# THE THIRD DAY

**SAGREDO.** I have been impatiently awaiting your arrival, that I might hear the novel views about the annual rotation of this globe of ours. This has made the hours seem very long to me last night and this morning, though I have not passed them idly. On the contrary, I have lain awake most of the night running over in my mind yesterday's arguments and considering the reasons adopted by each side in favor of these two opposing positions--the earlier one of Aristotle and Ptolemy, and this later one of Anistarchus and Copernicus. And truly it seems to me that whichever of these theories happens to be wrong, the arguments in its favor are so plausible that it deserves to he pardoned--so long as we pause at the ones produced by its original weighty authors. Yet because of its antiquity the Peripatetic opinion has had many followers, while the other has had but few, partly because of its difficulty and partly because of its novelty. And among the partisans of the former, especially in modem times, I seem to discern some who introduce very childish, not to say ridiculous, reasons in maintaining the opinion which appears to them to be true.

**SALV.** The same thing has struck me even more forcibly than you. I have heard such things put forth as I should blush to repeat--not so much to avoid discrediting their authors (whose names could always be withheld) as to refrain from detracting so greatly from the honor of the human race. In the long run my observations have convinced me that some men, reasoning preposterously, first establish some conclusion In their minds which, either because of its being their own or because of their having received it from some person who has their entire confidence, impresses them so deeply that one finds it impossible ever to get it out of their heads. Such arguments in support of their fixed idea as they hit upon themselves or hear set forth by others, no matter how simple and stupid these may be, gain their instant acceptance and applause. On the other hand whatever is brought forward against it, however ingenious and conclusive, they receive with disdain or with hot rage--if indeed it does not make them ill. Beside themselves with passion, some of them would not be backward even about scheming to suppress and silence their adversaries. I have had some experience of this myself.

**SAGR.** I know; such men do not deduce their conclusion from its premises or establish it by reason, but they accommodate (I should have said discommode and distort) the premises and reasons to a conclusion which for them is already established and nailed down. No good can come of dealing with such people, especially to the extent that their company may be not only unpleasant but dangerous. Therefore let us continue with our good Simplicio, who has long been known to me as a man of great ingenuity and entirely without malice. Besides, he is intimately familiar with the Peripatetic doctrine, and I am sure that whatever he does not think up in support of Aristotle's opinion is not I likely to occur to anybody.

But here, all out of breath, comes the very person who has been wished for so long today. -- We were just now maligning you.

**SIMP.** Please don't scold me; blame Neptune for my long delay. For in this morning's ebb he withdrew the waters in such a manner that the gondola in which I was riding, having

entered an unlined canal not far from here, was left high and dry. I had to stay there over an hour awaiting the return of the tide. And while I was there, unable to get out of the boat (which had run aground almost instantly), I fell to observing an event which struck me as quite remarkable. As the water slackened, it might he seen to run very swiftly through various rivulets, the mud being exposed in many places. While I was watching this effect, I saw this motion along one stretch come to a halt, and without pausing a moment the same water would begin to return, the sea turning from retreat to advance without remaining stationary for an instant. This is an effect which I have never happened to see before in all the time I have frequented Venice.

**SAGR.** Then you cannot often have happened to be stranded among little trickles. On account of their having scarcely any slope, the sinking or rising of the open sea by merely the thickness of a sheet of paper is enough to make the water flow and return a long distance through such rivulets. On some seacoasts the rising of the sea only a few yards makes the water spill over the plains for many thousands of acres.

**SIMP.** I know that well enough, but I should think that between the lowest point of the sinking and the first point of the rising, some perceptible interval of rest would be bound to intervene.

**SAGR.** It will appear so to you when you have in mind walls or pilings, upon which this change takes place vertically. But actually there is no state of rest.

**SIMP.** It would seem to me that these being two contrary motions, there would have to be some rest midway between them, in agreement with Aristotle's doctrine proving that *in puncto regressus mediat quies*.(note: At the instant of retreat, an interval of calm.)

**SAGR.** I remember the passage well, and I also recall that when I was studying philosophy I was not convinced by Aristotle's proof Indeed, I have had many experiences to the contrary. I might mention them now, but I do not want to have us wander into any more abysses. We have met here to discuss our subject, if possible, without interrupting it as we have in the past two days.

**SIMP.** Still it will be good, if not to interrupt it, at least to extend it somewhat. For upon returning home yesterday evening I fell to rereading that booklet of theses, where I found some very convincing proofs against this annual motion which is attributed to the earth. And since I did not trust myself to quote them exactly, I have brought the booklet along with me. (note: This is the pamphlet *De tribus novis stellis quae annis 1572, 1600, 1609 comparuere (1628)* by Scipio Chiaramonti, which Simplicio refenred to on the first day (*cf* p. 14).)

**SAGR.** You have done well. But if we mean to take up our discussion again in accordance with yesterday's agreement, we must first hear what Salviati has to say about the book on the new stars. Then, without further interruptions, we may examine the annual motion.

Now, Salviati, what have you to say in regard to these stars? Have they really been drawn down from the heavens into these baser regions by virtue of the calculations made by this author whom Simplicio has produced?

**SALV.** Last night I undertook to study his procedures, and this morning I gave them another glance, wondering whether what I thought I had been reading the night before was really written there, or whether I was the victim of ghosts and fantastic imaginings of the night. To my great regret, I found actually written and printed there that which, for the sake of this

philosopher's reputation, I should have wished had not been. It seems impossible to me that he does not realize the vanity of his enterprise, both because it Is so obvious and because I remember having heard our friend the Academician praise him. It also seems to me very hard to believe that out of deference to others he could be persuaded to hold his own reputation in such low esteem as to be induced to publish a work from which nothing but censure could be expected from the learned.

**SAGR.** You might add that there will be rather less than one in a hundred of these, to offset those who will celebrate and exalt him over all the most learned men who exist now or ever have. A man able to sustain the Peripatetic inalterability of the heavens against a host of astronomers, and one who, to their greater shame, has done battle against them with their own weapons! And if there are half a dozen to a province who perceive his trivialities, what are they against the innumerable multitude who (being able neither to discover these nor to comprehend them) are taken in by all the shouting, and applaud the more the less they understand? And even the few who do understand scorn to make a reply to such worthless and inconclusive scribbles. With good reason, too; for those who do understand have no need of this, and upon those who do not understand it is wasted effort.

**SALV.** Silence would indeed be the most appropriate reprimand for their worthlessness, were there not other reasons which practically force one to repudiate them. One reason is that we Italians are making ourselves look like ignoramuses and are a laughingstock for foreigners, especially for those who have broken with our religion; I could show you some very famous ones who joke about our Academician and the many mathematicians in Italy for letting the follies of a certain Lorenzini (note: A criticism leveled by Kepler.) appear in print and be maintained as his views without contradiction. But this also might be overlooked In comparison with another and greater occasion for laughter that might be mentioned, which is the hypocrisy of the learned toward the trifling of opponents of this stripe in matters which they do not understand.

**SAGR.** I could not ask for a better example of their petulance, or of the unhappy situation of a man like Copernicus, placed under the carping of those who do not understand even the rudiments of the position against which they have declared war.

**SALV.** You will be no less astonished at their manner of refuting the astronomers who declare the new stars to be above the orbits of the planets, and perhaps among the fixed stars themselves *(nel firmamento)*.

**SAGR.** But how can you have examined this whole book in such a short time? It is certainly a large volume, and there must be numerous demonstrations in it.

**SALV.** I stopped after these first refutations of his in which, with twelve demonstrations founded upon the observations of twelve of the astronomers who thought that the new star of 1572 (which appeared in Cassiopeia) was in the firmament, he proves it on the contrary to have been sublunar. To do this he compares, two by two, the meridian altitudes taken by different observers in places of different latitude, proceeding in a manner which you will understand presently. And it seems to me that in examining this first procedure of his I have detected in this author a great inability to prove anything against the astronomers or in favor of the Peripatetic philosophers, and that indeed he only confirms their opinion more conclusively. Therefore I did not want to devote myself with equal patience to the examination of his other methods; having given them a superficial glance, I am positive that the inconclusiveness which pervades his first refutation would exist in the others likewise.

And the fact is (as you will soon see) that a very few words suffice to refute this work, although it is built up with so many laborious calculations, as you have perceived.

Therefore you shall hear how I proceeded. The author, I say, in order to attack his adversaries with their own weapons, takes a large number of the observations which they themselves have made, these authors being twelve or thirteen in number. On a part of these he bases his calculations, and he deduces such stars to have been below the moon. Now since I am very fond of proceeding by interrogation, and since the author is not here himself, you, Simplicio, shall reply to the queries I am going to make, and say whatever you believe he would say.

Assuming that we are dealing with the nova of 1572 appearing in Cassiopeia, tell me, Simplicio, whether you think it might have been in different places at the same time. That is, could it he amidst the elements and also be among the planetary orbits, and in addition be above these among the fixed stars, as well as being infinitely higher?

**SIMP.** Doubtless one must say that it was located in a single place, at a unique and determinate distance from the earth.

**SALV.** Then if the observations made by the astronomers were correct, and if the calculations made by this author were not erroneous, both the former and the latter would necessarily have to yield exactly the same distance; isn't that right?

**SIMP.** So far as I can see it would necessarily be so, nor do I believe that the author would contradict this.

**SALV.** But if, of many computations, not even two came out in agreement, what would you think of that?

**SIMP.** I should judge that all were fallacious, either through some fault of the computer or some defect on the part of the observers. At best I might say that a single one, and no more, might be correct; but I should not know which one to choose.

**SALV.** But would you want to deduce a questionable conclusion and establish it as true, from a false basis? Surely not. Now this author's calculations are such that not one of them agrees with any other; you see, then, bow much faith you can put in them.

**SIMP.** If that is how matters stand, it is truly a serious defect.

**SAGR.** I want to help Simplicio and his author out by saying to you, Salviati, that your case would indeed be conclusive if the author had undertaken to find out definitely how far the star was from the earth. But I do not believe that that was his intent; he wished only to show that the star was sublunar. Now if, from the observations mentioned and from all the calculations made on these, the height of the star can always be inferred to have been less than that of the moon, this would suffice the author to convict of the crassest ignorance all those astronomers who, whether they erred in geometry or in arithmetic, could not deduce the true conclusions from their own observations.

**SALV.** Then I had better turn MY attention to you, Sagredo, since you so cunningly sustain the author's doctrine. And let us see whether I can also persuade Simplicio (although he is unskilled at calculations and proofs) that this author's demonstrations are inconclusive to say the least. Consider first that both he and all the astronomers he is in conflict with agree that

the new star had no motion of its own, but merely went around with the diurnal motion of the *primum mobile*. But they disagree about its place, the astronomers putting it in the celestial regions (that is, above the moon) and perhaps among the fixed stars, while he judges it to be near the earth; that is, under the arc of the moon's orbit. And since the site of the new star of which we are speaking was toward the north and at no great distance from the pole, so that for us northerners it never set, it was a simple matter to take its meridian altitudes by means of astronomical instruments--its minimal below the pole as well as its maximal above the pole. By combining these, when the observations were made at different places on the earth and at different distances from the north (that is, at places differing among themselves as to polar elevation), the distance of the star could be reasoned out. For if it was placed in the firmament among the other fixed stars, its meridian altitudes when taken at different elevations of the pole would have to differ among themselves in the same way as did these polar elevations. Thus, for example, if the altitude of the star above the horizon had been thirty degrees when taken at a place where the polar elevation was, say, forty-five degrees, then the altitude of the star ought to be increased four or five degrees in those more northerly lands in which the pole is four or five degrees higher. But if the distance of the star from the earth was very small in comparison with that of the firmament, then its meridian altitudes should have increased noticeably more than the polar elevations as the pole was approached. From such a greater increase--that is, from the excess of the increase of the star's elevation over the increase of the polar altitude, which is called a difference of parallax--the distance of the star from the center of the earth may be quickly calculated by a clear and certain method.

Now this author takes the observations made by thirteen astronomers at different polar elevations, and comparing a part of these (which he selects) he calculates, by using twelve pairings, that the height of the new star was always below the moon. But he achieves this by expecting such gross ignorance on the part of everyone into whose hands his book might fall that it quite turns my stomach. I can hardly see how the other astronomers contain themselves in silence. Especially Kepler, against whom this author particularly declaims; he would not be one to hold his tongue, unless he considered the matter beneath his notice.

Now for your information I have copied on these pages the conclusions that he deduces from his twelve investigations....

**SAGR.** This is as if I were watching some unfortunate farmer who, after having all his expected harvest beaten down and destroyed by a tempest, goes about with pallid and downcast face, gathering up such poor gleanings as would not serve to feed a chicken for one day.

**SALV.** Truly, it was with too scant a store of ammunition that this author rose up against the assailers of the sky's inalterability, and it is with chains too fragile that he has attempted to pull the new star down from Cassiopeia in the highest heavens to these base and elemental regions. Now, since the great difference between the arguments of the astronomers and of this opponent of theirs seems to me to have been very clearly demonstrated, we may as well leave this point and return to our main subject. We shall next consider the annual movement generally attributed to the sun, but then, first by Aristarchus of Samos and later by Copernicus, removed from the sun and transferred to the earth. Against this position I know that Simplicio comes strongly armed, in particular with the sword and buckler of his booklet of theses or mathematical disquisitions. It will be good to commence by producing the objections from this booklet.

