Commentariolus by Copernicus

From the Nicolaus Copernicus Thorunensis website

Our predecessors assumed, I observe, a large number of celestial spheres mainly for the purpose of explaining the planets' apparent motion by the principle of uniformity. For they thought it altogether absurd that a heavenly body, which is perfectly spherical, should not always move uniformly. By connecting and combining uniform motions in various ways, they had seen, they could make any body appear to move to any position.

Callippus and Eudoxus, who tried to achieve this result by means of concentric circles, could not thereby account for all the planetary movements, not merely the apparent revolutions of those bodies but also their ascent, as it seems to us, at some times and descent at others, [a pattern] entirely incompatible with [the principle of] concentricity. Therefore for this purpose it seemed better to employ eccentrics and epicycles, [a system] which most scholars finally accepted.

Yet the widespread [planetary theories], advanced by Ptolemy and most other [astronomers], although consistent with the numerical [data], seemed likewise to present no small difficulty. For these theories were not adequate unless they also conceived certain equalizing circles, which made the planet appear to move at all times with uniform velocity neither on its deferent sphere nor about its own [epicycle's] center. Hence this sort of notion seemed neither sufficiently absolute nor sufficiently pleasing to the mind.

Therefore, having become aware of these [defects], I often considered whether there could perhaps be found a more reasonable arrangement of circles, from which every apparent irregularity would be derived while everything in itself would move uniformly, as is required by the rule of perfect motion. After I had attacked this very difficult and almost insoluble problem, the suggestion at length came to me how it could be solved with fewer and much more suitable constructions than were formerly put forward, if some postulates (which are called axioms) were granted me. They follow in this order.

POSTULATES

1. There is no one center of all the celestial orbs or spheres.
2. The center of the earth is the center, not of the universe, but only of gravity and of the lunar sphere.
3. All the spheres encircle the sun, which is as it were in the middle of them all, so that the center of the universe is near the sun.
4. The ratio of the earth's distance from the sun to the height of the firmament is so much smaller than the ratio of the earth's radius to its distance from the sun that the distance between the earth and the sun is imperceptible in comparison with the loftiness of the firmament.
5. Whatever motion appears in the firmament is due, not to it, but to the earth. Accordingly, the earth together with the circumjacent elements performs a complete rotation on its fixed poles in a daily motion, while the firmament and highest heaven abide unchanged.
6. What appear to us as motions of the sun are due, not to its motion, but to the motion of the earth and our sphere, with which we revolve about the sun as [we would with] any other planet. The earth has, then, more than one motion.
7. What appears in the planets as [the alternation of] retrograde and direct motion is due, not to their motion, but to the earth's. The motion of the earth alone, therefore, suffices [to explain] so many apparent irregularities in the heaven.

Having thus propounded the foregoing postulates, I shall endeavor briefly to show to what extent the uniformity of the motions can be saved in a systematic way. Here, however, the mathematical demonstrations intended for my larger work should be omitted for brevity's sake, in my judgment. Nevertheless, in the explanation of the circles themselves I shall set down here the lengths of the spheres' radii. From these anybody familiar with mathematics will readily perceive how excellently this arrangement of circles agrees with the numerical data and observations.

Accordingly, lest anybody suppose that, with the Pythagoreans, I have asserted the earth's motion gratuitously, he will find strong evidence here too in my exposition of the circles. For, the principal arguments by which the natural philosophers attempt to establish the immobility of the earth rest for the most part on appearances. All these arguments are the first to collapse here, since I undermine the earth's immobility as likewise due to an appearance.

THE ORDER OF THE SPHERES

The celestial spheres embrace one another in the following order. The highest is the immovable sphere of the fixed stars, which contains and gives position to all things. Beneath it is Saturn's, which Jupiter's follows, then Mars'. Below Mars' is the sphere on which we revolve; then Venus'; last is Mercury's. The lunar sphere, however, revolves around the center of the earth and moves with it like an epicycle. In the same order also, one sphere surpasses another in speed of revolution, according as they measure out greater or smaller expanses of circles. Thus Saturn's period end in the thirtieth year, Jupiter's in the twelfth, Mars' in the third, and the earth's with the annual revolution; Venus completes its revolution in the ninth month, Mercury in the third.

