrarily chosen in the Ptolemaic System, the determination of the relative distances of the planets from the Sun suggests a natural order in the Copernican System. Ptolemy treats each planet separately: In the simplified theory an individual deferent and individual epicycle is assigned to it, in such a way that only the ratio of the radii of the two circles is relevant, because all that matters is the description of planetary motion on the celestial sphere. In the Copernican System, on the other hand, the planets are viewed comprehensively in the framework of a common description of planetary motion around the Sun.

All this expresses decisive renewal. Let us now turn to the *development* that followed the publication of Copernicus' great work. There is no doubt that the tradition—soon coming into existence and vigorously alive today—according to which Copernicus' contribution meant the *inauguration* of a new epoch in the development of the exact sciences, expresses *historical* reality. Copernicus' strong ties to ideas of Antiquity do not change the impression. Nor is it necessary to appeal to the fact that the impact of his works on political life in the century that followed was very strong, an aspect of the development we shall not consider further here.

A new era that has been called the *anni mirabiles* began with *De Revolutionibus* in 1543 and ended with Newton's *Philosophiae Naturalis Principia Mathematica* of 1687.

In the context considered, the first and most important result of the development following Copernicus was undoubtedly the discovery by Kepler of the *laws of planetary motion* (1609 and 1618) derived on the basis of Tycho Brahe's observations that were about ten times more accurate than those of previous times. According to these laws the orbit of a planet is an ellipse with the Sun at one of its foci; the line from the Sun to the planet sweep over equal areas in equal times; and the squares of the periods of the planets are in the ratio of the cubes of the major semi-axis of their respective orbits. With Kepler's laws emancipation from the traditional mathematical description of planetary motion in terms of superposition of uniform circular motion had finally been achieved. This meant a definite departure from an idea of Antiquity, an idea fully respected also by Copernicus, that uniform circular motion is the "natural motion" for celestial bodies, so to speak an intrinsic property.

Newton, basing his investigations on Kepler's laws and on the investigations by Galilei and Huygens concerning the free fall and oscillations of heavy bodies under the influence of gravity, created the new mechanics. The motions of the planets were explained as consequence of an attractive force between planet and Sun, proportional to the product of the masses of these bodies and inversely proportional to the square of their distance; and it was realized that the attractive force exerted by the Earth on terrestrial bodies obeyed the same law, the *Law of Gravitation.*

Copernicus' strong ties to ideas of Antiquity—including those on dynamics—not withstanding, his work forms an essential basis for this fascinating development.

The church authorities—both catholic and protestant—resisted the adoption of the Copernican System. Thus, in 1628 *De Revolutionibus* was put on index. This attitude contributed to the slow acceptance of the Copernican System. But clearly the fact that the Copernican System appeared alien and in contradiction to direct observation of the celestial phenomena also gave rise to difficulties in the process of acceptance.

Galilei through his work *Dialogo sopra i due massimi sistemi del Mondo, Tolemaico e Copernicano* [7], written in the Italian language and published in 1632, made a decisive contribution to diffusion and understanding of the Copernican System. A Latin edition appeared shortly afterward and quickly found readers all over Europe. The Lutheran clergyman Osiander in his preface to *De Revolutionibus* (we do not know whether it was with or without the dying Copernicus' consent) had cautiously stated as a possibility that the Copernican System did not correspond to reality, but was rather a mathematical hypothesis or device for computing the motions of celestial bodies. In Galilei's work, on the other hand, there is no doubt at all. The System of Copernicus is *the* real system. And in a lively and clever style, sprinkled with characteristic sarcasm, he argues vigorously and clearly for the Copernican System as representing reality.

More than that, through his telescopic discoveries Galilei had contributed direct and independent evidence in favour of the Copernican System of the Universe: He discovered the phenomenon of the phases of Venus, and his discovery of the system of Jupiter and its satellites yielded to the observer a Copernican System *en miniature*.

I have already referred to the phenomenon of annual parallax, i.e. the apparent motion of the fixed stars on the celestial sphere which is caused by the motion of the Earth around the Sun. In the days of Copernicus this phenomenon could not be observed, the angular displacements in question being too small to be detected, given the limited observational accuracy, because the distances to the stars are enormous in comparison with the radius of the Earth's orbit. Although Tycho Brahe had at his disposal improved instruments and used improved methods of observation, he could not detect any parallaxes of fixed stars. Therefore, although Tycho Brahe very much admired Copernicus, he was not willing to accept the Copernican System. I have already referred to the Tychonic System which he developed instead.