**SIMP.** If you don't mind, I am going to leave those for the last, since they were the most recently discovered.

**SALV.** Then you had better take up in order, in accordance with our previous procedure, the contrary arguments by Aristotle and the other ancients. I also shall do so, in order that nothing shall be left out or escape careful consideration and examination. Likewise Sagredo, with his quick wit, shall interpose his thoughts as the spirit moves him.

**SAGR.** I shall do so with my customary lack of tact; and since you have asked for this, you will be obliged to pardon it.

**SALV.** This favor will oblige me to thank and not to pardon you. But now let Simplicio begin to set forth those objections which restrain him from believing that the earth, like the other planets, may revolve about a fixed center.

**SIMP.** The first and greatest difficulty is the repugnance and incompatibility between being at the center and being distant from it. For if the terrestrial globe must move in a year around the circumference of a circle--that is, around the zodiac--it is impossible for it at the same time to be in the center of the zodiac. But the earth is at that center, as is proved in many ways by Aristotle, Ptolemy, and others.

**SALV.** Very well argued. There can be no doubt that anyone who wants to have the earth move along the circumference of a circle must first prove that it is not at the center of that circle. The next thing is for us to see whether the earth is or is not at that center around which I say it turns, and in which you say it is situated. And prior to this, it is necessary that we declare ourselves as to whether or not you and I have the same concept of this center. Therefore tell me what and where this center is that you mean.

**SIMP.** I mean by "center," that of the universe; that of the world; that of the stellar sphere; that of the heavens.

**SALV.** I might very reasonably dispute whether there is in nature such a center, seeing that neither you nor anyone else has so far proved whether the universe is finite and has a shape, or whether it is infinite and unbounded. Still, conceding to you for the moment that it is finite and of bounded spherical shape, and therefore has its center, it remains to be seen how credible it is that the earth rather than some other body is to be found at that center.

**SIMP.** Arislotle gives a hundred proofs that the universe is finite, bounded, and spherical.

**SALV.** Which are later all reduced to one, and that one to none at all. For if I deny him his assumption that the universe is movable all his' proofs fall to the ground, since he proves it to be finite and bounded only if the universe is movable. But in order not to multiply our disputes, I shall concede to you for the time being that the universe is finite, spherical, and has a center. And since such a shape and center are deduced from mobility, it will be the more reasonable for us to proceed from this same circular motion of world bodies to a detailed investigation of the proper position of the center. Even Aristotle himself reasoned about and decided this in the same way, making that point the center of the universe about which all the celestial spheres revolve, and at which he believed the terrestrial globe to be situated. Now tell me, Simplicio: if Aristotle had found himself forced by the most palpable experiences to rearrange in part this order and disposition of the universe, and to confess himself to have been mistaken about one of these two propositions--that is, mistaken either

about putting the earth in the center, or about saying that the celestial spheres move around such a center--which of these admissions do you think that he would choose?

**SIMP.** I think that if that should happen, the Peripatetics ...

**SALV.** I am not asking the Peripatetics, I am asking Aristotle himself As for the former, I know very well what they would reply. They, as most reverent and most humble slaves of Aristotle, would deny all the experiences and observations in the world, and would even refuse to look at them in order not to have to admit them, and they would say that the universe remains just as Aristotle has written; not as nature would have it. For take away the prop of his authority, and with what would you have them appear in the field? So now tell me what you think Aristotle himself would do.

**SIMP.** Really, I cannot make up my mind which of these two difficulties he would have regarded as the lesser.

**SALV.** Please, do not apply this term "difficulty" to something that may necessarily be so, wishing to put the earth in the center of the celestial revolutions was a "difficulty." But since you do not know to which side he would have leaned, and considering him as I do a man of brilliant intellect, let us set about examining which of the two choices is the more reasonable, and let us take that as the one which Aristotle would have embraced. So, resuming our, reasoning once more from the beginning, let us assume out of respect for Aristotle that the universe (of the magnitude of which we have no sensible information beyond the fixed stars), like anything that is spherical in shape and moves circularly, has necessarily a center for its shape and for its motion. Being certain, moreover, that within the stellar sphere there are many orbs one inside another, with their stars which also move circularly, our question is this: Which is it more reasonable to believe and to say; that these included orbs move around the same center as the universe does, or around some other one which is removed from that? Now you, Simplicio, say what you think about this matter.

**SIMP.** If we could stop with this one assumption and were sure of not running into something else that would disturb us, I should think it would be much more reasonable to say that the container and the things it contained all moved around one common center rather than different ones.

**SALV.** Now if it is true that the center of the universe is that point around which all the orbs and world bodies (that is, the planets) move, it is quite certain that not the earth, but the sun, is to be found at the center of the universe. Hence, as for this first general conception, the central place is the sun's, and the earth is to be found as far away from the center as it is from the sun.

**SIMP.** How do you deduce that it is not the earth, but the sun, which is at the center of the revolutions of the planets?

**SALV.** This is deduced from most obvious and therefore most powerfully convincing observations. The most palpable of these, which excludes the earth from the center and places the sun here, is that we find all the planets closer to the earth at one time and farther from it at another. The differences are so great that Venus, for example, is six times as distant from us at its farthest as at its closest, and Mars soars nearly eight times as high in the one state as in the other. You may thus see whether Aristotle was not some trifle deceived in believing that they were always equally distant from us.

**SIMP.** But what are the signs that they move around the sun?

**SALV.** This is reasoned out from finding the three outer planets--Mars, Jupiter, and Saturn--always quite close to the earth when they are in opposition to the sun, and very distant when they are in conjunction with it. This approach and recession is of such moment that Mars when close looks sixty times as large as when it is most distant. Next, it is certain that Venus and Mercury must revolve around the sun, because of their never moving far away from it, and because of their being seen now beyond it and now on this side of it, as Venus's changes of shape conclusively prove. (note: Venus has phases like the moon.) As to the moon, it is true that this can never separate from the earth in any way, for reasons that will be set forth more specifically as we proceed.

**SAGR.** I have hopes of hearing still more remarkable things arising from this annual motion of the earth than were those which depended upon its diurnal rotation.

**SALV.** You will not be disappointed, for as to the action of the diurnal motion upon celestial bodies, it was not and could not be anything different from what would appear if the universe were to rush speedily in the opposite direction. But this annual motion, mixing with the individual motions of all the planets, produces a great many oddities which in the past have baffled all the greatest men in the world.

Now returning to these first general conceptions, I repeat that the center of the celestial rotation for the five planets, Saturn, Jupiter, Mars, Venus, and Mercury, is the sun; this will hold for the earth too, if we are successful in placing that in the heavens. Then as to the moon, it has a circular motion around the earth, from which as I have already said it cannot be separated; but this does not keep it from going around the sun along with the earth in its annual movement.

**SIMP.** I am not yet convinced of this arrangement at all. Perhaps I should understand it better from the drawing of a diagram, which might make it easier to discuss.

**SALV.** That shall be done. But for your greater satisfaction and your astonishment, too, I want you to draw it yourself You will see that however firmly you may believe yourself not to understand it, you do so perfectly, and just by answering my questions you will describe it exactly. So take a sheet of paper and the compasses; let this page be the enormous expanse of the universe, in which you have to distribute and arrange its parts as reason shall direct you. And first, since you are sure without my telling you that the earth is located in this universe, mark some point at your pleasure where you intend this to be located, and designate it by means of some letter.

**SIMP.** Let this be the place of the terrestrial globe, marked A.

Figure 4

**SALV.** Very well. I know in the second place that you are aware that this earth is not inside the body of the sun, nor even contiguous to it, but is distant from it by a certain space. Therefore assign to the sun some other place of your choosing, as far from the earth as you like, and designate that also.

**SIMP.** Here I have done it; let this be the sun's position, marked 0.

**SALV.** These two established, I want you to think about placing Venus in such a way that its position and movement can conform to what sensible experience shows us about it. Hence you must call to mind, either from past discussions or from your own observations, what you know happens with this star. Then assign it whatever place seems suitable for it to you.

**SIMP.** I shall assume that those appearances are correct which you have related and which I have read also in the booklet of theses; that is, that this star never recedes from the sun beyond a certain definite interval of forty degrees or so; hence it not only never reaches opposition to the sun, but not even quadrature, nor so much as a sextile aspect. (note: i.e. 180° 90° and 60°.) Moreover, I shall assume that it displays itself to us about forty times as large at one time than at another, greater when, being retrograde, It is approaching evening conjunction with the sun, and very small when it is moving forward toward morning conjunction, and furthermore that when it appears very large, it reveals itself in a homed shape, and when it looks very small it appears perfectly round.

These appearances being correct, I say, I do not see how to escape affirming that this star revolves in a circle around the sun, in such a way that this circle cannot possibly be said to embrace and contain within itself the earth, nor to be beneath the sun (that is, between the sun and the earth), nor yet beyond the sun. Such a circle cannot embrace the earth because then Venus would sometimes be in opposition to the sun; it cannot be beneath the sun, for then Venus would appear sickle-shaped at both conjunctions; and it cannot be beyond the sun, since then it would always look round and never homed. Therefore for its lodging I shall draw the circle CH around the sun, without having this include the earth.

**SALV.** Venus provided for, it is fitting to consider Mercury, which, as you know, keeping itself always around the sun, recedes therefrom much less than Venus. Therefore consider what place you should assign to it.

**SIMP.** There is no doubt that, imitating Venus as it does, the most appropriate place for it

will be a smaller circle, within this one of Venus and also described about the sun. A reason for this, and especially for its proximity to the sun, is the vividness of Mercury's splendor surpassing that of Venus and all the other planets. Hence on this basis we may draw its circle here and mark it with the letters BG.

**SALV.** Next, where shall we put Mars?

**SIMP.** Mars, since it does come into opposition with the sun, must embrace the earth with its circle. And I see that it must also embrace the sun; for, coming into conjunction with the sun, if it did not pass beyond it but fell short of it, it would appear homed as Venus and the moon do. But it always looks round; therefore its circle must include the sun as well as the earth. And since I remember your having said that when it is in opposition to the sun it looks sixty times as large as when in conjunction, it seems to me that this phenomenon will be well provided for by a circle around the sun embracing the earth, which I draw here and mark DI. When Mars is at the point D, it is very near the earth and in opposition to the sun, but when it is at the point 1, it is in conjunction with the sun and very distant from the earth.

And since the same appearances are observed with regard to Jupiter and Saturn (although with less variation in Jupiter than in Mars, and With still less in Saturn than in Jupiter), it seems clear to me that we can also accommodate these two planets very neatly with two circles, still around the sun. This first one, for Jupiter, I mark EL; the other, higher, for Saturn, is called FM.

**SALV.** So far you have comported yourself uncommonly well. And since, as you see, the approach and recession of the three outer planets is measured by double the distance between the earth and the sun, this makes a greater variation in Mars than in Jupiter because the circle DI of Mars is smaller than the circle EL of Jupiter. Similarly, EL here is smaller than the circle FM of Saturn, so the variation is still less in Saturn than in Jupiter, and this corresponds exactly to the appearances. It now remains for you to think about a place for the moon.

**SIMP.** Following the same method (which seems to me very convincing), since we see the moon come into conjunction and opposition with the sun, it must be admitted that its circle embraces the earth. But it must not embrace the sun also, or else when it was in conjunction it would not look homed but always round and full of light. Besides, it would never cause an eclipse of the sun for us, as it frequently does, by getting in between us and the sun. Thus one must assign to it a circle around the earth, which shall be this one, NP, in such a way that when at P it appears to us here on the earth A as in conjunction with the sun, which sometimes it will eclipse in this position. Placed at N, it is seen in opposition to the sun, and in that position it may fall under the earth's shadow and be eclipsed.

**SALV.** Now what shall we do, Simplicio, with the fixed stars? Do we want to sprinkle them through the immense abyss of the universe, at various distances from any predetermined point, or place them on a spherical surface extending around a center of their own so that each of them will be the same distance from that center?

**SIMP.** I had rather take a middle course, and assign to them an orb described around a definite center and included between two spherical surfaces--a very distant concave one, and another closer and convex, between which are placed at vanious altitudes the innumerable host of stars. This might be called the universal sphere, containing within it the spheres of the planets which we have already designated.

**SALV.** Well, Simplicio, what we have been doing all this while is arranging the world bodies according to the Copernican distribution, and this has now been done by your own hand. Moreover you have assigned their proper movements to them all except the sun, the earth, and the stellar sphere. To Mercury and Venus you have attributed a circular motion around the sun without embracing the earth. Around the same sun you have caused the three outer planets, Mars, Jupiter, and Saturn, to move, embracing the earth within their circles. Next, the moon cannot move in any way except around the earth and without embracing the sun. And in all these movements you likewise agree with Copernicus himself It now remains to apportion three things among the sun, the earth, and the stellar sphere: the state of rest which appears to belong to the earth; the annual motion through the zodiac, which appears to belong to the sun; and the diurnal movement, which appears to belong to the stellar sphere, with all the rest of the universe sharing in it except the earth. And since it is true that all the planetary orbs (I mean Mercury, Venus, Mars, Jupiter, and Saturn) move around the sun as a center, it seems most reasonable for the state of rest to belong to the sun rather than to the earth--just as it does for the center of any movable sphere to remain fixed, rather than some other point of it remote from the center.

Next as to the earth, which is placed in the midst of moving object--I mean between Venus and Mars, one of which makes its revolution in nine months and the other in two years--a motion requiring one year may be attributed to it much more elegantly than a state of rest, leaving the latter for the sun. And such being the case, it necessarily follows that the diurnal motion, too, belongs to the earth. For if the sun stood still, and the earth did not revolve upon itself but merely had the annual movement around the sun, our year would consist of no more than one day and one night; that is, six months of day and six months of night, as was remarked once previously.