THE APPARENT MOTIONS OF THE SUN

The earth has three motions. First, it revolves annually in a Grand Orb about the sun in the order of the signs, always describing equal arcs in equal times. From the Grand Orb's center to the sun's center the distance is 1/25 of the Grand Orb's radius. This Orb's radius is assumed to have a length imperceptible in comparison with the height of the firmament. Consequently the sun appears to revolve with this motion, as if the earth lay in the center of the universe. This [appearance], however, is caused not by the sun's motion but rather by the earth's. Thus, for example, when the earth is in the Goat, the sun is seen diametrically opposite in the Crab, and so on. Moreover, on account of the aforementioned distance of the sun from the Orb's center, this apparent motion of the sun will be nonuniform, the maximum inequality being 2 1/6. The sun's direction with reference to the Orb's center is invariably toward a point of the firmament about 10° west of the more brilliant bright star in the head of the Twins. Therefore, when the earth is opposite this point, with the Orb's center lying between them, the sun is then seen at its greatest distance [from the earth]. By this Orb not only is the earth revolved, but also whatever else is associated with the lunar sphere.

The earth's second motion is the daily rotation. This is in the highest degree peculiar to the earth, which it turns on its poles in the order of the signs, that is, eastward. On account of this rotation the entire universe appears to revolve with enormous speed. Thus does the earth rotate together with its circumjacent waters and nearby air.

The third is the motion in declination. For, the axis of the daily rotation is not parallel to the Grand Orb's axis, but is inclined [to it at an angle that intercepts] a portion of a circumference, in our time about 23 1/2°. Therefore, while the earth's center always remains in the plane of the ecliptic, that is, in the circumference of a circle of the Grand Orb, the earth's poles rotate, both of them describing small circles about centers [lying on a line that moves] parallel to the Grand Orb's axis. The period of this motion also is a year, but not quite, being nearly equal to the Grand Orb's [revolution]. The Grand Orb's axis, however, being invariant with regard to the firmament, is directed toward what are called the poles of the ecliptic. The poles of the daily rotation would always be fixed in like manner at the same points of the heavens by the motion in declination combined with the Orb's motion, if their periods were exactly equal. Now with the long passage of time it has become clear that this alignment of the earth changes with regard to the configuration of the firmament. Hence it is the common opinion that the firmament itself has several motions. But even though the principle involved is not yet sufficiently understood, it is less surprising that all these phenomena can occur on account of the earth's motion. I am not prepared to state to what its poles are attached. I am of course aware that in more mundane matters a magnetized iron needle always points toward a single spot in the universe. It has nevertheless seemed a better view to ascribe the phenomena to a sphere, whose turning governs the movements of the poles. This sphere must doubtless be sublunar.

EQUAL MOTION SHOULD BE MEASURED NOT BY THE EQUINOXES BUT BY THE FIXED STARS

Accordingly, since the equinoxes and the other cardinal points of the universe shift considerably, whoever attempts to derive from them the equal length of the annual revolution necessarily falls into error. Besides, different determinations of this length were made in different ages on the basis of many observations. Hipparchus computed it as 365 1/4 days, and al-Battani the Chaldean as 365d 5h46m, that is, 13 3/5m or [13] 1/3m less than Ptolemy. Hispalensis, on the other band, increased al-Battani's length by the 20th part of an hour, since he determined the tropical year as 365d 5h 49m.

Lest these differences should seem to have arisen from errors of observation, [let me say that] if anyone will study the details carefully, he will find that the discrepancy has always corresponded to the shift in the equinoxes. For when the cardinal points of the universe moved 1° in 100 years, as was found in Ptolemy's time, the length of the year was then what Ptolemy himself reported. When however in the following centuries they moved with greater rapidity in opposition to lesser motions, the year became shorter by as much as the cardinal points' displacement increased. For by their swifter recurrence they encountered the annual motion in a shorter time. Therefore the derivation of the equal length of the year from the fixed stars is more accurate. Thus I used the Spike of the Virgin and discovered that the year has always been 365 days, 6 hours, and about 1/6 hour, the value also found in ancient Egypt. The same reasoning must be employed also with the other motions of the heavenly bodies because their apsides, which are likewise fixed in the firmament, with their true testimony make manifest the laws of the motions as well as heaven itself.