Following Tycho Brahe, Ole Rømer was the next great reformer of observational Astronomy. Great progress was achieved through his introduction of the meridian circle, used together with pendulum clocks, as introduced by HUYGENS. Rømer measured differences in right ascension, i.e. the arc between the projections of the stars on to the celestial equator, by determining differences in the time of transit across the meridian. (It is a pleasing thought that even today the Brorfelde Observatory of Copenhagen University, located not far from the site of Ole Rømer's private observatory, contributes relative meridian circle observations more accurate than any others). There is little doubt that Ole Rømer's efforts in the direction of refinement of the methods of positional Astronomy were motivated by his desire to measure stellar parallaxes [8]. In these efforts he went quite far, even constructing himself a thermometer with two fiducial points, determined by the temperature of boiling and freezing water, respectively. He further measured heat expansion coefficients for a number of metals, and was able to compute the influence of temperature changes upon the rate of his pendulum clocks. PEDER HORREBOW, a student of Rømer's, drew attention to a Rømer manuscript in which measures of the difference in the right ascensions of Sirius and Vega are discussed. Rømer believed that he had found an annual variation corresponding to the parallactic phenomenon. Today we know that the correct interpretation of Rømer's results is a different one (in terms of systematic errors of the observations). The fact that Rømer did not publish his paper, although it was in complete form, suggests that he did not fully trust the result; his self-criticism being highly developed, as we know from his correspondence with LEIBNITZ, expressing his anxiety of publishing incomplete observations [8].

Rømer's name is connected to the diffusion of Copernican ideas in still another way, namely, through his construction of *orreries* that illustrated the motions of the planets around the Sun. These machines were generally admired, and copies were given as presents to the rulers of France, China and Siam. This occurred while Rømer was a very active member of the French Academy.

After Kepler's discovery of the laws of planetary motion and Newton's interpretation of these laws within the framework of what today is called classical mechanics any remaining doubts about the fundamental feature of the Copernican System disappeared: It was clear that the planets moved around the Sun.

However, there is good reason to emphasize that Descartes, too, made an important contribution helping the final adoption of the teachings of Copernicus. For in presenting his *whirl theory* he was assuming the correctness of the Copernican picture, and with cautiousness, typical for him, he discussed the Copernican System and produced arguments in its favour.

From the point of view of the scientist it has been somewhat difficult to fully appreciate the great impact that Descartes' writings had on contemporary Physics, as is also true to some extent in the case of Plato. However, the very important influence of these two great philosophers is a fact even though their direct or specific contributions to the development of Physics, when viewed in perspective, are not too significant. There can be no doubt, however, that the ideas of Descartes in Physics made a great impression on his contemporaries, and thereby contributed in important fashion to the acceptance of the Copernican System. Similarly, it can be said that the ideas of Plato greatly influenced the development of Astronomy in Antiquity, above all because they led to the formulation of the claim or axion that the motions of celestial bodies must be described using the concept of uniform circular motion.

An immediate result of the work of Copernicus is present in the computations of ephemerides of the planets by Erasmus Reinhold. In 1551 Reinhold published the socalled *Tabulae Prutenicae* (Prussian Tables) that were meant to replace the previous widely used *Alphonsinian Tables.* Although Reinhold did not express himself in any way for or against the heliocentric hypothesis, he did use the methods of computation of Copernicus. While the Prussian Tables were used on the occasion of the *Gregorian Reform of the Calender,* they did not much influence the further development of Astronomy. For they built on an observational material essentially the same as that already contained in Ptolemy's Almagest, with very little added by subsequent generations of astronomers.

As for Copernicus himself, the number of new observations that he contributed was not large. There was in fact little progress in the field of observational Astronomy until the work of Tycho Brahe changed the picture.

I have attempted to describe on the one hand Copernicus' strong ties to the traditions of Antiquity, particularly as they appear in Ptolemy's Almagest, and on the other hand the great development that began with *De Revolutionibus,* but was foreshadowed and prepared through a short article, *De Hypotesibus Motuum Coelestium a se constitutis Commentariolus,* generally referred to as *Commentariolus,* which Copernicus distributed among friends about the year 1514.

It is well known that Copernicus had *predecessors,* even as is the case with others whose contributions meant great renewal of the exact sciences. In this connection Aristarchos is particularly mentioned, and with regard to the hypothesis of the diurnal rotation of the Earth, Nicole Oresme. The arguments of the latter, based as they are on Aristotelian dynamics, have a good deal in common with those of Copernicus.

Copernicus, far from claiming to be without predecessors, refers to the works of Astronomers of Antiquity to further support of his System: He mentions Philolaus, the Pythagoraean, who had claimed that the Earth moves around a central fire, as well as Ecphantos, who had attributed to the Earth a rotation around its own axis. Copernicus, however, is cautious in no referring to Aristarchos, whose ideas had been met with strong disapproval. A reference to Aristarchos, originally present in the manuscript of *De Revolutionibus,* was left out in the final version.

We find that some historians of science are intent on finding *predecessors,* and in this context the contributions of Pierre Duhem, in many respects of considerable interest, should be mentioned. His emphasis on the importance of predecessors from mediaeval natural philosophy has given rise in our days to a certain reaction, and caution in the discussion of the whole subject in order. When we compare the relevant references in Antiquity—even Aristarchos'—with *De Revolutionibus,* it appears, however, clear that it is completely intelligble, that Copernicus was regarded as the creator of a new, systematically developed, System of the Universe, in fact the Copernican System.