See, then, how neatly the precipitous motion of each twenty-four hours is taken away from the universe, and how the fixed stars (which are so many suns) agree with OUT sun in enjoying perpetual rest. See also what great simplicity is to be found in this rough sketch, yielding the reasons for so many weighty phenomena in the heavenly bodies.

**SAGR.** I see this very well indeed. But just as you deduce from this simplicity a large probability of truth in this system, others may on the contrary make the opposite deduction from it. If this very ancient arrangement of the Pythagoreans is so well accommodated to the appearances, they may ask (and not unreasonably) why it has found so few followers in the course of centuries; why it has been refuted by Aristotle himself, and why even Copernicus is not having any better luck with it in these latter days.

**SALV.** Sagredo, if you had suffered even a few times, as I have so often, from hearing the sort of follies that are designed to make the common people contumacious and unwilling to listen to this innovation (let alone assent to it), then I think your astonishment at finding so few men holding this opinion would dwindle a good deal. It seems to me that we can have little regard for imbeciles who take it as a conclusive proof in confirmation of the earth's motionlessness, holding them firmly in this belief, when they observe that they cannot dine today at Constantinople and sup in Japan, or for those who are positive that the earth is too heavy to climb up over the sun and then fall headlong back down again. There is no need to bother about such men as these, whose name is legion, or to take notice of their fooleries. Neither need we try to convert men who define by generalizing and cannot make room for distinctions, just in order to have such fellows for our company in very subtle and delicate doctrines. Besides, with all the proofs in the world what would you expect to accomplish in the minds of people who are too stupid to recognize their own limitations?

No, Sagredo, my surprise is very different from yours. You wonder that there are so few followers of the Pythagorean opinion, whereas I am astonished that there have been any up to this day who have embraced and followed it. Nor can I ever sufficiently admire the outstanding acumen of those who have taken hold of this opinion and accepted it as true; they have through sheer force of intellect done such violence to their own senses as to prefer what reason told them over that which sensible experience plainly showed them to the contrarv. For the arguments against the whirling of the earth which we have already examined are very plausible, as we have seen; and the fact that the Ptolemiacs and Aristotelians and all their disciples took them to be conclusive is indeed a strong argument of their effectiveness. But the experiences which overtly contradict the annual movement are Indeed so much greater in their apparent force that, I repeat, there is no limit to my astonishment when I reflect that Aristarchus and Copernicus were able to make reason so conquer sense that, in defiance of the latter, the former became mistress of their belief

**SAGR.** Then we are about to encounter still further strong attacks against this annual movement?

**SALV.** We are, and such obvious and sensible ones that were it not for the existence of a superior and better sense than natural and common sense to join forces with reason, I much question whether 1, too, should not have been much more recalcitrant toward the Copemican system than I have been since a clearer light than usual has illuminated me.

**SAGR.** Well, then, Salviati, let us get down to cases, as they say; for every word spent otherwise seems to me to be wasted.

**SALV.** I am at your service ...

**SIMP.** Gentlemen, please give me a chance to restore harmony to my mind, which I now find very much upset by certain matters which Salviati has just touched upon. Then, when this storm has subsided, I shall be able to listen to your theories more profitably. For there is no use forming an image in a wavy mirror, as the Latin poet has told us so graciously by writing:

*... nuper me in lillore vidi,*
*Cum placidum ventis staret mare.*

["Upon the shore I lately viewed myself, When the sea stood still, unruffled by the winds." (Virgil, Bucolics 2.25)]

**SALV.** You are quite right; tell us your difficulties.

**SIMP.** Those who deny the diurnal motion to the earth because they do not see themselves being transported to Persia or Japan have been called by you just as dull-witted as those who oppose the annual motion because of the repugnance they feel against admitting that the vast and ponderous bulk of the terrestrial globe can raise itself on high and then descend to the depths, as it would have to do if it revolved about the sun annually. Now I, without blushing to be numbered among such simpletons, feel in my own mind this very repugnance as to the second point against the annual motion, the more so when I see how much resistance is made to motion even over a plain by, I shall not say a mountain, but a mere stone; and even the former would be but the tiniest fraction of an Alpine range. Therefore I beg you not to scorn such objections entirely, but to solve them; and not for me alone, but also for others to whom they seem quite real. For I think it is very difficult for some people,

simple though they may be, to recognize and admit that they are simple just because they know themselves to be so regarded.

**SAGR.** Indeed, the simpler they are, the more nearly impossible it will be to convince them of their own shortcomings. And on this account I think that it is good to resolve this and all similar objections, not only that Simplicio should be satisfied, but also for other reasons no less important. For it is clear that there are plenty of people who are well versed in philosophy and. the other sciences but who, either through lack of astronomy or mathematics or some other discipline which would sharpen their minds for the penetration of truth, adhere to silly doctrines like these. That is why the situation of poor Copernicus seems to me lamentable; he could expect only censure for his views and could not let them fall into the hands of anyone who, being unable to comprehend his arguments (which are very subtle and therefore difficult to master), would be convinced of their falsity on account of some superficial appearances, and would go about declaring them to be wrong and full of error. If people cannot be convinced by the arguments, which are quite abstruse, it is good to make sure that they recognize the vapidity of these objections. From such knowledge comes moderation in their judgement and condemnation of the doctrine which at present they consider erroneous. Accordingly I shall raise two other objections against the diurnal motion, which not so long ago were to be heard put forward by important men of letters, and after that we shall look into the annual motion.

The first was that if it were true that the sun and other stars did not rise over the eastern horizon, but the eastern side of the earth sank beneath them while they remained motionless, then it would follow that after a short time the mountains, sinking downward with the rotation of the terrestrial globe, would get into such a position that whereas a little earlier one would have had to climb steeply to their peaks, a few hours later one would have to stoop and descend in order to get there.

The other was that if the diurnal motion belonged to the earth, it would have to be so rapid that anyone placed at the bottom of a well would not for a moment be able to see a star which was directly above him, being able to see it only during the very brief instant in which the earth traverses two or three yards, this being the width of the well. Yet experiment shows that the apparent passage of such a star in going over the well takes quite a while--a necessary argument that the mouth of the well does not move with that rapidity which is required for the diurnal movement. Hence the earth is motionless.

**SIMP.** Of these two arguments, the second really does seem persuasive to me; but as to the first, I think I could clear that up myself. For I consider it the same thing for the terrestrial globe to move about its own center and carry a mountain eastward with it, as for the globe to stand still while the mountain was detached at the base and drawn along the earth. And I do not see that carrying the mountain over the earth's surface is an operation any different from sailing a ship over the surface of the sea. So if the objection of the mountain were valid, it would follow I ikeW` 1'se that as the ship continued its voyage and became several degrees distant from our ports, we should have to climb its mast not merely in order to ascend, but to move about in a plane, or eventually even to descend. Now this does not happen, nor have I ever heard of any sailor, even among those who have circumnavigated the globe, who had found any difference in such actions (or any others performed on board ship) because of the ship being in one place rather than another.

**SALV.** You argue very well, and if it had ever entered the mind of the author of this objection to consider how this neighoring eastern mountain of his would, if the terrestrial

globe revolved, be found in a couple of hours to have been carried by that motion to where Mt. Olympus, for example, or Mt. Carmel is now located, he would have seen that by his own line of reasoning he would be obliged to believe and admit that in order to get to the top of the latter mountains one would in fact have to descend. Such people have the same kind of mind as do those who deny the antipodes on the grounds that one cannot walk with his head down and his feet attached to the ceiling; they produce ideas that are true and that they completely understand, but they do not find it easy to deduce the simplest solutions for their difficulties. I mean, they understand very well that to gravitate or to descend is to approach the center of the terrestrial globe, and that to ascend is to depart from that; but they fail to understand that our antipodes have no trouble at all in sustaining themselves or in walking because they are just like us, having the soles of their feet toward the center of the earth and their heads toward the sky.

**SAGR.** Yet we know that men who are profoundly ingenious in other fields are blind to such ideas. This confirms what I have just said; it is good to remove every objection, even the feeblest. Therefore the matter of the well should also be answered.

**SALV.** This second argument does indeed have some elusive appearance of cogency. Nevertheless, I think it certain that if one were to interrogate the very person to whom it occurs, to the end that he might express himself better by explaining just what results ought to follow if one assumes the diurnal rotation of the earth, but which appear to him not to take place; then, I say, I believe that he would get all tangled up in explaining this question and its consequences--perhaps no less than he would disentangle it by thinking it over.

**SIMP.** To be perfectly frank, I am sure that that is what would happen, although I too find myself right now in this same confusion. For at first glance it seems to me that the argument is binding, but on the other hand I am beginning to realize that other troubles would arise if the reasoning were to continue along the same line For this extremely rapid Course, which ought to be perceived in the star if the motion belonged to the earth, should also be discovered in it if the motion were its own--even more so, since it would have to be thousands of times as fast in the star as in the earth. On the other hand, the star must be lost to sight by passing the mouth of the well, which would be only a couple of yards in diameter, if the well goes along with the earth more than two million yards per hour. Indeed, this seems to be such a transitory glimpse that one cannot even imagine it; yet from the bottom of a well a star is seen for quite a long time. So I should like to be put in the clear about this matter.

**SALV.** Now I am strongly confirmed in my belief about the confusion of the author of this objection, seeing that you too, Simplicio, becloud what you mean and do not really grasp what you should be saying. I deduce this principally from your omitting a distinction which is a principal point in this matter. So tell me whether in carrying out this experiment (I mean this one of the star passing over the mouth of the well) you would make any distinction between the well being deeper or shallower; that is, between the observer being farther from or closer to its mouth. For I have not heard you make any mention of this.

**SIMP.** The fact is that I had not thought about it, but your question has awakened my mind to it, and hints to me that such a distinction must be quite necessary. Already I begin to see that in order to determine the time of the passage, the depth of the well may perhaps make no less difference than its width.

**SALV.** Still, I rather question whether the width makes any difference to us, or very much.

**SIMP.** Why, it seems to me that having to travel 10 yards of breadth takes ten times as long as to pass I yard. I am sure that a boat 10 yards long will pass beyond my view long before a galley 100 yards long will do so.

**SALV.** So, we still persist in that inveterate idea of not moving unless our legs carry us.

What you are saying is true, my dear Simplicio, if the object you see is in motion while you remain stationary to observe it. But if you are in a well when the well and you together are carried along by the rotation of the earth, don't you see that not in an hour, nor in a thousand, nor in all eternity will you ever be overtaken by the mouth of the well? The manner in which the moving or nonmoving of the earth acts upon you in such a situation can be recognized not from the mouth of the well, but from some other separate object not sharing the same state of motion--or I should say, of rest.

**SIMP.** So far so good; but assume that I, being in the well, am carried together with it by the diurnal motion, and that the star seen by me is motionless. The opening of the well (which alone allows my sight to pass beyond) being not more than three yards, out of so many millions of yards in the balance of the terrestrial surface which are hindering my view, how can the time of my seeing be a perceptible fraction of that of my not seeing?

**SALV.** You are still falling into the same quibble, and in fact you will need someone to help you out of it. It is not the width of the well, Simplicio, which measures the time of visibility of the star, since in that case you would see it perpetually, as the well would give passage to your vision perpetually. No, the measure of this time must be obtained from that fraction of the motionless heavens which remains visible through the opening of the well.

**SIMP.** Is not that part of the sky which I perceive the same fraction of the entire heavenly sphere as the mouth of the well is of the terrestrial sphere?

**SALV.** I want you to answer that for yourself. Tell me whether the mouth of the well is always the same fraction of the earth's surface.

**SIMP.** There is no doubt that it is always the same.

**SALV.** And how about the part of the sky which is seen by the person in the well? Is that always the same fraction of the whole celestial sphere?

**SIMP.** Now I am beginning to sweep the darkness from my mind, and to understand what you hinted to me a little while ago--that the depth of the well has something to do with this matter. For I do not question that the more distant the eye is from the mouth of the well, the smaller Will be the part of the sky which it Will perceive, and consequently the sooner this will have been passed and become lost to view by whoever is looking at it from the bottom of the well.

**SALV.** But is there any place in the well from which he would perceive exactly that fraction of the celestial sphere which the mouth of the well is of the earth's surface?

**SIMP.** It seems to me that if the well were excavated to the center of the earth, perhaps from there one might see a part of the sky which would be to it as the well is to the earth. But leaving the center and rising toward the surface, an ever larger part of the sky would be revealed.

**SALV.** And finally, placing the eye at the mouth of the well, it would perceive one-half the sky, or very little less, which would take twelve hours in passing, assuming that we were at the equator. A while ago I sketched for you an outline of the Copernican system, against the truth of which the planet Mars launches a ferocious attack. For If it were true that the distances of Mars from the earth varied as much from minimum to maximum as twice the distance from the earth to the sun, then when it is closest to us its disc would have to look sixty times as large as when it is most distant. Yet no such difference is to be seen. Rather, when it is in opposition to the sun and close to us, it shows itself as only four or five times as large as when, at conjunction, it becomes hidden behind the rays of the sun.

Another and greater difficulty is made for us by Venus, which, if it circulates around the sun as Copernicus says, would be now beyond it and now on this side of it, receding from and approaching toward us by as much as the diameter of the circle it describes. Then when it is beneath the sun and very close to us, its disc ought to appear to us a little less than forty times as large as when it is beyond the sun and near conjunction. Yet the difference is almost imperceptible.

