THE LOGICAL STRUCTURE OF GALILEO'S *DIALOGUE*: A CASE STUDY IN APPLIED LOGIC

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Abstract

By a detailed analysis of Galileo's *Dialogue*, it is shown in what way its logical structure is that of a complex argument whose conclusion is the proposition that the earth moves: virtually every idea and every argument found in the book can be integrated into this main argument by interpreting them, respectively, as premises or intermediate conclusions, and as sub-arguments of the main argument. This is shown by providing an outline with page reference to several editions of the *Dialogue*, and an Analytical Summary containing, for every subdivision in the book, a reconstruction of its main argument or a statement of its main conclusion. The Analytical Summary is preceded by introductory remarks designed to justify and explain the philosophical desirability and the scholarly-historical need of this type of analysis and the various features and interrelations of the outline and Summary. Some concluding remarks mention a number of historical and philosophical interpretations suggested by this analysis.

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I

Several philosophers have recently emphasized the desirability of using logical analysis for the understanding and evaluation of actual arguments in natural languages (1). The following investigation is a contribution to this neglected part of logic. The actual argument in question is the one contained in Galileo Galilei's *Dialogue Concerning the Two Chief World Systems*, the book first published in 1632 for which Galileo was tried by the Inquisition. My detailed and textually grounded reconstruction of the *Dialogue* suggests that this book has more structure and unity than Galilean scholars have been inclined to feel (2). Moreover, the fact that such a classic of scientific literature is susceptible to the logical analysis given below suggests that scientific method is, at least in some ways, more logical than often conceived (3). Since this sense of «logical» is that of the theory and practice of reasoning, this

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(1) Stephen TOULMIN, *The Uses of Argument* (Cambridge: University Press, 1958), especially pp. 253-59; Yehoshua Bar-Hillel, «A Neglected Recent Trend in Logic,» *Logique et Analyse*, 39(1967): 235-38; idem, «Comments,» in J. F. Staal, (ed.), «Formal Logic and Natural Languages (A Symposium),» *Foundations of Language*, 5(1969): 256-84; Michael Scriven, *Reasoning* (New York: McGraw-Hill, 1976, especially p. xv; and P. T. Geach, *Reason and Argument* (Oxford: Basil Blackwell, 1976)

(2) See, for example, Giorgio de SANTILLANA, *The Crime of Galileo* (Chicago: University of Chicago Press, 1955), p. 174.

(3) In such works as Thimas S. KUHN, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962 and 1970), and Paul K. Feyerabend, *Against Method* (Atlantic Highlands, N. J.: Humanities Press, 1975. For further evidence of the logical character of scientific inquiry, see my «Galileo as a Logician,» *Physis*, 16(1974): 129-48.

also means that science is more «rhetorical» than often conceived, in the sense of the term that equates rhetoric with the general theory of argumentation (4).

The logical structure of the *Dialogue* is that of an argument designed to show that the earth moves. The critiques of the various geostatic arguments can be easily integrated into such an argument as follows. Those critiques are designed to show that there are no sound reasons for thinking it false that the earth moves, or ontologically expressed, that there is no real evidence against the earth's motion. The reconstructed argument would then start as follows: We may conclude that the earth moves since there is no real evidence or sound reasons against its notion while there is considerable evidence and various reasons in its favor. The former is true because all arguments against the earth's motion are incorrect; the latter is true because there are sound arguments for the earth's motion. Then would come all the details of the arguments for and against the earth's motion, in such a way that virtually every main topic mentioned in the book would be integrated into this main argument.

However it will be almost impossible to appreciate this integration, or to understand the details of the argument, or to give a statement of it, or to check its accuracy, without some fairly precise way of referring to the various portions of the book. What is needed is an outline, something that historians and scholars also need, for their own reasons. So, I have constructed the Analytical Summary given below with page references to the standard scholarly edition by Antonio Favaro (5), to Stillman Drake's English translation (6), and to Pietro Pagnini's edi-

(4) I take this to be the sense of the concept elaborated in Ch. PERELMAN and L. OLBRECHTS-TYTECA, *The New Rhetoric: A Treatise on Argumentation* (Translated by J. Wilkinson and P. Weaver. Notre Dame: University of Notre Dame Press, 1969).