THE MOON

The moon, on the other hand, seems to me to have four motions in addition to the annual revolution which has been mentioned. For on its deferent sphere it revolves once a month about the center of the earth in the order of the signs. That deferent in fact carries what is commonly called the epicycle of the first anomaly or of the argument, but I call the first or larger epicycle. In its upper portion this [larger epicycle] revolves in the direction opposite to the deferent's in a period of a little more than a month. A second epicycle is attached to this larger epicycle, by which it is carried around. Lastly, as the moon clings to this second epicycle, it completes two revolutions a month in the direction opposite to the first epicycle's. As a result, whenever the larger epicycle's center touches the line drawn from the Grand Orb's center through the earth's center (I call this line the Grand Orb's diameter), the moon is then nearest to the larger epicycle's center. This occurs around the new and full moon. But contrariwise at the quadratures, halfway between new and full moon, the moon is most remote [from the larger epicycle's center]. In length, the larger epicycle's radius is to its deferent sphere's radius as 1 1/18:10, and to the smaller epicycle's radius as 4 3/4:1.

By reason of these [arrangements], therefore, the moon appears to be fast at some times, and at other times slow, as well as to drop down and climb higher. Into the first anomaly the smaller epicycle's motion introduces two irregularities. For it withdraws the moon from uniform motion on the larger epicycle's circumference, the maximum inequality being 12 1/4° of a circumference of corresponding size or diameter; and it also brings the larger epicycle's center at times farther from [the moon], at times nearer [to it], within the limits of the [smaller epicycle's] radius. Therefore, since for this reason the moon describes unequal peripheries of circles around the larger epicycle's center, it happens that the first anomaly undergoes complicated variations. Thus, the greatest variation of this kind does not exceed 4°56' near conjunctions and oppositions to the sun, but in the quadratures it increases to 7° 36'.

Those, however, who believe that this [variation] is caused by an eccentric circle improperly treated the motion on that circle as nonuniform and, in addition, they fell into two manifest errors. For, the consequence by mathematical reasoning is that in the quadratures, when the moon drops down to the lowest part of the epicycle, it would appear nearly four times greater (if the entire [disk] were luminous) than when new and full, unless they also irrationally claim that the size of its body increases and decreases. So too, because the earth's size is sensible in comparison with its distance [from the moon], the eccentric makes the parallax increase very greatly near the quadratures. But if anyone investigates rather carefully, he will find that both [the apparent size and parallax] differ very little in the quadratures as compared with new and full moon, and accordingly he will not lightly doubt that my theory is the truer.

Indeed, with these three motions in longitude, the moon passes through the points of its motion in latitude. The epicycles' axes are parallel to the deferent's axis, and therefore the moon does not move away from the [plane of the] deferent. But the deferent's axis is inclined to the axis of the Grand Orb or ecliptic and therefore makes the moon move out of the plane of the ecliptic. Thus the deferent's axis is inclined at an angle which subtends 5° of the circumference of a circle. Its poles revolve [around centers lying on a line that moves] parallel to the ecliptic's axis, in nearly the same manner as was explained regarding declination. Also in the present case they move in the reverse order of the signs but much more slowly, with a revolution being completed in the nineteenth year. It is the common opinion that this [motion] takes place in a higher sphere, to which the poles are attached as they revolve in the manner described. Such a fabric of motions, then, does the moon seem to have.

THE THREE OUTER PLANETS SATURN-JUPITER-MARS

Saturn, Jupiter, and Mars have a similar system of motions, since their spheres completely enclose the Grand Orb associated with the year and revolve in the order of the signs around its center as their common center. But Saturn's sphere completes its revolution in the thirtieth year, Jupiter's in the twelfth year, and Mars' in the twenty-ninth month, just as if these revolutions axe delayed by the spheres' size. For if the Grand Orb's radius is divided into 25 units, the radius of Mars' sphere will be 38, Jupiter's 130 5/12, and Saturn's 230 5/6. By "radius" [of the sphere] I mean the distance from the sphere's center to the center of the first epicycle.