Add to these another difficulty; for if the body of Venus is intrinsically dark, and like the moon it shines only by illumination from the sun, which seems reasonable, then it ought to appear homed when it is beneath the sun, as the moon does when it is likewise near the sun--a phenomenon which does not make itself evident in Venus. For that reason, Copernicus declared that Venus was either luminous in itself or that its substance was such that it could drink in the solar light and transmit this through its entire thickness in order that it might look resplendent to us. In this manner Copernicus pardoned Venus its unchanging shape, but he said nothing about its small variation in size; much less of the requirements of Mars. I believe this was because he was unable to rescue to his own satisfaction an appearance so contradictory to his view, yet being persuaded by so many other reasons, he maintained that view and held it to be true.

Besides these things, to have all the planets move around together with the earth, the sun being the center of their rotations, then the moon alone disturbing this order and having its own motion around the earth (going around the sun in a year together with the earth and the whole elemental sphere) seems in some way to upset the whole order and to render it improbable and false.

These are the difficulties which make me wonder at Aristarchus and Copernicus. They could not have helped noticing them, without having been able to resolve them; nevertheless they were confident of that which reason told them must be so in the light of many other remarkable observations. Thus they confidently affirmed that the structure of the universe could have no other form than that which they had described. Then there are other very serious but beautiful problems which are not easy for ordinary minds to resolve, but which were seen through and explained by Copernicus; these we shall put off until we have answered the objections of people who show themselves hostile to this position.

Coming now to the explanations and replies to the three grave objections mentioned, I say that the first two are not only not contrary to the Copernican system, but that they absolutely favor it, and greatly. For both Mars and Venus do show themselves variable in the assigned proportions, and Venus does appear homed when beneath the sun, and changes her shape in exactly the same way as the moon.

**SAGR.** But if this was concealed from Copemicus, how is it revealed to you?

**SALV.** These things can be comprehended only through the sense of sight, which nature has not granted so perfect to men that they can succeed in discerning such distinctions. Rather, the very instrument of seeing introduces a hindrance of its own. But in our time it has pleased God to concede to human ingenuity an invention so wonderful as to have the power of increasing vision four, six, ten, twenty, thirty, and forty times, and an infinite number of objects which were invisible, either because of distance or extreme minuteness, have become visible by means of the telescope.

**SAGR.** But Venus and Mars are not objects which are invisible because of any distance Or small size. We perceive these by simple natural vision. Why, then, do we not discern the differences in their sizes and shapes?

**SALV.** In this the impediment of our eyes plays a large part, as I have just hinted to you. On account of that, bright distant objects are not represented to us as simple and plain, but are festooned with adventitious and alien rays which are so long and dense that the bare bodies are shown as expanded ten, twenty, a hundred, or a thousand times as much as would appear to us if the little radiant crown which is not theirs were removed.

**SAGR.** Now I recall having read something of the sort, but I don't remember whether it was in the *Solar Letters* or in *Il Saggiatore* by our friend. (note: Galileo.) It would be a good thing, in order to refresh my memory as well as to inform Simplicio, who perhaps has not read those works, to explain to us in more detail how the matter stands. For I should think that a knowledge of this would be most essential to an understanding of what is now under discussion.

**SIMP.** Everything that Salviati is presently setting forth is truly new to me. Frankly, I had no interest in reading those books, nor up till now have I put any faith in the newly introduced optical device. Instead, following in the footsteps of other Peripatetic philosophers of my group, I have considered as fallacies and deceptions of the lenses those things which other people have admired as stupendous achievements. If I have been in error, I shall be glad to be lifted out of it; and, charmed by the other new things I have heard from you, I shall listen most attentively to the rest.

**SALV.** The confidence which men of that stamp have in their own acumen is as unreasonable as the small regard they have for the judgments of others, It is a remarkable thing that they should think themselves better able to judge such an instrument without ever having tested it, than those who have made thousands and thousands of experiments with it and make them every day. But let us forget about such headstrong people, who cannot even be censured without doing them more honor than they deserve.

Getting back to our purpose, I say that shining objects, either because their light is refracted in the moisture that covers the pupil, or because it is reflected from the edges of the eyelids and these reflected rays are diffused over the pupil, or for some other reason, appear to our eyes as if surrounded by new rays. Hence these bodies look much larger than they would if they were seen by us deprived of such irradiations. This enlargement is made in greater and greater proportion as such luminous objects become smaller and smaller, in exactly such a manner as if we were to suppose a growth of shining hair, say four inches long, to be added around a circle four inches in diameter, which would increase its apparent size nine times; but ...

**SIMP.** I think you meant to say "three times," since four inches added on each side of a

circle four inches in diameter would amount to tripling its magnitude and not to enlarging it nine times.

**SALV.** A little geometry, Simplicio; it is true that the diameter increases three times, but the surface (which is what we are talking about) grows nine times. For the surfaces of circles, Simplicio, are to each other as the squares of their diameters, and a circle four inches in diameter has to another of twelve inches the same ratio which the square of four has to the square of twelve; that is, 16 to 144. Therefore it will be nine times as large, not three. This is for your information, Simplicio.

Now, to continue, if we add this coiffure of four inches to a circle of only two inches in diameter, the diameter of the crown will be ten inches and the ratio of the circle to the bare body will be as 100 to 4 (for such are the squares of 10 and of 2), so the enlargement would be twenty-five times. And finally, the four inches of hair added to a tiny circle of one inch in diameter would enlarge this eighty-one times. Thus the increase is continually made larger and larger proportionately, according as the real objects which are increased become smaller and smaller.

**SAGR.** The question which gave Simplicio trouble did not really bother me, but there are some other things about which I desire a clearer explanation. In particular I should like to team the basis upon which you affirm such a growth to be always equal in all Visible objects.

**SALV.** I have already partly explained by saying that only luminous objects increase; not dark ones. Now I shall add the rest. Of shining objects, those which are brightest in light make the greatest and strongest reflections upon our pupils, thereby showing themselves as much more enlarged than those less bright. And so as not to go on too long about this detail, let us resort to what is shown us by our greatest teacher; this evening, when the sky is well darkened, let us look at Jupiter; we shall see it very radiant and large. Then let us cause our vision to pass through a tube, or even through a tiny opening which we may leave between the palm of our hand and our fingers, clenching the fist and bringing it to the eye; or through a hole made by a fine needle in a card. We shall see the disc of Jupiter deprived of rays and so very small that we shall indeed judge it to be even less than one-sixtieth of what had previously appeared to us to be a great torch when seen with the naked eye. Afterwards, we may look at the Dog Star, a very beautiful star and larger than any other fixed star. To the naked eye it looks to be not much smaller than Jupiter, but upon taking away its headdress in the manner described above, its disc will be seen to be so small that one would judge it to be no more than one-twentieth the size of Jupiter. Indeed, a person lacking perfect vision will be able to find it only with great difficulty, from which it may reasonably be inferred that this star is one which has a great deal more luminosity than Jupiter, and makes larger irradiations.

Next, the irradiations of the sun and of the moon are as nothing because of the size of these bodies, which by themselves take up so much room in our eye as to leave no place for adventitious rays, so that their discs are seen as shorn and bounded.

We may assure ourselves of the same fact by another experiment which I have made many times--assure ourselves, I mean, that the resplendent bodies Of More vivid illumination give out many more rays than those which have only a pale light. I have often seen Jupiter and Venus together, twenty-five or thirty degrees from the sun, the sky being very dark. Venus would appear eight or even ten times as large as Jupiter when looked at with the naked eye.

But seen afterward through a telescope, Jupiter's disc would be seen to be actually four or more times as large as Venus. Yet the liveliness of Venus's brilliance was incomparably greater than the pale light of Jupiter, which comes about only because Jupiter is very distant from the sun and from us, while Venus is close to us and to the sun.

These things having been explained, it will not be difficult to understand how it might be that Mars, when in opposition to the sun and therefore seven or more times as close to the earth as when it is near conjunction, looks to us scarcely four or five times as large in the former state as in the latter. Nothing but irradiation is the cause of this. For if we deprive it of the adventitious rays we shall find it enlarged in exactly the proper ratio. And to remove its head of hair from it, the telescope is the unique and supreme means. Enlarging its disc nine hundred or a thousand times, it causes this to be seen bare and bounded like that of the moon, and in the two positions Varying in exactly the proper proportion.

Next in Venus, which at its evening conjunction when it is beneath the sun ought to look almost forty times as large as in Its morning conjunction, and is seen as not even doubled, it happens in addition to the effects of irradiation that it is sickle--shaped, and its horns, besides being very thin, receive the sun's light obliquely and therefore very weakly. So that because it is small and feeble, it makes its irradiations less ample and lively than when it shows itself to us with its entire hemisphere lighted. But the telescope plainly shows us its horns to be as bounded and distinct as those of the moon, and they are seen to belong to a very large circle, in a ratio almost forty times as great as the same disc when it is beyond the sun, toward the end of its morning appearances.

**SAGR.** Nicholas Copernicus, what a pleasure it would have been for you to see this part of your system confirmed by so clear an experiment!

**SALV.** Yes, but how much less would his sublime intellect be celebrated among the learned! For as I said before, we may see that with reason as his guide he resolutely continued to affirm what sensible experience seemed to contradict. I cannot get over my amazement that he was constantly willing to persist in saying that Venus might go around the sun and be more than six times as far from us at one time as at another, and still look always equal, when it should have appeared forty times larger.

**SAGR.** I believe then that in Jupiter, Saturn, and Mercury one ought also to see differences of size corresponding exactly to their varying distances.

**SALV.** In the two outer planets I have observed this with precision in almost every one of the past twenty-two years. In Mercury no observations of importance can be made, since it does not allow itself to be seen except at its maximum angles with the sun, in which the inequalities of its distances from the earth are imperceptible. Hence such differences are unobservable, and so are its changes of shape, which must certainly take place as in Venus. But when we do see it, it would necessarily show itself to us in the shape of a semicircle, just as Venus does at its maximum angles, though its disc is so small and its brilliance so lively that the power of the telescope is not sufficient to strip off its hair so that it may appear completely shorn.

It remains for us to remove what would seem to be a great objection to the motion of the earth.. This is that though all the planets turn about the sun, the earth alone Is not solitary like the others, but goes together in the company of the moon and the whole elemental sphere around the sun in one year, while at the same time the moon moves around the earth

every month. Here one must once more exclaim over and exalt the admirable perspicacity of Copernicus, and simultaneously regret his misfortune at not being alive in our day. For now Jupiter removes this apparent anomaly of the earth and moon moving conjointly. We see Jupiter, like another earth, going around the sun in twelve years accompanied not by one but by four moons, together with everything that may be contained within the orbits of its four satellites.

**SAGR.** And what is the reason for your calling the four Jovian planets "moons"?

**SALV.** That is what they would appear to be to anyone who saw them from Jupiter. For they are dark in themselves, and receive their light from the sun; this is obvious from their being eclipsed when they enter into the cone of Jupiter's shadow. And since only that hemisphere of theirs is illuminated which faces the sun, they always look entirely illuminated to us who are outside their orbits and closer to the sun; but to anyone on Jupiter they would look completely lighted only when they were at the highest points of their circles. In the lowest part--that is, when between Jupiter and the sun--they would appear homed from Jupiter. In a word, they would make for Jovians the same changes of shape which the moon makes for us Terrestrials.

Now you see how admirably these three notes harmonize with the Copernican system, when at first they seemed so discordant with it. From this, Simplicio will be much better able to see with what great probability one may conclude that not the earth, but the sun, is the center of rotation of the planets. And since this amounts to placing the earth among the world bodies which indubitably move about the sun (above Mercury and Venus but beneath Saturn, Jupiter, and Mars), why will it not likewise be probable, or perhaps even necessary, to admit that it also goes around?

**SIMP.** These events are so large and so conspicuous that it is impossible for Ptolemy and his followers not to have had knowledge of them. And having had, they must also have found a way to give reasons sufficient to account for such sensible appearances; congruous and probable reasons, since they have been accepted for so long by so many people.

**SALV.** You argue well, but you must know that the principal activity of pure astronomers is to give reasons just for the appearances of celestial bodies, and to fit to these and to the motions of the stars such a structure and arrangement of circles that the resulting calculated motions correspond with those same appearances. They are not much worried about admitting anomalies which might in fact be troublesome in other respects. Copernicus himself writes, in his first studies, of having rectified astronomical science upon the old Ptolemaic assumptions, and corrected the motions of the planets in such a way that the computations corresponded much better with the appearances, and vice versa. But this was still taking them separately, planet by planet. He goes on to say that when he wanted to put together the whole fabric from all individual constructions, there resulted a monstrous chimera composed of mutually disproportionate members, incompatible as a whole. Thus however well the astronomer might be satisfied merely as a calculator, there was no satisfaction and peace for the astronomer as a scientist. And since he very well understood that although the celestial appearances might be saved by means of assumptions essentially false in nature, it would be very much better if he could derive them from true suppositions, he set himself to inquiring diligently whether any one among the famous men of antiquity had attributed to the universe a different structure from that of Ptolemy's which is commonly accepted. Finding that some of the Pythagoreans had in particular attributed the diurnal rotation to the earth, and others the annual revolution as well, he began to examine

under these two new suppositions the appearances and peculiarities of the planetary motions, all of which he had readily at hand. And seeing that the whole then corresponded to its parts with wonderful simplicity, he embraced this new arrangement, and in it he found peace of mind.

**SIMP.** But what anomalies are there in the Ptolemaic arrangement which are not matched by greater ones in the Copernican?