(5) Galileo GALILEI, *Dialogo sopra i due massimi sistemi* (Vol. vii of *Opere*. 20 volumes edited by A. Favaro Florence: Barbera, 1890-1909 and later editions).

(6) Galileo GALILEI, *Dialogue Concerning the Two Chief World Systems* (Translated by S. Drake. Berkeley: University of California Press, 1953 and later editions).

tion (7), which is the most valuable and easily available one in Italian. The various subdivisions are partly grounded on the book's literary structure and so will remain unaffected by possible changes in the headings; good examples of this are IIC and IIIA. The subdivisions are also grounded on the subject matter or topical unity of a given section, and the various headings are usually descriptions of this subject matter; a good example of this is ICI, 2, 3, and 4. Moreover, both the headings and the subdivisions are partly grounded on the logical unity, clarity, or beauty of the various paragraphs making up the Analytical Summary. However, it is primarily the analytical summaries that originate from the subdivisions. It should be noted that the headings are in every instance the grammatical subjects of the first (or only) sentence in the corresponding paragraph of the Summary. The Analytical Summary constitutes my reconstruction of the main steps of the argument in the *Dialogue*. It thus defines what may be called the logical structure of this work. Of course, many paragraphs of the summary could themselves be expanded in such a way as to integrate (and thus number) almost literally every proposition in the book.

My Analytical Summary is thus open-ended in a downward direction, so to speak. That is, there are many subarguments (long, complex, important, and interesting arguments) of which I have stated only the conclusion in order to use it as a premise of the subarguments that I did state. It is clear, however, that this open-endedness does not make the summary incomplete but is a necessity because a summary should be a summary and not a complete reconstruction. An Analytical Reconstruction of the *Dialogue* would include the whole iceberg of which my Analytical Summary is the tip. Since it is obvious that the various paragraphs of my Analytical Summary vary in logical complexity (some even being mere propositions, not arguments) I should mention that I have followed rather rigorously a criterion of comprehensibility in deciding how

(7) Galileo GALILEI, *Dialogo dei messimi sistemi* (Volumes ii and iii of *Opere*. 5 volumes edited by P. Pagnini. Florence: Salani, 1964).

much to include. That is, I have left out the reasoning and stated merely the conclusion in those sections where the reasoning is either too complicated or too controversial or relatively easy. Examples of excessive complexity are IA3, IB3, IIB6; examples of controversy are IA3, IIB2c; examples of relative ease are IB2, IC1, IVB3. In some cases (e.g., IIB2a, IIB3e), I have given reasoning which is relatively complex because it is particularly beautiful and it is in part this logical beauty that justifies making that portion of the text into a distinct subdivision.

Besides being thus open ended in a downward direction, my Analytical Summary is open-ended in an upward direction, namely insofar as it leaves undetermined other steps in the over-all argument which are not too explicit in the text and which would serve to ingerate into it those sections which are not as obviously relevant as the examination of the objections and the statement of the favorable arguments. The sections I am referring to primarily are IIIA and I. In summarizing IIIA1, IIIA2, and IIIA3 as I have in IIIA, I have already taken a step toward integrating into the main argument this section of the *Dialogue* which at first looks like a digression. However, it would have been inaccurate as a summary to go too far in that direction; but as part of what might be called the latent structure we could add the following intended consequence: Hence it is not improper to consider astronomical evidence nonquantitatively (as it is done in IIIB1, IIIB2, and IIIB3). The relevance of the First Day (I) is more or less obvious. It is an examination of the main conceptual objections to the earth's motion, and this can be made clear by the following argument: The earth's motion is not a conceptual impossibility because neither the objection from natural motion nor the objection from the earth-heaven distinction is sound. The objection from natural motion is that the natural motion of the earth parts is straight toward the center of the universe (and hence the whole earth stands still therein); this objection is groundless because the empirical argument that the earth parts move toward the center of the universe is circular (IA4) and because any conceptual justification of the same premise would involve all the

problems besetting the concept of natural straight motion (IA2, IA3). The objection from the earth-heaven distinction is that the earth's annual motion would involve the conceptual absurdity of placing the earth in (the third) heaven; this objection is groundless because the earth-heaven distinction is untenable and false (IB, IC).