For, each [deferent sphere] has two epicycles. One of these carries the other, in much the same way as was explained in the case of the moon. The arrangement, however, is different. For, the first epicycle revolves in the direction opposite to the deferent sphere's, the periods of both being equal. On the other hand, the second epicycle, revolving in the direction opposite to the first's with twice the velocity, carries the planet around. As a result, whenever the second epicycle is at its greatest distance from the deferent sphere's center, or again at its nearest approach thereto, the planet is then at its closest to the [first] epicycle's center; but it is at its greatest distance therefrom whenever [the second epicycle is] at a quadrant's distance [from the two positions just mentioned and] halfway [between them]. Therefore, through the combination of these motions of the deferent sphere and epicycles, as well as the commensurability of their periods, it happens that these withdrawals and approaches occupy absolutely fixed places of their own in the firmament. [These planets] constantly adhere to unchanging patterns of motion throughout, so that their apsides are immovable: Saturn's, near the star described as being above the Archer's elbow; Jupiter's, 8° east of the star called the end of the Lion's tail; and Mars', 6 1/2° west of the Lion's heart.

The sizes of their epicycles are as follows. In those units of which the Grand Orb's radius was taken to be 25 [25p 0m], the radius of Saturn's first epicycle consists of 19p 41m, while the second epicycle's radius has 6p 34m. Similarly in the case of Jupiter, the first epicycle has a radius of 10p 6m; the second, 3p 22m. As for Mars, its first [epicycle's radius is] 5p 34m; its second [epicycle's radius is 1p] 51m. Thus, the first [epicycle's] radius is throughout three times greater than the second [epicycle's radius].

Now the irregularity imposed by the epicycles' motion upon the deferent sphere's motion bas usually been called the "first anomaly" which, as I said, adheres throughout to unchanging boundaries in the firmament. For there is a second anomaly, in which the planet is seen sometimes to retrograde and often to become stationary. This second anomaly happens by reason of the motion, not of the planet, but of the earth as it changes its observational position on the Grand Orb. For since the earth's speed surpasses the motion of the planet, the line of sight directed toward the firmament regresses, and the earth more than neutralizes the planet's motion. This regression peaks at the time when the earth is nearest to the planet, that is, when it comes between the sun and the planet at the planet's evening rising. On the other hand, about the time when the planet is setting in the evening or rising in the morning, the earth advances the line of sight in the forward direction. But when the line of sight is moving in the direction opposite to the planet's and at an equal rate, the planet seems to stand still because the opposite motions neutralize each other in this way. This generally happens when the angle at the earth between the sun and the planet is about 120°. In all these planets, however, the lower the sphere by which the planet is moved, the greater is this anomaly. Hence in Saturn it is smaller than in Jupiter, and again greatest in Mars, in accordance with the ratio of the Grand Orb's radius to their radii. This anomaly peaks for each of them at the time when the planet is seen along a line of sight tangent to the Grand Orb's circumference. For us, at any rate, these three planets do indeed wander about [in longitude].

In latitude, on the other hand, their digression is twofold. [In the first place,] while the epicycles' circumferences remain in a single plane with their deferent, the planets deviate from the ecliptic in accordance with the axes' inclinations. These do not revolve, as in the case of the moon, but are always directed toward the same region of the heavens. Therefore the intersections of the circles (the deferent's and the ecliptic, these intersections being called the "nodes") also occupy eternal places in the firmament. Thus, the node where the ascent toward the north begins is, for Saturn, 8 1/2° east of the star said to be in the head of the eastern Twin; for Jupiter, 4° west of that star; and for Mars, 6 1/2° west of Vergiliae. Hence in these and the diametrically opposite [nodes] a planet has no latitude.

On the other hand, its maximum latitude, which occurs when these planets are at a quadrant's distance [from the nodes], is quite variable. For, the inclination of the axes and circles seems, as it were, to be attached to those nodes, while oscillating [around them]. In fact, it peaks at the time when the earth is nearest to the planet, that is, when the planet is rising in the evening. For then the axis' inclination is 2 2/3° for Saturn, 1 2/3° for Jupiter, and 1 5/6° for Mars. On the other hand, near evening setting and morning rising, the earth being then at its greatest distance [from the planet], this inclination decreases for Saturn and Jupiter by 5/12°, but for Mars by 1 2/3°. Thus this variation is most notable in the greatest latitudes, and for any latitude it diminishes as the planet's distance from the node lessens, so that the variation increases and decreases in phase with the latitude.