**SALV.** The illnesses are in Ptolemy, and the cures for them in Copernicus. First of all, do not all philosophical schools hold it to be a great Impropriety for a body having a natural circular movement to move irregularly with respect to its own center and regularly around another point? Yet Ptolemy's structure is composed of such uneven movements, while in the Copernican system each movement is equable around its own center. With Ptolemy it is necessary to assign to the celestial bodies contrary movements, and make everything move from east to west and at the same time from west to east, whereas with Copernicus all celestial revolutions are in one direction, from west to east. And what are we to say of the apparent movement of a planet, so uneven that it not only goes fast at one time and slow at another, but sometimes stops entirely and even goes backward a long way after doing so? To save these appearances, Ptolemy introduces vast epicycles, adapting them one by one to each planet, with certain rules about incongruous motions--all of which can be done away with by one very simple motion of the earth. Do you not think it extremely absurd, Simplicio, that in Ptolemy's construction where all planets are assigned their own orbits, one above another, it should be necessary to say that Mars, placed above the sun's sphere, often falls so far that it breaks through the sun's orb, descends below this and gets closer to the earth than the body of the sun is, and then a little later soars immeasurably above it? Yet these and other anomalies are cured by a single and simple annual movement of the earth.

**SAGR.** I should like to arrive at a better understanding of how these stoppings, retrograde motions, and advances, which have always seemed to me highly improbable, come about in the Copernican system.

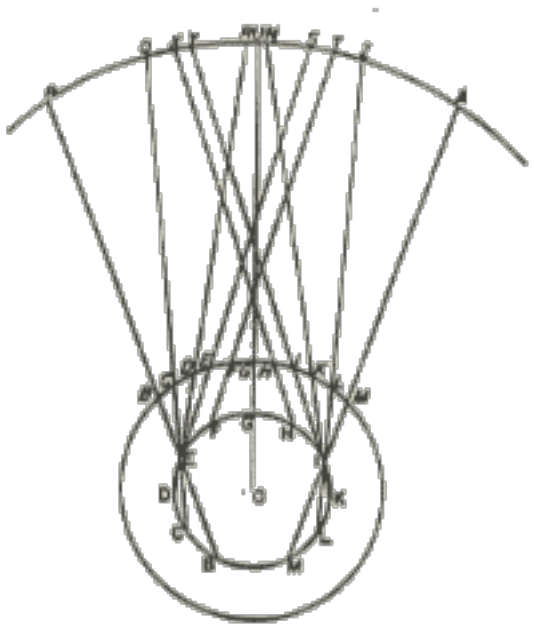

Figure 5

**SALV.** Sagredo, you will see them come about in such a way that the theory of this alone ought to be enough to gain assent for the rest of the doctrine from anyone who is neither stubborn nor unteachable. I tell you, then, that no change occurs in the movement of Saturn

in thirty years, in that of Jupiter in twelve, that of Mars in two, Venus in nine months, or in that of Mercury in about eighty days. The annual movement of the earth alone, between Mars and Venus, causes all the apparent irregularities of the five stars named. For an easy and full understanding of this, I wish to draw you a picture of it. Now suppose the sun to be located in the center 0, around which we shall designate the orbit described by the earth with its annual movement, BGM. The circle described by Jupiter (for example) in 12 years will be *BGM* here, and in the stellar sphere we shall take the circle of the zodiac to be *PUA*. In addition, in the earth's annual orbit we shall take a few equal arcs, BC, CD, DE, EF, FG, GH, H1, IK, KL, and LK and in the circle of Jupiter we shall indicate these other arcs passed over in the same times in which the earth is passing through these. These are *BC, CD, DR, EF, FG, GH, Hf, IK, KL,* and *LM,* which will be proportionately smaller than those noted on the earth's orbit, as the motion of Jupiter through the zodiac is slower than the annual celestial motion.

Now suppose that when the earth is at B, Jupiter is at *B*, then it will appear to us as being in the zodiac at *P*, along the straight line B*BP*. Next let the earth move from B to C and Jupiter from B to C in the same time; to us, Jupiter will appear to have arrived at *Q* in the zodiac, having advanced in the order of the signs from *P* to *Q*. The earth then passing to D and Jupiter to *D*, it will be seen in the zodiac at *R*; and from E, Jupiter being at *E*, it will appear in the zodiac at S, still advancing. But now when the earth begins to get directly between Jupiter and the sun (having arrived at F and Jupiter at *F*), to us Jupiter will appear to be ready to commence returning backward through the zodiac, for during the time in which the earth will have passed through the arc EF, Jupiter will have been slowed down between the points S and T, and will look to us almost stationary. Later the earth coming to G, Jupiter at *G* (in opposition to the sun) will be seen in the zodiac at *U*, turned far back through the whole arc *TU* in the zodiac; but in reality, following always its uniform course, it has advanced not only in its own circle but in the zodiac too, with respect to the center of the zodiac and to the sun which is located there.

The earth and Jupiter then continuing their movements, when the earth is at H and Jupiter is at *H*, It will be seen as having returned far back through the zodiac by the whole arc *UX*; but the earth having arrived at I and Jupiter at *I*, it will apparently have moved in the zodiac by only the small space *XY* and will there appear stationary. Then when the earth shall have progressed to K and Jupiter to *K*, Jupiter will have advanced through the arc *YN*, in the zodiac; and, continuing its course, from L the earth will see Jupiter at *L* in the point Z Finally, Jupiter at *M* will be seen from the earth at M to have passed to A, still advancing. And its whole apparent retrograde motion in the zodiac will be as much as the arc *TX*, made by Jupiter while it is passing in its own circle through the arc *FH*, the earth going through FH in its orbit.

Now what is said here of Jupiter is to be understood of Saturn and Mars also. In Saturn these retrogressions are somewhat more frequent than in Jupiter, because its motion is slower than Jupiter's, so that the earth overtakes it in a shorter time. In Mars they are rarer, its motion being faster than that of Jupiter, so that the earth spends more time in catching up with it.

Next, as to Venus and Mercury, whose circles are included within that of the earth, stoppings and retrograde motions appear in them also, due not to anv motion that really exists in them, but to the annual motion of the earth. This is acutely demonstrated by Copernicus, enlisting the aid of Apollonius of Perga, in chapter 35 of Book V in his *Revolutions*.

You see, gentlemen, with what ease and simplicity the annual motion--if made by the earth--lends itself to supplying reasons for the apparent anomalies which are observed in the movements of the five planets, Saturn, Jupiter, Mars, Venus, and Mercury. It removes them all and reduces these movements to equable and regular motions; and it was Nicholas Copernicus who first clarified for us the reasons for this marvelous effect.

But another effect, no less wonderful than this, and containing a knot perhaps even more difficult to untie, forces the human intellect to admit this annual rotation and to grant it to our terrestrial globe. This is a new and unprecedented theory touching the sun itself For the sun has shown itself unwilling to stand alone in evading the confirmation of so important a conclusion, and instead wants to be the greatest witness of all to this, beyond exception. So now hear this new and mighty marvel....

...This, Simplicio, is all that occurred to my friend and to myself regarding that which might be adduced in explanation of the appearances in defense of their opinions by the Copernicans and by the Ptolemaics. You may do with it whatever your own judgment persuades you to do.

**SIMP.** I recognize my own incapacity to take upon myself so important a decision. As to my own ideas, I remain neutral, in the hope that a time Will come when the mind will be freed by an illumination from higher contemplations than these of our human reasoning, and all the mists which keep it darkened will be swept away.

**SAGR.** Simplicio's counsel is excellent and pious, and worthy of being accepted and followed by everyone, since only that which is derived from the highest wisdom and supreme authority may be embraced with complete security. But so far as human reason is allowed to penetrate, confining myself within the bounds of theory and of probable causes, I shall indeed say (with a little more boldness than Simplicio exhibits) that I have not, among all the many profundities that I have ever heard, met with anything which is more wonderful to my intellect or has more decisively captured my mind (outside of pure geometrical and arithmetical proofs) than these two conjectures, one of which is taken from the stoppings and retrograde motions of the five planets, and the other from the peculiarities of movement of the sunspots. And it appears to me that they yield easily and clearly the true cause of such strange phenomena, showing the reason for such phenomena to be a simple motion which is mixed with many others that are also simple but that differ among themselves. Moreover they show this without introducing any difficulties; rather, they remove all those which accompany other viewpoints. So much so that I am rapidly coming to the conclusion that those who remain hostile toward this doctrine must either not have heard it or must not have understood these arguments, which are so numerous and so conclusive.

**SALV.** I do not give these arguments the status of either conclusiveness or of inconclusiveness, since (as I have said before) my intention has not been to solve anything about this momentous question, but merely to set forth those physical and astronomical reasons which the two sides can give me to set forth. I leave to others the decision, which ultimately should not be ambiguous, since one of the arrangements must be true and the other false. Hence it is not possible within the bounds of human learning that the reasons adopted by the right side should be anything but clearly conclusive, and those opposed to them, vain and ineffective.

**SAGR.** Then it is now time for us to hear the other side, from that booklet of theses or disquisitions which Simplicio has brought back with him.

**SIMP.** Here is the book, and here is the place in which the author first briefly describes the system of the world according to the position of Copernicus, saying: *Terram igitur una cum Luna lotoque hoc elementari Copernicus* etc. ("Therefore the earth, together with the moon and all this elemental world, Copernicus" etc.)

**SALV.** Wait a bit, Simplicio; for it seems to me that this author at the very outset declares himself to be very ill-informed about the position he undertakes to refute, when he says that Copernicus makes the earth together with the moon trace out the orbis magnnus in a year, moving from east to west; a thing which, as it is false and impossible, has accordingly never been uttered by Copernicus. Indeed, he makes it go in the opposite direction (I mean from west to east; that is, in the ord6r of the signs of the zodiac), so that it appears that the annual motion belongs to the sun, which 'is placed immovably in the center of the zodiac.

You see the excessive boldness of this man's self-confidence, setting himself up to refute another's doctrine while remaining ignorant of the basic foundations upon which the greatest and most important parts of the whole structure are supported. This is a poor beginning for gaining the confidence of the reader, but let us proceed.

**SIMP.** The system of the universe explained, he begins to propose his objections against the annual movement. The first of these he utters ironically, in derision of Copernicus and his followers, writing that in this fantastic arrangement of the world one must affirm the most sublime inanities: That the sun, Venus, and Mercury are beneath the earth; that heavy material naturally ascends and light stuff descends; that Christ, our Saviour and Redeemer, rose to hell and descended into heaven when He approached the sun. That when Joshua commanded the sun to stand still, the earth stood still--or else the sun moved opposite to the earth; that when the sun is in Cancer, the earth is running through Capricorn, so that the winter signs make the summer and the spring signs the autumn; that the stars do not rise and set for the earth, but the earth for them; and that the east starts in the west while the west begins in the east; in a word, that nearly the whole course of the world is turned inside out.

**SALV.** All of this is satisfactory to me except his having mixed passages from the ever venerable and mighty Holy Scriptures among these apish puerilities, and his having tried to utilize sacred things for wounding anybody who might, without either affirming or denying anything, philosophize Jokingly and in sport, having made certain assumptions and desiring to argue about them among friends.

**SIMP.** Truly he scandalized me too, and not a little; especially later, when he adds that if indeed the Copernicans answer these and the like arguments in some distorted way, they still will not be able to answer satisfactorily some things which come later.

**SALV.** Oh, that is worst of all, for he is pretending to have things which are more effective and convincing than the authority of Holy Writ. But let us, for our part, revere it, and pass on to physical and human arguments. Yet if he does not adduce among his physical arguments matters which make more sense than those set forth up to this point, we may as well abandon him entirely. I am certainly not in favor of wasting words answering such trifling tomfooleries. And as for his saying that the Copernicans do reply to these objections, that is quite false. I cannot believe that any man would put himself to such a pointless waste of time.

**SIMP.** I, too, concur in this decision, let us, then, listen to his other objections, which are more strongly supported. Now here, as you see, he deduces with very precise calculations

that if the orbit in which Copernicus makes the earth travel

Around the sun in a year were scarcely perceptible with respect to the immensity of the stellar sphere, as Copernicus says must be assumed, then one would have to declare and maintain that the fixed stars were at an inconceivable distance from us, and that the smallest of them would be much larger than this whole orbit, while others would be larger than the orbit of Saturn. Yet such bulks are truly too vast, and are incomprehensible and unbelievable.

**SALV.** I have indeed seen something similar argued against Copernicus by Tycho, so this is not the first time that I have revealed the fallacy--or better, the fallacies--of this argument, built as it is upon completely false hypotheses. It is based upon a dictum of Copernicus which is taken by his adversaries with rigorous literalness, as do those quarrelsome people who, being wrong about the principal issue of the case, seize upon some single word accidentally uttered by their opponents and make a great fuss about it without ever letting up.

For your better comprehension, know that Copernicus first explains the remarkable consequences to the various planets deriving from the annual movement of the earth; in particular the forward and retrograde movements of the three outer planets. Then he adds that these apparent mutations which are perceived to be greater in Mars than in Jupiter, from Jupiter's being more distant, and still less in Saturn, from its being farther away than Jupiter, remain imperceptible in the fixed stars because of their immense distance from us in comparison with the distance of Jupiter or of Saturn. Here the adversaries of this opinion rise up, and take what Copernicus has called "imperceptible" as having been assumed by him to be really and absolutely nonexistent. Remarking that even the smallest of the fixed stars is still perceptible, since it strikes our sense of sight, they set themselves to calculating (with the Introduction of still more false assumptions), and deduce that in Copernicus's doctrine one must admit that a fixed star is much larger than the orbit of the earth.