Finally, in my Analytical Summary I have used some semi-technical terminology which it will be good to explain briefly. *The objection from A* (where *A* is a noun phrase) refers to the argument from *A* against *B* (where it is contextually obvious what *B* is). *The argument from A* refers to the argument whose main premise is some proposition *p(A)* constructed from *A* (in a contextually obvious manner) and whose conclusion is some proposition *p(B)* whose identity is contextually obvious and unproblematic. For example, in the argument from the motion of sunspots: *A* is the motion of sunspots; *B* is the earth's annual motion; *p(A)* is the proposition that sunspots move as described in (a), (b) and (c) of IIIB3 in the Summary; and *p(B)* is the proposition that the earth has the annual motion, *The argument from A is false* means that the proposition *p(A)*, constructed from *A* in a contextually obvious and unproblematic way, is false. *The argument from A is groundless* means that the proposition *p(A)* is not in the context supported by any sound argument. *The argument from A is invalid* means that, whether or not *p(A)* is true, it does not support the conclusion of the argument. *The argument from A is unsound* means that the argument from *A* is false, groundless, invalid, and/or subject to some other problem.

II

ANALYTICAL SUMMARY

I. First Day: The Unity of the World (33/9/93) ([8])

([8]) These paranthetical references within the Analytical Summary denote the beginning page of each subdivision. The three sets of numbers correspond respectively to the pagination found in Favaro's edition, in Drake's translation, and in Pagnini's edition.

A. *Natural motions* are the same for all bodies (33/9/93).

1. *The perfection of the world* is better grounded on its being the work of God rather than on its three-dimensionality (33/9/93).
2. *Aristotle's classification of motions* into straight and circular, simple and mixed, and natural and violent is untenable *because* (a) his equation of natural circular motion with motion around the center, and of natural straight motion with motion toward or away from the center, is conceptually unjustified (and *hence* prejudicial); (b) his idea of mixed motion is incoherent; and (c) his distinction between simple and mixed motion is viciously circular (38/14/101).
3. *Straight and circular motions* are not two distinct instances of (simple) natural motion but rather two different stages of natural motion: straight motion can be acquired naturally but cannot naturally continue forever, whereas circular motion can naturally continue forever but cannot be acquired naturally without straight motion (43/19/108).
4. *The evidence from the senses,* namely the up and down motion of terrestrial bodies, constitutes a methodologically significant but ultimately unsound objection to the idea of natural circular motion; it is methodologically significant *because* the idea seems to conflict with that evidence (and *hence* to violate one of the fundamental principles of philosophizing); and it is ultimately unsound *because* that up and down motion is likely to be either not straight or not natural or not peculiar to the earth. It may not be straight *because* the fact that it appears to be straight does not imply that it really is straight (as it will be shown later). It may not be natural *because* it has not been shown to be toward and away from the center of the universe, and it is more likely to be primarily toward and away from the center of the earth. And it may not be peculiar

to the earth *because* that motion is likely to exist on each of the celestial bodies (57/32/129).

B. *The terrestrial-celestial dichotomy* is untenable and false (62/38/138).

1. *The argument from contrariety* is that celestial and terrestrial bodies are very different because change derives only from contrariety, contrariety exists only among terrestrial bodies, and hence change exists only among terrestrial bodies. It uses an assumption (namely, the connection between change and contrariety) which is more questionable than its main intended consequence (namely, the motionlessness of the earth). It may be self-contradictory *because* it implies that celestrial bodies are changeable as well. It is groundless to the extent that the contrariety of rarity and density exists among celestial bodies and insofar as the contrariety of straight-up and straight-down does not exist among terrestrial bodies only. And it is ambiguous *because* the various mentioned «bodies» sometimes refer to *whole* bodies, sometimes to *parts* of bodies (62/38/138).
2. *The a posteriori justification* of the unchangeability of the sky is that no celestial changes have ever been observed, and it is both invalid and factually false (71/47/151).
3. *The teleological argument* for the unchangeability of the sky is that celestial changes would be superfluous and useless, and it is unsound (83/58/169).