In the second place, it happens that the earth's motion on the Grand Orb causes the apparent latitudes to change for us. Thus, [the earth's] approach toward and withdrawal from [the planet] increase and decrease the angles of the apparent latitude, as mathematical reasoning requires. If in fact this oscillating motion occurs along a straight line, it is nevertheless possible for a motion of this kind to be produced by a combination of two spheres. Although these are concentric, [the higher] one carries around the other one's poles, which are inclined. In addition, the lower sphere makes the poles of the deferent sphere bearing the epicycles revolve with twice the velocity of the upper sphere and in the opposite direction. The deferent's poles are also inclined, their inclination away from the poles of the sphere halfway above being equal to the inclination of this sphere's poles away from those of the highest sphere. So much for Saturn, Jupiter, and Mars as well as the spheres which enclose the earth.

VENUS

What is enclosed within the Grand Orb's embrace, that is, Venus' and Mercury's motions, remains to be investigated. To begin with, Venus has a system of circles closely resembling that of the outer planets, but the motions are executed differently. As was said above, Venus' deferent sphere completes its revolution in the ninth month, which is likewise the period of the larger epicycle. Their composite motion brings the smaller epicycle back in a constant relation to the firmament everywhere, and establishes the higher apse at the point toward which I said the sun is directed. On the other hand, the smaller epicycle's period, while incommensurable with the other two, is commensurable with the Grand Orb's motion: in one revolution of the Orb, the smaller epicycle completes two revolutions. As a result, whenever the earth is in the diameter drawn through the apse, the planet is then nearest to the larger epicycle's center, and farthest from it [when the earth is] on the perpendicular [to the line of apsides] at a quadrant's distance from them. [This arrangement] closely resembles the way in which the moon's smaller epicycle in its aspects is related to the sun. But the radii of the Grand Orb and of Venus' deferent sphere have the ratio 25p:18p; the larger epicycle, 3/4p; and the smaller, 1/4p.

Venus too is sometimes seen to retrograde, particularly when it is nearest to the earth. Its regression occurs for a reason that in a certain way is like the reason for the outer planets' regression, but is its opposite. For their regression occurs because the earth's motion is faster [than theirs], but in this case because it is slower; moreover, in their case the earth's sphere is enclosed, whereas in this case it does the enclosing. Hence Venus is never in opposition to the sun, since the earth cannot come between them. On the contrary, it turns back within fixed elongations to either side of the sun. These are determined by tangents to the circumference drawn from the earth's center, and never exceed 48° in our observations. This in substance is the motion by which Venus is carried around in longitude.

Its latitude also changes for a twofold reason. For Venus too has the axis of its deferent sphere inclined, at an angle of 2 1/2° and the node whence it turns north is in its apse. But although in itself this inclination is one and the same, the digression arising from it appears to us as twofold. For when the earth faces either node of Venus, these digressions are seen on perpendiculars [to the nodal plane] above and below it, and are termed the "reflexions." The deferent sphere's natural inclinations, which are called the "declinations" appear when the earth is at a quadrant's distance [from the nodal line], but they are the same. In all the other positions [of the earth], however, both latitudes mingle and are combined: the larger one prevails over the other, as they augment and eliminate each other by their likeness and difference.

But the axis' inclination is the following. It has an oscillating motion hinged, not on the nodes as in the case of the outer planets, but on certain other points that revolve by performing annual revolutions of their own with reference to the planet. As a result, whenever the earth faces an apse of Venus, at that time the oscillation peaks, and this [affects] the planet itself, no matter what part of its deferent it is in then. Consequently, if the planet is then in an apse or its diametric opposite, it will not completely lack latitude even though it is then in the nodes. From these [peak positions], however, this oscillation decreases until the earth moves through a quadrant of a circle away from the aforesaid [apsidal] location and, their motions being similar, until the peak point of this deviation has moved an equal distance away from the planet, when absolutely no trace of this deviation is found. The deviational swing continues uninterrupted, with that initial [peak] point dropping from north to south and moving as far away from the planet as the earth moves away from the apse. The planet again reaches the peak when a semicircle of the libration is completed. Here the deviation becomes maximal once more, being similar [in sign] and equal to its initial [value]. Thus, finally, the remaining semicircle is traversed in the same way [as the first]. Consequently this latitude, which is usually called the "deviation," never becomes southern. Here too it seems reasonable that these phenomena are produced by two concentric spheres with oblique axes, as I explained in the case of the outer planets.