Now in order to reveal the folly of their entire method, I shall show that by assuming that a star of the sixth magnitude may be no larger than the sun, one may deduce by means of correct demonstrations that the distance of the fixed stars from us is sufficiently great to make quite imperceptible in them the annual movement of the earth which in turn causes such large and observable variations in the planets. Simultaneously I shall clearly expose to you a gigantic fallacy in the assumptions made by the adversaries of Copernicus.

To begin with, I assume along with Copernicus and in agreement with his opponents that the radius of the earth's orbit, which is the distance from the sun to the earth, contains 1,208 of the earth's radii. Secondly, I assume with the same concurrence and in accordance with the truth that the apparent diameter of the sun at its average distance is about one-half a degree, or 300 minutes; this is 1,800 seconds, or 108,000 third-order divisions. And since the apparent diameter of a fixed star of the first magnitude is no more than 5 seconds, or 300 thirds, and the diameter of one of the sixth magnitude measures 50 thirds (and here is the greatest error of Copernicus's adversaries), then the diameter of the sun contains the diameter of a fixed star of the sixth magnitude 2,160 times. Therefore if one assumes that a fixed star of the sixth magnitude is really equal to the sun and not larger, this amounts to saying that if the sun moved away until its diameter looked to be 1/2160th of what it now appears to be, its distance would have to be 2,160 times what it is In fact now.

This is the same as to say that the distance of a fixed star of the sixth magnitude is 2,160

radii of the earth's orbit. And since the distance from the earth to the sun is commonly granted to contain 1,208 radii of the earth, and the distance of the fixed star is, as we said, 2,160 radii of the orbit, then the radius of the earth in relation to that of its orbit is much greater than (almost double) the radius of that orbit in relation to the stellar sphere. Therefore the difference in aspect of the fixed star caused by the diameter of the earth's orbit would be little more noticeable than that which is observed in the sun due to the radius of the earth. (note: Galileo's numbers are Inaccurate, but serve the purposes of his argument; he seriously underestimated stellar distance, but nevertheless placed the stars well beyond more typical estimations made by those he proceeds to mention.)

**SAGR.** For a first step, this Is a bad fall.

**SALV.** It is indeed wrong, since according to this author a star of the sixth magnitude would have to be as large as the earth's orbit in order to justify the dictum of Copernicus. Yet assuming it to be equal only to the sun, which in turn is rather less than one ten-millionth of that orbit, makes the stellar sphere so large and distant that this alone is sufficient to remove this objection against Copernicus.

**SAGR.** Please make this computation for me.

**SALV.** The calculation is very short and simple. The diameter of the sun is 11 radii of the earth, and the diameter of the earth's orbit contains 2,416 of these radii, as both parties agree. So the diameter of the orbit contains that of the sun approximately 220 times, and since spheres are to each other as the cubes of their diameters, we take the cube of 220 and we have the orbit 10,648,000 times as large as the sun. The author would say that a star of the sixth magnitude would have to be equal to this orbit.

**SAGR.** Then their error consists in their having been very much deceived in taking the apparent diameter of the fixed stars.

**SALV.** That is the error, but not the only one. And truly I am quite surprised at the number of astronomers, and famous ones too, who have been quite mistaken in their determinations of the sizes of the fixed as well as the moving stars, only the two great luminaries being excepted. Among these men are al-Fergani, al-Battani, Thabit ben Korah, and more recently Tycho, Clavius, and all the predecessors of our Academician. For they did not take care of the adventitious irradiation which deceptively makes the stars look a hundred or more times as large as they are when seen without haloes. Nor can these men be excused for their carelessness; it was within their power to see the bare stars at their pleasure, for it suffices to look at them when they first appear in the evening, or just before they vanish at dawn. And Venus, if nothing else, should have warned them of their mistake, being frequently seen in daytime so small that it takes sharp eyesight to see it, though in the following night it appears like a great torch. I Will not believe that they thought the true disc of a torch was as It appears in profound darkness, rather than as it is when perceived in lighted surroundings; for our lights seen from afar at night look large, but from near at hand their true flames are seen to be small and circumscribed. This alone might have sufficed to make them cautious.

To speak quite frankly, I thoroughly believe that none of them--not even Tycho himself, accurate as he was in handling astronomical instruments and despite his having built such large and accurate ones without a thought for their enormous expense--ever set himself to determine and measure the apparent diameter of any star except the sun and moon. I think that arbitrarily and, so to speak, by rule of thumb some one among the most ancient astronomers stated that such-and-such was the case, and the later ones without any further

experiment adhered to what this first one had declared. For if any of them had applied himself to making any test of the matter, he would doubtless have detected the error.

**SAGR.** But if they lacked the telescope (for you have already said that our friend came to know the truth of the matter by means of that instrument), they ought to be pardoned, not accused of negligence.

**SALV.** That would be true if they could not have obtained the result without the telescope. It Is true that the telescope, by showing the disc of the star bare and very many times enlarged, renders the operations much easier, but one could carry them on without it, though not with the same accuracy. I have done so, and this is the method I have used. I hung up a light rope in the direction of a star (I made use of Vega, which rises between the north and the northeast) and then by approaching and retreating from this cord placed between me and the star, I found the point where its width just hid the star from me. This done, I found the distance of my eye from the cord, which amounts to the same thing as one of the sides which includes the angle formed at my eye and extending over the breadth of the cord....

**SALV.** Simplicio, I wish you could for a moment put aside your affection for the followers of your doctrines and tell me frankly whether you believe that they comprehend in their own minds this magnitude which they subsequently decide cannot be ascribed to the universe because of its immensity. I myself believe that they do not. It seems to me that here the situation is just as it is with the grasp of numbers when one gets up into the thousands of millions, and the imagination becomes confused and can form no concept. The same thing happens in comprehending the magnitudes of immense distances; there comes into our reasoning an effect similar to that which occurs to the senses on a serene night, when I look at the stars and judge by sight that their distance is but a few miles, or that the fixed stars are not a bit farther off than Jupiter, Saturn, or even the moon.

But aside from all this, consider those previous disputes between the astronomers and the Peripatetic philosophers about the reasoning as to the distance of the new stars in Cassiopeia and Sagittarius, the astronomers placing these among the fixed stars and the philosophers believing them to be closer than the moon. How powerless are our senses to distinguish large distances from extremely large ones, even when the latter are in fact many thousands of times the larger!

And finally I ask you, O foolish man: Does your imagination first comprehend some magnitude for the universe, which you then judge, to be too vast? If it does, do you like imagining that your comprehension extends beyond the Divine power? Would you like to imagine to yourself things greater than God can accomplish? And if it does not comprehend this, then why do you pass judgment upon things you do not understand?

**SIMP.** These arguments are very good, and no one denies that the size of the heavens may exceed our imaginings, since God could have created it even thousands of times larger than it is. But must we not admit that nothing has been created in vain, or is idle, in the universe? Now when we see this beautiful order among the planets, they being arranged around the earth at distances commensurate with their producing upon it their effects for our benefit, to what end would there then be interposed between the highest of their orbits (namely, Saturn's), and the stellar sphere, a vast space without anything in it, superfluous, and vain? For the use and convenience of whom?

**SALV.** It seems to me that we take too much upon ourselves, Simplicio, when we will have

it that merely taking care of us is the adequate work of Divine wisdom and power, and the limit beyond which it creates and disposes of nothing.

I should not like to have us tie its hand so. We should be quite content in the knowledge that God and Nature are so occupied with the government of human affairs that they could not apply themselves more to us even if they had no other cares to attend to than those of the human race alone. I believe that I can explain what I mean by a very appropriate and most noble example, derived from the action of the light of the sun. For when the sun draws up some vapors here, or warms a plant there, it draws these and warms this as if it had nothing else to do. Even in ripening a bunch of grapes, or perhaps just a single grape, it applies itself so effectively that it could not do more even if the goal of all its affairs were just the ripening of this one grape. Now if this grape receives from the sun everything it can receive, and is not deprived of the least thing by the sun simultaneously producing thousands and thousands of other results, then that grape would be guilty of pride or envy if it believed or demanded that the action of the sun's rays should be employed upon itself alone.

I am certain that Divine Providence omits none of the things which look to the government of human affairs, but I cannot bring myself to believe that there may not be other things in the universe dependent upon the infinity of its wisdom, at least so far as my reason informs me; yet if the facts were otherwise, I should not resist believing in reasoning which I had borrowed from a higher understanding. Meanwhile, when I am told that an immense space interposed between the planetary orbits and the starry sphere would be useless and vain, being idle and devoid of stars, and that any immensity going beyond our comprehension would be superfluous for holding the fixed stars, I say that it is brash for our feebleness to attempt to judge the reason for God's actions, and to call everything in the universe vain and superfluous which does not serve us.

**SAGR.** Say rather, and I think you will be speaking more accurately, "which we do not know to serve us." I believe that one of the greatest pieces of arrogance. or rather madness, that can be thought of is to say, "Since I do not know how Jupiter or Saturn is of service to me, they are superfluous, and even do not exist." Because, O deluded man, neither do I know how my arteries are of service to me, nor my cartilages, spleen, or gall, I should not even know that I had gall, or a spleen, or kidneys, if they had not been shown to me in many dissected corpses. Even then I could understand what my spleen does for me only if it were removed. In order to understand how some celestial body acted upon me (since you want ail their actions to be directed at me), it would be necessary to remove that body for a while, and say that whatever effect I might then feel to be missing in me depended upon that star.

Besides, what does it mean to say that the space between Saturn and the fixed stars, which these men call too vast and useless, is empty of world bodies? That we do not see them, perhaps? Then did the four satellites of Jupiter and the companions of Saturn come into the heavens when we began seeing them, and not before? Were there not innumerable other fixed stars before men began to see them"The nebulae were once only little white patches; have we with our telescopes made them become clusters of many bright and beautiful stars? Oh, the presumptuous, rash ignorance of mankind!

**SALV.** There is no need, Sagredo, to probe any farther into their fruitless exaggerations. Let us continue our plan, which is to examine the validity of the arguments brought forward by each side without deciding anything, leaving the decision to those who know more about it than we.

Returning to our natural and human reason, I say that these terms "large," "small" "immense," "minute," etc. are not absolute, but relative; the same thing in comparison with various others may be called at one time "immense" and at another "Imperceptible," let alone "small." Such being the case, I ask: In relation to what can the stellar sphere of Copernicus be called too vast? So far as I can see, it cannot be compared or said to be too vast except in relation to some other thing of the same kind. Now let us take the smallest thing of the same kind, which will be the orbit of the moon. If the stellar orb must be considered too vast in relation to that of the moon, then every other magnitude which exceeds some other of its kind by a similar or greater ratio ought also to be said to be too vast; and likewise, by the same reasoning, it should be said not to exist in the universe. Then the elephant and the whale will be mere chimeras and poetical fictions, because the former are too vast in comparison with ants (being land animals), and the latter in relation to gudgeons (being fish). And if actually found in nature, they would be immeasurably large; for the elephant and whale certainly exceed the ant and gudgeon in a much greater ratio than the stellar sphere does that of the moon, taking the stellar sphere to he as large as is required by the Copernican system.

Besides, how large is the sphere of Jupiter, and how great is that assigned to Saturn as the receptacle of a single star, though the planet itself is small in comparison with a fixed star! Surely if to each fixed star such a large portion of the space in the universe should be assigned as its container, that orb which contains an innumerable quantity of these would have to he made many thousands of times larger than suffices for the needs of Copernicus. Moreover, do you not call a fixed star very small--I mean even one of the most conspicuous ones, let alone those which escape our sight? And we call it so in comparison with the surrounding space. Now if the whole stellar sphere were one single blazing body, who is there that does not understand that in an infinite space there could be assigned a distance so great that, from there, such a brilliant sphere would appear as small as or even smaller than a fixed star now appears to us from the earth? So from such a point we should judge as small the very things which we now call immeasurably huge.

**SAGR.** To me, a great ineptitude exists on the part of those who would have it that God made the universe more in proportion to the small capacity of their reason than to Ms immense, His infinite, power.

**SEMP.** All this that you are saying is good, but what the other side objects to is having to grant that a fixed star must be not only equal to, but much greater than, the sun; for both are still individual bodies located within the stellar orb. And it seems to me much to the purpose that this author inquires, "To what end and use are such vast frames? Produced for the earth, perhaps? That is, for a trifling little dot? And why so remote as to appear very small and be absolutely unable to act in any way upon the earth? To what purpose such a disproportionately large abyss between these and Saturn? All these things are baffling, for they cannot be maintained by probable reasons."