C. *The moon and the earth* do not differ in their nature (87/62/175).

1. *Similarities* between the moon and the earth include: shape, darkness and opacity, solidity, uneveness of

apparent brightness, phases, reciprocal illumination, and reciprocal eclipsing (87/62/175).

2. *The roughness of the lunar surface* may be justified by the fact that it is visible at all and by its mountainous appearance through the telescope (95/71/189).
3. *The reflecting power of the earth* may be justified by the fact that during daylight both terrestrial objects and the moon appear equally bright and that during the night the moon has a secondary light (whose cause can only be the light reflected by certain parts of the earth) [112/87/213].
4. *Differences* between the moon and the earth do exist *because* the moon has (a) no water, (b) a night-and-day period of one month, (c) no significant seasons, and (d) no rain, and *hence* no life similar to ours. Other unimaginable differences are bound to exist *because* the human mind cannot pretend to be a measure of what can occur in nature (124/98/229).

II. Second day: The Earth's Diurnal Motion (132/106/255)

A. *The problem* with the idea of the earth's motion is that it goes counter to Aristotle's authority, that the arguments favoring it though plausible are indirect and only probable, and that there are apparently insuperable objections to it (132/106/255).

1. *Aristotle's authority* deserves respect but is abused and harmed by his followers *because* they accept blindly and construe prejudicially his words; what is needed in the philosophical search for truth is not an authority but rather independent-mindedness (132/106/255).
2. *The arguments in favor* of the earth's diurnal motion are plausible but merely probable *because*

they derive from the problems besetting the contrary view, namely that a celestial diurnal motion would (a) violate the principle of simplicity, (b) imply that each planet has two contrary circular motions, (c) violate the law of periods of revolution, (d) imply that the fixed stare have incongrously unequal orbits and velocities, (e) imply that each fixed star keeps on changing its orbit and velocity, (f) make it inexplicable why the circular motion transferred from one celestial sphere to the one below it is not transferred to the earth, and (g) force the Aristotelians to postulate the existence of a fictitious *primum mobile* (139/114/266).

3. *The objections* to the earth's diurnal motion are numerous and apparently conclusive, and *hence* great open-mindedness and great rational-mindedness are required for their refutation (150/124/283).

B. *Examination of the classical* objections to the earth's diurnal motion shows that all the phenomena alleged as counterevidence would happen the same way whether the earth is rotating or standing still (159/133/296).

1. *Aristotle's first two arguments* (from violent motion and from the doubleness of circular motions) are equivocations, the first *because* the clause «the parts of the earth would also move circularly» can mean either that those parts would move around their own centers or else that they would move around the earth's center, the second *because* its conclusion could be a denial either of the diurnal motion or of the annual motion (159/133/296).
2. *Falling bodies* provide no evidence against the motion of the earth but rather provide the basis for a new concept of motion, according to which motion has the properties of conservation and composition (164/138/303).

a. *The objection from vertical fall* is either circular or invalid *because* if it is stated in terms of *actual* vertical fall then it depends on the assumption that apparent vertical fall implies *actual* vertical fall (which is true if and only if the earth stands still), and if it is stated in terms of *apparent* vertical fall then it depends on the invalid argument that the nonoccurrence of mixed motion on a moving ship implies its physical impossibility (164/138/303).

b. *The ship analogy argument* is false *because* the body falls at the foot of the mast even when the ship is moving (169/143/310).

c. *Conservation and composition of motion* are two properties suggested by the criticism of the objection from falling bodies; they mean that motion is conserved if undisturbed and that it may be mixed without its components interfering with each other; and such a concept of motion can be further justified as follows: (1) it is the one required for adequately solving the problem of the cause of projectible motion, (2) it has interesting and novel consequences concerning the motion of projectiles, (3) it can explain certain puzzling facts about projectiles, and (4) it fits well with the idea of natural circular motion (175/149/318).

