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The Copernican Hypotheses
Part 2

Summary. The Copernicus constructed by Thomas S. Kuhn in *The Copernican Revolution* (1957) is a decidedly non-revolutionary astronomer who unwittingly ignited a conceptual revolution in the European worldview. Kuhn's reading of Copernicus was crucial for his model of science as a deeply conservative discourse, which presented in *The Structure of Scientific Revolutions* (1962). This essay argues that Kuhn's construction of Copernicus and depends on the suppression of the most radical aspects of Copernicus' thinking, such as the assumptions of the *Commentariolus* (1509-14) and the conception of hypothesis of *De Revolutionibus* (1543). After comparing hypothetical thinking in the writings of Aristotle and Ptolemy, it is suggested that Copernicus' conceptual breakthrough was enabled by his rigorous use of hypothetical thinking.

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Hypothetical Thinking in the *Commentariolus* and *De Revolutionibus*

Commentariolus

Copernicus first made his alternative system public in the *Commentariolus*, a short treatise written some time between 1509 and 1514, around thirty years before the publication of *De Revolutionibus*. The *Commentariolus* ('Brief Description'), was not written for wide public consumption, but rather for specialists in his social network. The treatise received wider exposure in 1575, when Tycho Brahe distributed copies to German astronomers.[1]

The private nature of the *Commentariolus* entailed that Copernicus was considerably less reticent concerning his motivations and thought processes than he was in *De Revolutionibus*.

Indeed, Copernicus does not beat about the bush at all: in the very first sentence of the *Commentariolus* he focuses on how assumptions provide the basis for explanations of observed phenomena:

> Our predecessors assumed, I observe, a large number of celestial spheres mainly for the purpose of explaining the planets' apparent motion by the principle of uniformity. For they thought it altogether absurd that a heavenly body, which is perfectly spherical, should not always move uniformly. By connecting and combining uniform motions in various ways, they had seen, they could make any body appear to move to any position.[2]

The celestial spheres are classed an assumption, whereas uniform motion is treated as a fundamental principle.

Two observations made by our predecessors can be identified; namely, 1) that the heavenly bodies are spherical objects, and 2) that these heavenly bodies have been seen to move with an irregular, non-uniform motion. Observation 2) is incompatible with observation 1), since our predecessors deem the proper motion of a perfect sphere to be perfectly uniform, therefore any evidence of non-uniform motion has to be treated as *merely* apparent. The celestial spheres, were a mechanism assumed by our predecessors – a geometrical mechanism which could produce the appearance of irregular motion through a combination of regular motions. For the sake of explaining the appearances, the visible heavenly bodies were assumed to be transported through their orbits by invisible celestial spheres.

Copernicus then informs us that the assumption of the celestial spheres was, however, not sufficient to explain all planetary motion:

> Callippus and Eudoxus, who tried to achieve this result by means of concentric circles, could not thereby account for all the planetary movements, not merely the apparent

[1] N.M. Swerdlow, *The Derivation and First Draft of Copernicus's Planetary Theory: A Translation of the Commentariolus with Commentary*, "Proceedings of the American Philosophical Society" vol. 117, no. 6, 1973, pp. 423-512.

[2] N. Copernicus, *Commentariolus*, in *Nicholas Copernicus Minor Works*, Warsaw – Cracow 1985; N. Copernicus, G.R. Joachim, E. Rosen, *Three Copernican Treatises*, transl. E. Rosen, New York 1939.

> revolutions of those bodies but also their ascent, as it seems to us, at some times and descent at others, [a pattern] entirely incompatible with [the principle of] concentricity. Therefore for this purpose it seemed better to employ eccentrics and epicycles, [a system] which most scholars finally accepted.[3]

Since the celestial spheres are modelled on concentric circles, the assumed model was not able to account for observed variation in the altitude of the planets. The appearances could only be saved if eccentric circles and epicycles were employed. Copernicus refrains from classing eccentrics and epicycles as assumptions, or indeed anything else. Rosen interprets Copernicus' Latin as suggesting eccentrics and epicycles are employed in 'a system,' while Swerdlow opts for 'theory.'[4]

A possible interpretation for Copernicus' restraint here is that the predecessors assumed the celestial spheres had real, physical existence, whereas Calliopes and Eudoxus devised and employed eccentrics and epicycles purely for the basis of computation; i.e. their physical existence was not assumed. While Copernicus avoids discussing the status of these devices, he does suggest that scholars/experts accepted them with some reluctance (no doubt because they betrayed the perfection of concentricity).