**SALV.** From the questions this fellow asks, it seems to me that one may deduce that if only the sky, the stars, and their distances were permitted to keep the sizes and magnitudes which he has believed in up to this point (though he has surely never imagined for them any comprehensible magnitudes), then he would completely understand and be satisfied about the benefits which would proceed from them to the earth, which itself would no longer be such a trifling thing. Nor would these stars any longer be so remote as to seem quite minute, but large enough to be able to act upon the earth. And the distance between them and Saturn would be in good proportion, and he would have Very probable reasons for everything,

which I should very much like to have heard. But seeing how confused and contradictory he is in these few words leads me to believe that he is very thrifty with or else hard up for these probable reasons, and that what he calls reasons are more likely fallacies, even shadows of foolish fantasies. Therefore I ask him whether these celestial bodies really act upon the earth, and whether it was for that purpose that they were made of such-and-such sizes and arranged at such-and-such distances, or whether they have nothing to do with terrestrial affairs? If they have nothing to do with the earth, then it is a great folly for us Terrestrials to want to be arbiters of their sizes and regulators of their local dispositions, we being quite ignorant of all their affairs and interests. But if he says that they do act, and that it is to this end that they are directed, then this amounts to admitting what he denies in another place, and praising what he has just finished condemning when he said that celestial bodies located at such distances from the earth as to appear minuscule could not act upon it in any way. Now, my good man, in the starry sphere, which is already established at whatever distance it is, and which you have just decided is well proportioned for an influence upon terrestrial matters, a multitude of stars do appear quite small, and a hundred times as many are entirely invisible to us--which is to appear smaller than small. Therefore you must now (contradicting yourself) deny their action upon the earth, or else (still contradicting yourself) admit that their appearing small does not detract from their power to act. Or else (and this would be a frank and honest confession) you must grant and freely admit that your judgment about their sizes and distances was folly, not to say presumption or brashness.

**SIMP.** As a matter of fact, I also saw immediately, upon reading this passage, the obvious contradiction in his saying that the stars of Copernicus, so to speak, could not act upon the earth because they appeared so small, and his not noticing that he had granted action upon the earth to the stars of Ptolemy and his own, these not merely appearing small but being for the most part invisible.

**SALV.** But now I come to another point. Upon what basis does he say that the stars appear so smaII? Is it perhaps because that is the way they look to us? Does he not know that this comes about from the instrument which we use in looking at them--that is, our eyes? Or for that matter that by changing instruments we may see them larger and larger, as much as we please? Who knows; perhaps to the earth, which beholds them without eyes, they may appear quite huge and as they really are?

But it is time for us to leave these trifles and get to more important matters. I have already demonstrated two things: first, at what distance the firmament may be placed so that the diameter of the earth's orbit would make no greater variation in it than that which the terrestrial diameter makes with respect to the sun at its distance therefrom, and I then showed that in order to make a fixed star appear to us as of the size we see, it is not necessary to assume it to be larger than the sun. Now I should like to know whether Tycho or any of his disciples has ever tried to investigate in any way whether any phenomenon is perceived in the stellar sphere by which one might boldly affirm or deny the annual motion of the earth.

**SAGR.** I should answer "no" for them, they having had no need to do so, since Copernicus himself says that there is no such variation there; and they, arguing *ad hominem*, grant this to him. Then on this assumption they show the improbability which follows from it; namely, it would be required to make the sphere so immense that in order for a fixed star to look as large as it does, it would actually have to be so immense in bulk as to exceed the earth's orbit--a thing which is, as they say, entirely unbelievable. SALV. So it seems to me, and I believe that they argue against the man more in the defense of another man than out of any

great desire to get at the truth. And not only do I believe that none of them ever applied himself to making such observations, but I am not even sure that any of them knew what variation ought to be produced in the fixed stars by the annual movement of the earth, if the stellar sphere were not at such a distance that any variation in them would vanish on account of its smallness. For to stop short of such researches and fall back upon the mere dictum of Copernicus may suffice to refute the man, but certainly not to clear up the fact.

Now it might be that there is a variation, but that it Is not looked for; or that because of its smallness, or through lack of accurate instruments, it was not known by Copernicus. (note: Stellar parallax will not be detected until 1837.) This would not be the first thing that he failed to know, either for lack of instruments or from some other deficiency. Yet, grounded upon most solid theories, he affirmed what seemed to be contradicted by things he did not understand. For as already said, without a telescope it cannot be comprehended that Mars does increase sixty times and Venus forty times in one position as against another, and their differences appeared to be much less than the true ones. Yet since that time it has become certain that such variations are, to a hair, Just what the Copernican system required. Hence it would be a good thing to investigate with the greatest possible precision whether one could really observe such a variation as ought to be perceived in the fixed stars, assuming an annual motion of the earth....

**SIMP.** Really, to be quite frank, I do feel a great repugnance against having to concede the distance of the fixed stars to be so great that the alterations just explained would have to remain entirely imperceptible in them.

**SALV.** Do not completely despair, Simplicio; perhaps there is yet some way of tempering your difficulties. First of all, that the apparent size of the stars is not seen to alter visibly need not appear entirely improbable to you when you see that men's estimates in such a matter may be so grossly in error, particularly when looking at brilliant objects. Looking, for example, at a burning torch from a distance of two hundred paces, and then coming closer by three or four yards, do you believe that you yourself would perceive it as larger? For my part, I should certainly not discover this even if I approached by twenty or thirty paces; sometimes I have even happened to see such a light at a distance, and been unable to decide whether it was coming toward me or going away, when in fact it was approaching. Now what of this? If the same approach and retreat of Saturn (I mean double the distance from the sun to us) is almost entirely imperceptible, and if it is scarcely noticeable in Jupiter, what could it amount to in the fixed stars, which I believe you would not hesitate to place twice as far away as Saturn? In Mars, which while approaching us. . .

**SIMP.** Please do not labor this point, for I am indeed convinced that what you have said about the unaltered appearance of the apparent sizes of the fixed stars may very well be the case. But what shall we say to that other difficulty which arises from no variation at all being seen in their changing aspects?

**SALV.** Let us say something which will perhaps satisfy you also on this point. Briefly, would you be content if those alterations really were perceived in the stars which seem to you so necessary if the annual motion belongs to the earth?

**SIMP.** I should indeed be, so far as this particular is concerned.

**SALV.** I wish you had said that if such a variation were perceived, nothing would remain that could cast doubt upon the earth's mobility, since no counter could be found to such an

event. But even though this may not make itself visible to us, the earth's mobility Is not thereby excluded, nor its immobility necessarily proved. It is possible, Copernicus declares, that the immense distance of the starry sphere makes such small phenomena unobservable. And as has already been remarked, it may be that up to the present they have not even been looked for, or, if looked for, not sought out in such a way as they need to be; that is, with all necessary precision and minute accuracy. It is hard to achieve this precision, both on account of the imperfection of astronomical instruments, which are subject to much variation, and because of the shortcomings of those who handle them with less care than is required. A cogent reason for putting little faith in such observations is the disagreement we find among astronomers in assigning the places, I shall say not merely of novas and of comets, but of the fixed stars themselves, and even of polar altitudes, about which they disagree most of the time by many minutes.

As a matter of fact, how would you expect anyone to be sure, with a quadrant or sextant that customarily has an arm three or four yards long, that he is not out by two or three minutes in the setting of the perpendicular or the alignment of the alidade? (note: An instrument for angular measurements.) For on such a circumference this will be no more than the thickness of a millet seed. Besides which, it is almost impossible for the instrument to be constructed absolutely accurate and then maintained so. Ptolemy distrusted an armillary instrument constructed by Archimedes himself for determining the entry of the sun into the equinox.

**SIMP.** But if the instruments are thus suspect, and the observations are so dubious, how can we ever safely accept them and free them from error? I have heard great vauntings of Tycho's instruments, which were made at enormous expense, and of his remarkable skill in making observations.

**SALV.** I grant you all this, but neither the one fact nor the other suffices to make us certain in affairs of such importance. I want to have us use instruments far larger than those of Tycho's; quite precise ones, and made at minimum cost, whose sides will be four, six, twenty, thirty, or fifty miles, so that a degree is a mile wide, a minute is fifty yards, and a second is little less than a yard. In a word, we may have them as large as we please, without their costing us a thing.

Being at a villa of mine near Florence, I plainly observed the arrival of the sun at the summer solstice and its subsequent departure. For one evening at its setting it hid itself behind a cliff in the Pietrapana Mountains, about sixty miles away, leaving only a small shred of itself revealed to the north, the breadth of which was not the hundredth part of its diameter. But the following evening, at the same position of setting, it left a like part of itself showing which was noticeably thinner. This is a conclusive proof that it had commenced to move away from the tropic; yet the sun's return between the first and second observations surely did not amount to one second of arc along the horizon. Making the observation later with a fine telescope which would multiply the disc of the sun more than a thousandfold turned out to be pleasant and easy.

Now my idea is for us to make our observations of the fixed stars with similar instruments, utilizing some star in which the changes would be conspicuous. These are, as I have already explained, the ones which are farthest from the ecliptic. Among them Vega, a very large star close to the pole of the ecliptic, would be the most convenient when operating in the manner I am about to describe to you, so far as the more northern countries are concerned, though I am going to make use of another star. I have already been looking by myself for a place well adapted for such observations. The place Is an open plain, above which there rises to the

north a very prominent mountain, at the summit of which is built a little chapel facing west and east, so that the ridgepole of its roof may cut at right angles the meridian over some house situated in the plain. I wish to affix a beam parallel to that ridgepole and about a yard above it. This done, I shall seek in the plain that place from which one of the stars of the Big Dipper is hidden by this beam which I have placed, just when the star crosses the meridian. Or else, if the beam is not large enough to hide the star, I shall find the place from which the disc of the star is seen to be cut in half by the beam--an effect which can be discerned perfectly by means of a fine telescope. It will be very convenient if there happens to be some house at the place from which this event can be perceived, but if not, then I shall drive a stick firmly into the ground and affix a mark to indicate where the eye is to be placed whenever the observation is to be repeated. I shall make the first of these observations at the summer solstice, in order to continue them from month to month, or whenever I please, until the other solstice.

By means of such observations, the star's rising or lowering can be perceived no matter how small it may be. And if in the course of these operations any such variation shall happen to become known, how great an achievement will be made in astronomy' For by this means, besides ascertaining the annual motion, we shall be able to gain a knowledge of the size and distance of that same star.

**SAGR.** I thoroughly understand the whole procedure, and the operations seem to me to be so easy and so well adapted to what is wanted, that it may very reasonably be believed that Copernicus himself, or some other astronomer, has actually performed them.

**SALV.** It seems the other way around to me, for it is improbable that if anyone had tried this he would not have mentioned the result, whichever opinion it turned out to favor. But no one is known to have availed himself of this method, for the above or for any other purpose; and without a fine telescope it could not very well be put into effect.

**SAGR.** What you say completely satisfies me. Now, since quite a while remains until the night, if you want me to find any rest then, I hope it will not be too much trouble for you to explain to us those problems which a little while ago you asked us to put off until tomorrow. Please give us back the reprieve which we extended to you, and abandoning all other arguments explain to us how (assuming the motions which Copernicus attributes to the earth, and keeping immovable the sun and the fixed stars) such events may follow as pertain to the elevation and lowering of the sun, the changing of the seasons, and the inequalities of nights and days, in Just the way that is so easily understood to take place in the Ptolemaic system.

**SALV.** I must not and cannot refuse anything which Sagredo pleads for. The delay that I requested was only to give me time to rearrange in my mind the premises which are useful for a clear and comprehensive explanation of the manner in which these events take place in the Copernican as well as in the Ptolemaic system. Indeed, more easily and simply in the former than in the latter, so that it may be clearly seen that the former hypothesis is as easy for nature to put into effect as it is hard for the intellect to comprehend. Nevertheless I hope, by utilizing explanations other than those resorted to by Copernicus, to make even the learning of it very much less obscure. In order to do this, I shall set forth some assumptions as known and self-evident, as follows:

First. I assume that the earth is a spherical body which rotates about its own axis and poles, and that every point on its surface traces out the circumference of a circle, greater or lesser

according as the designated point is more or less distant from the poles. Of these circles, that one is greatest which is traced out by a point equidistant from the poles. All these circles are parallel to one another, and we shall refer to them as *parallels*.

Second. The earth being spherical in shape and its material being opaque, half its surface is continually lighted and the rest is dark. The boundary which separates the lighted part from the dark being a great circle, we shall call this the boundary circle of light.

Third. When the boundary circle of light passes through the earth's poles It will cut all the parallels into equal sections, it being a great circle; but, not passing through the poles, it will cut them all into unequal parts except the central circle; this, being also a great circle, will be cut into equal parts in any case.

Fourth. Since the earth turns about its own poles, the length of day and night is determined by the arcs of the parallels cut by the boundary circle of light. The arc which remains in the illuminated hemisphere determines the length of the day, and the remainder that of the night.

These things being set forth, we may wish to draw a diagram for a clearer understanding of what comes next. (Fig. 6) First let us indicate the circumference of a circle, to represent for us the orbit of the earth, described in the plane of the ecliptic. This we may divide by two diameters into four equal parts; Capricorn, Cancer, Libra, and Aries, which shall here represent at the same time the four cardinal points; that is, the two solstices and the two equinoxes. And in the center of this circle, let us denote the sun, O, fixed and immovable

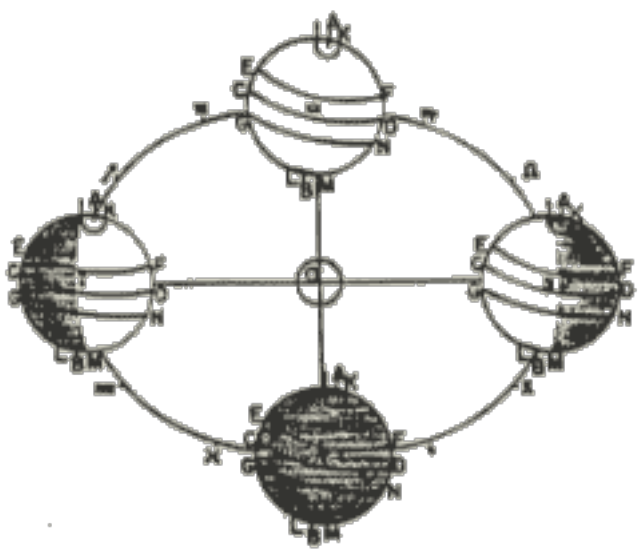

**Figure 6**

Now with the four points Capricorn, Cancer, Libra, and Aries as centers, we shall draw four equal circles which to us will represent the earth at these four different seasons. The center of the earth travels in the space of a year around the whole circumference Capricorn-Aries-Cancer Libra,) moving from west to east in the order of the signs of the zodiac. It is already evident that when the earth is in Capricorn the sun Will appear in Cancer, the earth moving along the arc from

Capricorn to Aries, the sun will appear to be moving along the arc from Cancer to Libra. In a word, it will run through the signs of the zodiac in their order during the space of a year. So with this first assumption, the apparent annual motion of the sun around the ecliptic is

satisfied beyond any argument.