3. *Projectiles* provide no evidence against the motion of the earth but rather illustrations of the new concept of motion with the properties of conservation, composition, and relativity (193/167/345).

a. *East-west gunshots* provide no evidence against the earth's motion *because* on a rotating earth the range of gunshots in one such direction would still be equal to the range in the opposite direction (193/167/345).

b. *The relativity of motion* is the concept which shows that there would be no denial of the senses if bodies were regarded to move transversal-

ly in reality while they were seen to fall vertically (197/171/350).

c. *Vertical gunshots* provide no evidence against the earth's motion *because* their horizontal motion on a rotating earth would be conserved; rather they provide a clear illustration of the composition of motion (200/174/354).

d. *North-south gunshots* provide no evidence against the earth's motion, but not *because* shooting on a rotating earth is analogous to hunters' shooting at birds, rather *because* on a rotating earth the cannon ball would have the same eastward speed as the target (203/178/359).

e. *Point-blank gunshots* provide no evidence against the earth's motion primarily *because* computation shows that the alleged deviation would be imperceptibly small (and *hence* there is no way of knowing that such gunshots are *not* in fact high toward the east and low toward the west), but also *because* on a rotating earth the gun as well as the target is rising (or falling) at the same rate (and *hence* the cannon ball would have the same motion, up or down with respect to the fixed tangent, as the target), and *because* one could argue equally plausibly that if the earth stood still such gunshots would *then* be high toward the west and low toward the east (205/180/362).

4. *The flight of birds* is the basis of a distinct argument against the motion of the earth *because* birds unlike projectiles have the power of self-movement (and *hence* they could not follow the earth's rotation naturally but would have to do so through their own efforts). This argument is groundless *because* the air within which birds fly would be following the earth's motion (and *hence* they would not have to do so by their own efforts) [209/183/367].

5. *A crucial experiment* (to nullify all the evidence al-

leged against the earth's motion from falling bodies projectiles, and the flight of birds) could be made below decks on a ship by observing the flight of flies and butterflies, the swimming of fish in an aquarium, the dripping of water, the motion of smoke from incense, and the effort required to jump or throw objects in different directions. You would notice that everything would happen the same way when the ship is moving uniformly as when it is standing still (212/186/372).

6. *The extruding power of whirling* provides no evidence against the earth's motion *because* (a) the argument as ordinarily stated would prove at best only that the earth did not at one time start rotating after having been at rest; (b) the extruding motion would be tangential, and the downward tendency due to the weight is always large enough to overcome the tangential tendency; and (c) the extruding tendency depends not on the linear speed at the circumference, which is large, but rather on the angular speed, which is small (214/188/374).

C. *Examination of contemporary authors* opposing the earth's motion shows that none of their objections has any force (244/218/417).

1. *The time of fall from the moon* to a rotating earth constitutes no objection to the earth's motion *because* the objection conflicts with (a) the mathematical fact that the radius of a circle is only a fraction of its circumference, (b) the law of squares which yields a time of less than a day rather than six days, and (c) the double-distance rule which yields a much greater terminal speed (244/218/417).
2. *The objection from the inexplicability of the earth's motion* is invalid *because* our relative ignorance of a cause does not imply the non-existence of the effect, and groundless *because* it cannot be shown that the

cause of the earth's rotation is neither external nor internal (260/233/439).

3. *The objection from the deception of the senses* is false (a) *because* shared motion is imperceptible (and *hence* there is nothing for our eyes to see about falling bodies besides their downward motion); (b) *because* wind is air moving relative to us (and *hence* there is no perpetual wind due to the earth's rotation for us to feel); and (c) *because* experience with navigation shows that we can only feel changes in motion (and *hence* the earth's rotation is not something susceptible of being felt). Moreover, the objection is invalid *because* the fact that the senses are to some extent deceived in this and other cases implies that one has to be careful about what the senses tell us rather than that they are useless (272/247/455).
4. *The objection from the impossibility of multiple natural motions* in simple bodies is (a) groundless *because* the function of joints in animals is not to allow multiple motions but rather to allow some parts to be moved while others are not (and *hence* it is unjustified to say that bodies without joints cannot have multiple natural motions); (b) irrelevant *because* there is no way for the earth to have joints which would enable it to have its three multiple motions (and *hence* even if it did have joints, it could not have the types of motion it has, and *hence* there is no point in saying that bodies without joints cannot have multiple natural motions); and (c) false *because* Jupiter's satellites and the sun have multiple motions but no joints (281/256/468).
5. *The similarity of motions of similar substances* does not constitute a valid objection to the earth's rotation *because* (a) dissimilar substances like water and air need not have dissimilar motions completely but only to the extent that their dissimilar na-