In other words, we must regard Copernicus as a scientist whose work led to an epochmaking breakthrough and development of the exact sciences. A development that was precipitated above all by the first book of *De Revolutionibus* in which Copernicus through a simplified picture of the motions of the planets, using uniform circular motion around the Sun, advances his new System so convincingly that his work came to be regarded in posterity as the beginning of a new epoch.

The fact that his vigorous and persistant efforts to incorporate details of the description of planetary motion in the system did not lead to results quite as satisfactory as those obtained by Ptolemy and his predecessors, particularly Hipparchos and Apollonius, this fact should not influence adversely the impression of a glorious contribution. I quoted Otto Neugebauer who has expressed the view that had it not been for Tycho Brahe and Kepler, the works of Copernicus would have contributed to "the perpetuation of the Ptolemaic system in a slightly more complicated form but more pleasing to the philosophical minds." Granted that the expression "philosophical minds" is taken to suggest an evaluation, more positive than perhaps might appear at first sight from the quotation, and taking into account that great scientists—indeed certainly also Tycho Brahe, Kepler and Galilei —with a view to the nature of their work could be referred to as *philosophical minds,* Neugebauer's judgement can be accepted. Copernicus' important contribution was "pleasing" to such "philosophical minds." Very much, indeed. We only need to read Galilei.

I wish to refer, finally, to certain results of recent studies according to which Copernicus was influenced not only by the Astronomy of Antiquity, as revived in the years before his own time by immediate predecessors such as Peurbach and his student Regiomontanus, but also rather strongly by Astronomers working in late mediaeval times within the cultural sphere of *Islam.* However this influence seems to have no connection with Copernicus' advancing the heliocentric hypothesis, but it is relevant in connection with his efforts to improve in detail the theory of planetary and lunar motions [9].

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Ptolemaios' Almagest has been edited by L. J. Heiberg, I-II, Leipzig 1888–99. French translation by Halma, I-II. Paris 1816; new edition Paris 1927. A more reliable translation, in German, is given by Karl Manitius, Leipzig 1912.
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Commentariolus, in which Copernicus already about 1514 gave a primary account of his system (see p. 15), is translated in English in E. Rosen: *Three Copernican Treatises*, 3rd ed., New York 1971. In this book is given an annotated Copernicus-Bibliography 1939–70. A French, annotated translation of the first 12 chapters of the *First Book* of *De Revolutionibus*, edited parallel with the Latin text, is given by A. Koyré in *Textes et Traductions*, Paris 1934.
An important contribution to the promotion of the Copernican System was given by Joachim Rheticus, who went to study with Copernicus in 1539 and persuaded him to publish *De Revolutionibus*. Rheticus gave in his famous *Narratio Prima* a clear survey over the Copernican System. An English translation of *Narratio Prima* is given in the before mentioned book by E. Rosen.
An important work in Copernican-research, containing a wealth of interesting details, but stamped by a somewhat unpleasant nationalistic tendency is:
Ernst Zinner: *Entstehung und Ausbreitung der Coppernicanischen Lehre*, Erlangen 1943.
The same nationalistic tendency can be observed in the comprehensive, but unfinished biography:

LEOPOLD PROWE: *Nicolaus Copernicus* I-II, Berlin 1883–84; reprinted Osnabrück 1967.

See also:

EDWARD ROSEN: *Nicholaus Copernicus* in *Dictionary of Scientific Biography* III, New York 1971, p. 401.

A. ARMITAGE: *Copernicus, The Founder of Modern Astronomy.* London and New York 1947.

A. ARMITAGE: *Sun, Stand Thou Still, The Life and Work of Copernicus, The Astronomer,* London and New York 1947.

HERMANN KESTEN: *Copernicus und seine Welt,* Amsterdam 1948. The two last mentioned books are of a very popular kind. Kesten's book has almost the character of a novel, but it is worth reading.

2. DIJKSTERHUIS in [1], p. 321.
3. J. L. E. DREYER in [1].
4. DIJKSTERHUIS in [1].
5. *Publications of the Astronomical Society of the Pacific,* 58, p. 116, 1946.
6. O. NEUGEBAUER: *On the Planetary Theory of Copernicus, Vistas in Astronomy,* 10, p. 103, Oxford and New York 1960.
7. English translation:

   GALILEO GALILEI: *Dialogue Concerning the Two Chief World Systems—Ptolemaic and Copernican* (translated by *Stillman Drake*), Berkeley and Los Angeles 1953.
8. MOGENS PIHL: *Ole Rømers Videnskabelige Liv.* Publ. by Videnskabernes Selskab, København 1944.

   See also:

   K. P. MOESGAARD: *Copernican Influence on Tycho Brahe, Colloquia Copernicana,* I, p. 31, Wroclaw, Warszawa, Krakow and Gdansk 1972 and *How Copernicanism took Root in Denmark and Norway,* ibid. p. 117. In these two papers is given an interesting and comprehensive account of the propagation of Copernican ideas in our country.
9. A brief account with reference to litterature is given by

   O. PEDERSEN: *Copernicus and the Astronomical Tradition,* UNESCO, Paris, 1973.