Coming now to the other movement-that is, the diurnal motion of the earth about itself--its poles and axis must be established. These must be understood to be not perpendicularly erect to the plane of the ecliptic; that is, not parallel to the axis of the earth's orbit, but inclined from right angles about twenty-three and one-half degrees, with the North Pole toward the axis of the earth's orbit when the center of the earth is at the solstitial point in Capricorn Assuming, then, that the center of the terrestrial globe Is at that point, let us indicate the poles and the axis AB, tilted twenty-three and one-half degrees from the perpendicular on the Capricorn-Cancer diameter, so that the angle A-Capricorn-Cancer amounts to the complement, or sixty-six and one-half degrees, and this inclination must be assumed to be immutable. We shall take the upper pole, A, to be the north, and the other, B, the south.

If the earth is assumed to revolve about its axis AB in twenty-four hours, also from west to east, circles parallel to one another will be described by all points noted on its surface. In this first position of the earth, we shall designate the great circle CD and the two which are twenty-three and one-half degrees from it--EF above, and GN below--and these others at the two extremes, 1K and LM, at a similar distance from the poles A and B; and we could have drawn countless other circles parallel to these five, traced by innumerable points on the earth. Let us now assume that the earth is transported by the annual motion of its center to the other positions already marked, passing to them according to the following laws: That its own axis AB not only does not change its inclination to the plane of the ecliptic, but that it does not vary its direction, either; remaining thus always parallel to itself, it points continually toward the same parts of the universe, or let us say of the firmament. This means that if we imagine the axis to be prolonged, it would describe with its upper end a circle parallel and equal to the earth' s orbit through Libra, Capricorn, Aries, and Cancer, as the upper base of a cylinder described by itself in its annual motion upon the lower base, Libra-Capricorn-Aries-Cancer. Hence, because of this unchanging tilt, let us draw these other three figures around the centers of Aries, Cancer, and Libra, exactly similar to the one drawn around the center of Capricorn.

Next let us consider the first diagram of the earth. Because of the axis AB being inclined at twenty-three and one-half degrees toward the sun, and since the arc Al is also twenty-three and one-half degrees, the light of the sun illumines the hemisphere of the terrestrial globe exposed to the sun (of which only half is seen here), divided from the dark part by the boundary of light, IM The parallel CD, being a great circle, will be divided into equal parts by this, but all others will be cut into unequal parts because the boundary of light W does not pass through the poles A and B. The parallel IK together with all others described between it and the pole A, will be entirely within the illuminated part, just as on the other hand the opposite ones toward the pole B and contained within the parallel LM will remain in the dark.

Besides this, since the arc Al is equal to the arc FD, and the arc AF is common to IKF and AFD, the latter two are equal, each being one quadrant; and since the whole arc IFM is a semicircle, the arc MF will also be a quadrant and equal to FKI. Hence the sun, 0, in this position of the earth, will be vertical to anyone. at the point F. But through the diurnal revolution around the fixed axis AB, all points on the parallel EF pass through this same point F, and therefore on such a day the sun at midday will be overhead to all inhabitants of the parallel EF; and to them it will seem to describe by its motion that circle which we call the tropic of Cancer.

But to the inhabitants of all parallels above the parallel EF toward the North Pole, A, the sun is below their zenith toward the south. On the other hand, to all inhabitants of the parallels below EF toward the equator CID and the South Pole B, the midday sun is elevated above the zenith toward the North Pole, A.

Next you may see how of all parallels, only the great circle CD is cut into equal parts by the boundary of light IM, the others above and below this all being cut into unequal parts. Of the upper ones, the semidiurnal arcs (which are those in the part of the earth lighted by the sun) are greater than the seminocturnal ones, which remain in the dark. The contrary happens for the remainder which are beneath the great circle CD toward the pole B; of these, the semidiurnal arcs are smaller than the seminocturnal. Also you may see quite plainly that the differences of these arcs go on increasing as the parallels become closer to the poles, until the parallel IK stays entirely in the lighted part, and its inhabitants have a twenty-four-hour day without night. In contrast to this the parallel LM, remaining all in the dark, has a night of twenty-four hours without day.

Next let us proceed to the third diagram of the earth, here placed with its center at the Cancer point, from which the sun would appear to be at the first point of Capricorn. It Is indeed easy to see that as the axis AB has not changed its tilt, but has remained parallel to itself, the appearance and situation of the earth are precisely the same as in the first diagram, except that the hemisphere which in the first was lighted by the sun remains in shadow here, and the one which was previously dark now becomes illuminated. Hence what occurred in the first diagram is now reversed with respect to the differences of days and nights and their relative length or shortness.

The first thing noticed is that where in the first figure, the circle 1K was entirely in the light it is now all in the dark; and LM, which opposite, is now entirely in the light, where it was previously completely in shadow. Of the parallels between the great circle CD and the pole A, the semidiurnal arcs are now smaller than the seminocturnal, which is the opposite of the first; and of the others toward the pole B, the semidiurnal arcs are now longer than the seminocturnal, likewise the opposite of What took place in the other position of the earth. You may now see the sun made vertical to the inhabitants of the tropic GN, and for those of the parallel EF it is depressed southward through the entire arc ECG; that is, forty-seven degrees. It has, in short, gone from one tropic to the other, passing through the equator, being raised and then dropped along the meridian through the said interval of forty-seven degrees. This entire change has its origin not in any dropping or rising of the earth; on the contrary, in its never dropping nor rising, but in generally keeping itself always in the same location with respect to the universe and merely going around the sun, which is situated at the center of this same plane in which the earth moves around it in the annual motion.

Here a remarkable phenomenon must be noticed, which is that just as the preservation of the axis of the earth in the same direction with respect to the universe (or let us say toward the highest fixed stars) makes the sun appear to us to rise and fall by as much as forty-seven degrees without any rise or drop in the fixed stars at all, so if on the contrary the earth's axis were continually kept at a given inclination toward the sun (or we might say toward the axis of the zodiac), no alteration of ascent or descent would appear to be made by the sun. Thus the inhabitants of a given place would always have the same periods of night and day, and the same kind or season; that is, some people would always have Writer, some always summer, some spring, etc. But on the other hand, the changes in the fixed stars with regard to rising and falling would then appear enormous to us, amounting to this same forty-seven degrees. For an understanding of this let us go back to a consideration of the position of the

earth in the first diagram, where the axis AB is seen with its upper pole A tilted toward the sun. In the third figure the same axis has kept the same direction toward the highest sphere by remaining parallel to itself, so the upper pole A no longer tilts toward the sun but tilts away from it, and lies forty-seven degrees from its first position. Thus, in order to reproduce the same inclination of the pole A toward the sun, it would be required (by turning the globe along its circumference ACBD) to take it forty-seven degrees toward E; and any Fixed star observed on the meridian would be raised or lowered by that many degrees. Now let us proceed with an explanation of the rest, and consider the earth placed in the fourth diagram with its center at the first point of Libra, the sun appearing in the beginning of Aries. Thus the earth's axis, which in the first diagram was assumed to be inclined to the Capricorn-Cancer diameter and hence to be in the same plane as that which cuts the earth's orbit perpendicularly in the Capricorn-Cancer line, when transferred to the fourth figure (being kept always parallel to itself, as we have said), comes to be in a plane which is likewise vertical to the plane of the earth's orbit, and parallel to the one which cuts the latter at right angles along the Capricorn-Cancer diameter. Hence the line from the center of the sun to the center of the earth (from 0 to Libra) Will be perpendicular to the axis BA. But this same line from the center of the sun to the center of the earth is always perpendicular also to the boundary circle of light; therefore this same circle will pass through the poles A and B in the fourth figure, and the axis AB will lie in its plane. But the great circle, passing through the poles of the parallels, will divide them all into equal parts, therefore the arcs IK EF, CD, GN, and LM will all be semicircles, and the lighted hemisphere will be this one which faces us and the sun, and the boundary circle of light will be this very circumference ACBD. And when the earth is at this place, the equinox will occur for all its inhabitants.

The same Will happen in the second diagram, where the earth having its lighted hemisphere toward the sun shows to us its dark side with the nocturnal arcs. These are also all semicircles, and consequently also make an equinox. Finally, since the line produced from the center of the sun to the center of the earth is perpendicular to the axis AB, to which likewise the great circle CD among the parallels is perpendicular, the same line O--Libra necessarily passes through the same plane as the parallel CD, cutting its circumference in the center of the daytime arc CD; therefore the sun will be vertical to anyone located in that cut. But all inhabitants of that parallel pass by there, carried by the earth's rotation, and have the midday sun directly overhead; therefore the sun will appear to all inhabitants of the earth to be tracing out the greatest parallel, called the equatorial circle.

Moreover, the earth being at either of the solstitial points, one of the polar circles IK or LM is entirely in the light and the other in the shadow; but when the earth is at the equinoctial points, half of each of these polar circles is in the light and the balance in the dark. It should not be hard to see how the earth in passing, for example, from Cancer (where the parallel IK is entirely dark) to Leo, a part of the parallel IK toward the point I will commence to enter the light, and the boundary of light IM will begin to retreat toward the poles A and B, cutting the circle ACBD no longer at I and M, but in two other points failing between the endpoints I, A, M, and B, of the arcs IA and MB. Thus the inhabitants of the circle IK begin to enjoy the light, and those of the circle LM to experience the darkness.

See, then, how two simple noncontradictory motions assigned to the earth, performed in periods well suited to their sizes, and also conducted from west to east as in the case of all movable world bodies, supply adequate causes for all the visible phenomena. These phenomena can be reconciled with a fixed earth only by renouncing all the symmetry that is seen among the speeds and sizes of moving bodies, and attributing an inconceivable velocity to an enormous sphere beyond all the others, while lesser spheres move very

slowly. Besides, one must make the motion of the former contrary to that of the latter, and to increase the improbability, must have the highest sphere transport all the lower ones opposite to their own inclination. I leave it to your judgment which has the more likelihood in it.

**SAGR.** For my part, so far as my senses are concerned, there is a great difference between the simplicity and ease of effecting results by the means given in this new arrangement and the multiplicity, confusion, and difficulty found in the ancient and generally accepted one. For if the universe were ordered according to such a multiplicity, one would have to remove from philosophy many axioms commonly adopted by all philosophers. Thus it is said that Nature does not multiply things unnecessarily; that she makes use of the easiest and simplest means for producing her effects; that she does nothing in vain, and the like.

I must confess that I have not heard anything more admirable than this, nor can I believe that the human mind has ever penetrated into subtler speculations. I do not know how it looks to Simplicio.

**SIMP.** If I must tell you frankly how it looks to me, these appear to me to me some of those geometrical subtleties which Aristotle reprehended in Plato when he accused him of departing from sound philosophy by too much study of geometry. I have known some very great Peripatetic philosophers, and heard them advise their pupils against the study of mathematics as something which makes the intellect sophistical and inept for true philosophizing; a doctrine diametrically opposed to that of Plato, who would admit no one into philosophy who had not first mastered geometry.

**SALV.** I endorse the policy of these Peripatetics of yours in dissuading their disciples from the study of geometry, since there is no art better suited for the disclosure of their fallacies. You see how different they are from the mathematical philosophers, who much prefer dealing with those who are well informed about the general <--The Third Day 81--> Peripatetic philosophy than with those who lack such information and because of that deficiency are unable to make comparisons between one doctrine and the other.

But setting all this aside, please tell me what absurdities or excessive subtleties make this Copernican arrangement the less plausible so far as you are concerned.

**SIMP.** As a matter of fact, I did not completely understand it, perhaps because I am not very well versed either in the way the same effects are produced by Ptolemy--I mean these planetary stoppings, retrograde movements, approaches and retreats, lengthenings and shortenings of the day, alterations of the seasons, etc. But passing over the consequences which stem from the basic assumptions, I feel no small difficulties to exist in these assumptions themselves, and if the assumptions fall to the ground then they bring the whole structure into ruin. Now since the whole framework of Copernicus seems to me to be built upon a weak foundation (being supported upon the mobility of the earth), then if this were removed, there would be no room for further argument. And to remove it, Aristotle's axiom that to a simple body only one simple motion can be natural appears to be sufficient. Here three movements, if not four, are assigned to the earth, a simple body; and all of them are quite different from one another. For besides the straight motion toward the center, which cannot be denied to it as a heavy body, there are ascribed to it a circular motion in a great circle around the sun in one year, and a whirling upon itself every twenty-four hours, and (what is most extreme, and possibly for that reason you have remained silent about this) another whirling about its own center, completed in a year, and opposite to the previously

mentioned twenty-four-hour motion. My mind feels a great repugnance to this....

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