tures can be inferred from differences in motion or other behavior (and *hence* if the earth rotates the common diurnal motion of water and air would not conflict with their dissimilar natures); and (b) similar are the earth and the planets on the one hand and the sun and the fixed stars on the other due to their darkness and luminosity (and *hence* the rotation of the earth would not imply that similar bodies — the fixed stars, planets, and the sun — were having dissimilar motions) [289/264/480].

6. *The objection that motion causes tiring* is false and invalid: false *because* the cause of animal tiring is the use of parts to move the whole, and *because* much animal motion is violent rather than natural; invalid *because* even if motion caused tiring the earth would not tire any more than the *primum mobile* or stellar sphere do in the Peripatetic system (293/269/487).

III. Third Day: The Earth's Annual Motion (299/276/5).

A. *The 1572 nova* provides a good example of how unreliable quantitative astronomical data are and of how careful and critical one must be in drawing conclusions from them (299/276/5).

1. *Preliminary discussions* point out that though certain arguments are fallacious they deserve discussion for reasons other than their logical merit (299/276/5).
2. *The evidence from parallax differences* examined by Chiaramonti does not imply that the 1572 nova was sublunary *because* his 12 computations yield distances differing by as much as a factor of 1500 and *because* those computations are a biased fraction of all those possible from his own evidence. This evidence, if a conclusion must be drawn, sup-

ports rather the superlunary location of the nova *because* when all his data are taken into account some corrections are necessary, and fewer are needed to harmonize the data yielding a superlunary location than those yielding a sublunary location (303/280/11).

3. *The polar and stellar distances* of the nova can be used to argue that it is superlunary *because* the needed observations are very simple and are not invalidated by, respectively, the effects of refraction and the instrumental difficulties of using the sextant (337/309/54).

B. *The favorable arguments* for the earth's annual motion are very cogent (346/318/66).

1. *The heliocentrism of planetary motions* supports the earth's annual motion (*because* the earth is located between bodies that go around the sun) and is supported by the planets' pattern of changes in their apparent size and shape *because*: (a) each planet's distance from the earth varies greatly (and *hence* the earth is not the center of their motion); (b) the outer planets are close to the earth when they are in opposition, and they are distant and look round when they are in conjunction ; (c) Venus always stays close to the sun and appears horned in shape when large and round when small; and (d) Mercury stays even closer to the sun and is brighter that Venus (346/318/66).
2. *Retrograde planetary motion* supports the earth's annual motion *because* it is best explained as resulting from the earth's annual motion (368/340/100).
3. *The motion of sunspots* is best explained in terms of the earth's annual motion *because* they appear to move across the solar disc along paths which exhibit the following features: (a) they curve upwards in the solar disc for half a year and downwards for

the other half; (b) they also slant upwards in the solar disc for half a year and downwards for the other half; and finally (c) both the curvature and the slant are continuously changing in such a way that the paths are straight twice a year when the slant is greatest, and the slant is absent twice a year when the curvature is greatest (372/345/106).

C. *The objections* to the earth's annual motion are inconconclusive though they are instructive and cannot be dismissed (383/356/122).