The discomfort hinted at with regard to eccentrics and epicycles becomes explicit when Copernicus then deals with Ptolemy's equant:

> Yet the widespread [planetary theories], advanced by Ptolemy and most other [astronomers], although consistent with the numerical [data], seemed likewise to present no small difficulty. For these theories were not adequate unless they also conceived certain equalizing circles, which made the planet appear to move at all times with uniform velocity neither on its deferent sphere nor about its own [epicycle's] center. Hence this sort of notion seemed neither sufficiently absolute nor sufficiently pleasing to the mind.[5]

This is a curious paragraph. Copernicus rejects Ptolemy's equant, not because it fails to account for the appearances — he acknowledges that it does — but because it is not 'sufficiently absolute/perfect enough' ('*non satis absoluta*') and nor 'sufficiently pleasing to the mind/in accordance with reason'[6] ('*neque rationi satis concinna*'). This paragraph in itself would seem to refute Kuhn's claim that the Co-

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[3] Ibidem.

[4] Copernicus' original Latin: "Itaque potiore visa est sententia per eccentricos et epicyclos id agi, in qua demum maxima pars sapientium conuenit." N. Copernicus, *Commentariolus*...

[5] Ibidem.

[6] Swerdlow's translation: 'in accordance with reason.'

pernican Revolution was born, in part, from a widely-perceived crisis in 16th century astronomy; i.e. that the crisis was engendered by dissatisfaction with accumulated anomalies and inaccuracies.

A key question can be posed in response to this paragraph: what exactly did Copernicus expect from astronomy? Since the job of astronomy was to account for the appearances, why did it matter if Ptolemy's equant violated the principle of uniform velocity, which was a principle of cosmology? If astronomy responded to discrepancies in the numerical data by devising models that violated cosmological principles, but which nonetheless proved consistent with the data and enabled accurate prediction of planetary movements, on what basis could a 16th century astronomer reject Ptolemy's equant (and consequently his entire system)?

The minimal interpretation of Copernicus rejection of the equant is that Copernicus wanted astronomy to be more aesthetically pleasing, by devising computational models and a system that did not violate the fundamental principles of cosmology. This interpretation would suggest that Copernicus believed the universe to be fundamentally elegant, with all real motion following simple, fundamental principles. The job of astronomy would be to devise elegant, simple models that strictly mirror cosmological principles. This interpretation would support Kuhn's contention that Copernicus did not see how interdependent astronomy and cosmology were; that he did not appreciate the extent to which changes to astronomical models could have ramifications in the field of cosmology. Replacing the Ptolemaic system with a more aesthetically pleasing system might retain key features of the Aristotelian two-sphere universe (i.e. the principle of uniform motion), but it could (and did) violate other qualitative distinctions, such as the absolute distinction between the sublunary and celestial spheres. On this interpretation, Copernicus was a revolutionary astronomer, but a traditionalist when it came to cosmology, and furthermore a traditionalist who failed to appreciate how his astronomical mirror distorted the cosmological reality.

A more generous interpretation is that in rejecting Ptolemy's equant, despite the fact it was consistent with numerical data, Copernicus did not acknowledge the strict division between astronomy and cosmology that Kuhn's model of the Copernican Revolution hinges upon. This interpretation would have to suggest that either Copernicus (and maybe many of his contemporaries) did not perceive the distinction between qualitative astronomy and quantitative cosmology to be so clear cut, or that Copernicus consciously rejected the distinction between the two fields. Copernicus' criticising the Ptolemaic system, somewhat ambiguously, for its not being 'sufficiently absolute' could, on this interpretation, suggest that Copernicus wanted astronomy to claim correspondence between it's models and the physical reality of the universe. In the next section of the *Commentariolus,* Copernicus explains how he arrived at his new system:

> Therefore, having become aware of these [defects], I often considered whether there could perhaps be found a more reasonable arrangement of circles, from which every apparent irregularity would be derived while everything in itself would move uniformly, as is required by the rule of perfect motion. After I had attacked this very difficult and almost insoluble problem, the suggestion at length came to me how it could be solved with fewer and much more suitable constructions than were formerly put forward, if some postulates (which are called axioms) were granted me. They follow in this order.[7]

Following the more generous interpretation of Copernicus' rejection of the Ptolemaic system, the gloss for this paragraph would be that Copernicus found himself unable to devise a more 'reasonable' astronomical system in keeping with the cosmological 'rule of perfect motion' without reaching for and revising assumptions that were – as Copernicus was fully aware – fundamental to both astronomy and cosmology.