MERCURY

Of all the orbits in the heaven, however, the most remarkable is that of Mercury, which traverses almost untraceable paths so that it cannot be easily studied. There is the further difficulty that it generally follows a course invisible in the sun's rays and is observable on very few days. Yet Mercury too will be understood, provided that it is investigated by someone of superior ability.

For Mercury too, as for Venus, two epicycles revolving on their deferent sphere will be suitable. For, as in the case of Venus, the larger epicycle has the same period as its deferent sphere, and fixes the position of Mercury's apse at 14 1/2° east of the Spike of the Virgin. The smaller epicycle, on the other hand, revolves with twice the [earth's] speed. But by contrast with the principle governing Venus, in every position of the earth passing over Mercury's [higher] apse or facing it from the opposite direction, the planet is farthest from the larger epicycle's center, and nearest to it [when the earth is] at a quadrant's distance [from the apsidal line]. As I said, Mercury's deferent sphere completes its revolution in the third month, that is, in 88 days. Its radius contains 9 2/5p, of the 25p which I have assumed for the Grand Orb's radius. Of these units, the first epicycle takes 1p 41m, while the second epicycle takes one-third as much, that is, about 34m.

But this combination of circles is not sufficient here, by contrast with the other [planets]. For when the earth passes through the aforementioned positions with respect to the apse, the planet seems to move along a far smaller periphery, and again, when the earth is at a quadrant's distance [from the apsidal line], along an even larger periphery, than is consistent with the aforesaid system of circles. Yet no other perceptible longitudinal irregularity is produced by this [disparity].

Its occurrence, consequently, is reasonably explained by a certain approach [of the planet] toward and withdrawal from the deferent's center along a straight line. This oscillation must be caused by two interlocking small spheres, whose axes are parallel to the deferent's axis. At the same time the center of the larger epicycle, or of this whole [epicyclic structure], is exactly as far away from the center of the small sphere which without any gap contains [the epicycle's center] as the center of this [inner sphere] is from the center of the outer [small sphere]. This distance has been found to be 0p 14 1/2m, the universal measure I have used being 25p 0m. In addition, the outer small sphere's motion 303 performs two revolutions in the course of a year, while the inner one completes four revolutions in the same time with twice the speed in the opposite direction. For by this composite motion the centers of the larger epicycle are carried along a straight line, just as I explained with regard to the oscillating latitudes. In this manner, therefore, when the earth is in the aforementioned positions with respect to the apse, the larger epicycle's center is nearest to the deferent's center, but farthest [from it when the earth is] at a quadrant's distance [from the apsidal line]. However, [when the earth is] at the midpoints, that is, 45° from these [four points, just mentioned], the larger epicycle's center joins the Outer small sphere's center, and both [these centers] coincide. This approach-and-withdrawal amounts to 0p 29m of the aforementioned units. And this ends the discussion of Mercury's motion in longitude.

In latitude it does not differ from Venus, except that it is always in the opposite region. For where Venus turns north, Mercury heads south. But its deferent sphere is inclined to the ecliptic at an angle of 7°. Here too there is a deviation, but it is always southern and never exceeds 3/4°. Otherwise, what was said about Venus' latitudes may be recalled here too, to avoid frequent repetition of the same statements.

Thus, Mercury runs on seven circles in all; Venus, on five; the earth, on three, and around it the moon on four; finally, Mars, Jupiter, and Saturn on five each. Thus altogether, therefore, 34 circles suffice to explain the entire structure of the universe and the entire ballet of the planets.

Translation by Edward Rosen

Taken from the Nicolaus Copernicus Thorunensis website:
http://copernicus.torun.pl/en/archives/astronomical/1/?view=transkrypcja&lang=en