1. *Biblical passages* cannot properly be used in hypothetical reasoning about natural phenomena (383/356/122).
2. *The stellar dimensions* implied by the earth's motion and by the lack of annual parallax would not be absurdly great *because* apparent stellar diameters have been universally overestimated by a factor of about 30 (and *hence* stellar sizes have been universally overestimated), and *because* the required stellar sizes and distances, though very great, are not absurd; this is so *because* (a) some Ptolemaic estimates of distances are of the same order of magnitude, (b) size and distance are concepts such that all large ones after a certain amount are unimaginable, (c) there is no justification for saying that the space between Saturn and the fixed stars is useless, and (d) size and distance are relative concepts (385/358/124).
3. *Tycho's objection* from stellar dimensions is groundless *because* he assumes without investigation that stellar positions show no annual change and *because* he is unclear about the exact changes implied by the earth's annual motion (399/372/146).
4. *The celestial polar elevation* would not show any annual change if the earth had the annual motion *because* in that case the celestial pole would be

defined by the terrestrial one and the elevation of the latter can change only by moving on the earth's surface, not by moving the whole earth as in the annual motion; *hence* the objection that the celestial pole shows no annual change in elevation is invalid (400/373/148).

5. *The changes in stellar elevations* implied by the earth's annual motion would not be at all comparable to the changes resulting from moving along the earth's surface *because* the former motion occurs on a plane surface while the latter occurs on a relatively highly curved one; *hence* the objection that stellar elevations show no great changes is invalid (403/376/151).
6. *The annual constancy in stellar appearances* constitutes an invalid objection *because* the changes implied by the earth's motion are complicated and no one has systematically tried to observe them, and they are very small and no instruments are available for directing them (and *hence* the apparent constancy does not imply that the changes do not exist) [404/377/154].
7. *The sun's apparent motion* provides no evidence against the earth's annual motion *because* (a) the direction of the sun's apparent motion in the order of the signs of the zodiac would be a simple consequence of the earth's own motion in the same direction; (b) the significant seasonal changes in solar elevation and length of nights and days would be consequences of the inclination of the earth's axis and of its unchanging direction; and (c) there is no conflict between the large changes in solar elevation and the small ones in stellar elevations implied by the earth's annual motion (416/389/172).
8. *The properties of loadstones* invalidate the objection that a simple body like the earth cannot have three or four natural motions *because* (a) loadstones have several natural motions; and (b) they have the

property of always pointing toward the same place, and there is evidence that the earth is a loadstone (and *hences* its axis is always parallel to itself, and the third motion attributed to the earth by Copernicus does not exist) [423/397/182].

IV. Fourth Day: The Cause of the Tides (442/416/223)

A. *Previous theories* about the cause of the tides must all be rejected *because* (1) differences in sea depth cannot produce and sustain the motion of the water, (2) lunar attraction could not produce tides in only certain parts of a given sea and not in others, (3) the water in a tide has the same temperature and density as ordinary water (and *hence* lunar heat is inoperative), (4) the miracle explanation is not to be invoked unless one can find no other cause, and (5) the periodic attraction and expulsion of water by the earth through undersea caves could not produce tides in only certain parts of a given sea and not in others (442/416/223).

B. *The geokinetic theory* explains the main features of the tides as resulting from the interaction of two causes: the primary cause is the combination of the earth's diurnal and annual motions, the secondary cause consists of the fluid properties of water (449/423/235).

1. *The diurnal period* of the tides is caused by the daily accelerations and retardations produced in every part of the earth as the diurnal component is added to or subtracted from the annual component of the earth's motion; this is so *because* water in a container can be made to move like the tides by accelerating or retarding the container (449/423/235).
2. *The fluid properties of water* which act as a secondary cause of the tides are that (a) it tends to oscillate before reaching equilibrium; (b) its oscillations

take less, the smaller the length of the basin; (c) the deeper the water, the shorter the period of oscillation; (d) it moves vertically at the extremities and horizontally at the middle of the basin; and (e) different parts of the same body of water can move at different speeds simultaneously (454/428/241).

3. *The basic tidal effects* that can be explained as resulting from the interaction of the primary and secondary causes are (a) the absence of tides in lakes and small seas, (b) the six-hour tidal periods in the Mediterranean, (c) the absence of tides in seas that are narrow in an east-west direction, (d) that tides are greatest at the extremities and least at the middle of a gulf, (e) the great currents through certain straits, (f) the violent agitations and vortices in certain straits, and (g) the unidirectional flow of currents through certain straits (457/431/247).

C. *The behavior of winds* provides no evidence against the geokinetic explanation of the tides *because* air unlike water does not have the property of retaining acquired motion (and *hence* the earth's motion could cause the tides without causing a perpetual wind); and *because* the turning of the lunar orb could not produce the prevailing westward winds that do exist, and these could not produce the back and forth motion of the tides (and *hence* these winds are not the link between the diurnal motion of the lunar orb and the tides) [462/436/254].

D. *The monthly and annual periods* of the tides must be caused by variations in the velocity changes that cause the diurnal period (namely, variations in the speed of the earth's annual or diurnal motion or both); *hence,* the monthly period is caused by the variations in the speed of the earth's annual motion that occur monthly as the earth-moon system goes around the sun in a circle whose effective radius undergoes monthly variations as a result of the changing relative positions of

the earth, sun, and moon; *hence* also, the annual period is caused by the variations in the effective speed of the earth's diurnal motion resulting from the inclination of the earth's axis to the plane of its orbit (470/444/266).

III

The fact that it is possible to reconstruct the *Dialogue* in the way just described suggests the following historical and philosophical theses. First, it is a mistake to regard the book as primarily a defense of the whole Copernican system and then to blame Galileo for neglecting the details of technical astronomy; instead, the detailed examination of the *whole* book shows that it is primarily a defense of Copernicanism only to the extent that the proposition «the earth moves» (with the diurnal and annual motions) is part of Copernicanism. The book is rich enough in its content, as it is; there is no good reason why Galileo *should* have discussed the details of technical astronomy.

Second, it is unfair to fault Galileo for not explicitly discussing the Tychonic system since from the point of view of the proposition «the earth moves» there is no difference between it and the Ptolemaic system. Tycho's arguments are discussed in IIIC insofar as they are relevant to Galileo's purpose.

Third, Galileo's commitment to natural circular motion, if not taken out of context, is part of a critique of Aristotle's concept of natural motion (in IA1), and of an elucidation of a new concept of motion (IIB2c). When seen in this light, there is nothing very obviously wrong with it.

Fourth, it is a mistake to regard Galileo as inimical to or unappreciative of logic (9). The possibility and accuracy of the above reconstruction makes Galileo a logician-in-action or

(9) See, for example, William R. Shea, *Galileo's Intellectual Revolution* (New York: Science History Publications, 1972), p. 88.

applied logician, that is a skillful practitioner of logical analysis and explicitly formulated argumentation.

Fifth, if it should turn out, from another type of analysis of the *Dialogue*, that the book has no unity or prevalent characteristic in terms of some other epistemological-methodological idea or practice, then we would have to conclude that Galileo is *first and foremost* a logician. At present I state this thesis as a conditional, though my conjecture is that the book lacks any other prevailing methodological characteristic; and this conjecture is quite consistent with the claim that the book is full of philosophy and methodology. In fact, I believe that the full extent of the wealth of its philosophical content has not so far been appreciated. What we seem to have in the *Dialogue* is a philosophical goldmine, but one lacking a unifying theme, other than that of applied logic exhibited in this paper.

Finally, there is no conflict between this reconstruction of the *Dialogue* and the rhetorical interpretation, popularized by Feyerabend ([10]), that the book is a piece of propaganda aimed at winning the argument and at persuading the opponents at all costs, and exploiting their weaknesses. On the contrary, a reconstruction of the internal structure of the *Dialogue* is logically prior to the rhetorical interpretation since the formulation of the latter amounts to claiming that certain arguments actually given in the book are fallacious or deceptive in various ways. The rhetorical interpretation loses its relevance if and to the extent that its reconstructions are inaccurate, or taken out of context.

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([10]) P. K. FEYERABEND, «Problems of Empiricism II,» in Robert Colodny (ed.), *The Nature and Function of Scientific Theories* (Pittsburgh: University of Pittsburgh Press, 1970), pp. 275-353; and *Against Method.*