Postulates

1. There is no one center of all the celestial orbs or spheres.

2. The center of the earth is the center, not of the universe, but only of gravity and of the lunar sphere.

3. All the spheres encircle the sun, which is as it were in the middle of them all, so that the center of the universe is near the sun.

4. The ratio of the earth's distance from the sun to the height of the firmament is so much smaller than the ratio of the earth's radius to its distance from the sun that the distance between the earth and the sun is imperceptible in comparison with the loftiness of the firmament.

5. Whatever motion appears in the firmament is due, not to it, but to the earth. Accordingly, the earth together with the circumjacent elements performs a complete rotation on its fixed poles in a daily motion, while the firmament and highest heaven abide unchanged.

6. What appear to us as motions of the sun are due, not to its motion, but to the motion of the earth and our sphere, with which we revolve about the sun as [we would with] any other planet. The earth has, then, more than one motion.

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[7] Ibidem.

7. What appears in the planets as [the alternation of] retrograde and direct motion is due, not to their motion, but to the earth's. The motion of the earth alone, therefore, suffices [to explain] so many apparent irregularities in the heaven.

Having thus propounded the foregoing postulates, I shall endeavor briefly to show to what extent the uniformity of the motions can be saved in a systematic way. Here, however, the mathematical demonstrations intended for my larger work should be omitted for brevity's sake, in my judgment.[8]

Copernicus previously suggested that these 'postulates/assumptions' (*petitiones*) can be considered as 'axioms' (*quas axiomata vocant*). There was some controversy in Copernicus studies over the meaning of Copernicus' *petitiones.* Edward Rosen originally translated *petitiones* as 'assumptions' in *Three Copernican Treatises*, but revised the translation to 'postulates' following Swerdlow's translation.[9] In *The Commentariolus of Copernicus* Swerdlow expressed his frustration with Copernicus' terminology and reasoning, and argued that the *petitiones* are not equivalent to 'axioms,' since they are not 'self-evident.' For example, Swerdlow argues that since postulate 2 follows from postulates 3 and 6, it cannot classed as a self-evident assumption without proof, as it contradicts the first principle of spherical astronomy (which is only challenged in postulates 3 and 6).[10] In *Copernicus' Axioms*, Rosen argues that Copernicus did not intend to present a set of logically independent axioms, and accuses Swerdlow of anachronistically applying the requirements of nineteenth or twentieth century formal mathematics to Copernicus' postulates. Rosen's position is that a) Copernicus' axioms were not put forth as self-evident propositions because Copernicus asks the reader to 'grant' him them, so they function as assumptions,[11] and b) Copernicus' axioms are inspired by the Archimedean method and the Aristotelian conception of propositions, as laid out in *Posterior Analytics*, wherein axioms are defined as "the primary propositions from which a proof proceeds."[12]

Both Swerdlow and Rosen agree on one point, however. Copernicus' postulates were not proposed as assumptions made merely for the sake of producing accurate computations: for Swerdlow, Copernicus' postulates are statements, made by a 'pure astronomer,' about the "real motions of the planets and the arrangement of the heavens,"[13] while Rosen insists that for Copernicus "astronomy deals with

[8] Ibidem.

[9] E. Rosen, *Copernicus and his successors*, London 1995.

[10] N. M. Swerdlow, *The Derivation...*, p. 438.

[11] E. Rosen, *Copernicus and his successors*, p. 100.

[12] Ibidem.

[13] N. M. Swerdlow, *The Derivation...*, p. 440.

reality."[14] Thus this Copernicus, in contrast to Kuhn's, is seen as challenging the traditional supremacy and prerogative of Aristotelian cosmology, by asserting the right of quantitative, mathematical astronomy to lay claim to the real.

It is on the basis of the 'postulates' of the *Commentariolus* (and the conception of 'hypotheses' employed in *De revolutionibus*) that Copernicus can be viewed and cast as revolutionary thinker. It is noteworthy that Kuhn only mentioned the *Commentariolus* in passing in *The Copernican Revolution*,[15] and overlooked Copernicus' revealing comments about 'hypotheses' in *De revolutionibus*. Copernicus' postulates simply do not sit well with either Kuhn's depiction of Copernicus or his model of scientific revolutions.

The postulates of the *Commentariolus* are a set of deceptively simple statements that describe the supposed shape, scale and motions of the universe. The postulates are not self-evident axioms, and nor do they, when taken as a whole, constitute a chain of internally consistent syllogistic deductions. The postulates are rather the conclusions arrived at through conditional reasoning from the primary sun-centred hypothesis. Once Copernicus had posited the sun at the centre of the universe, he rigorously deduced the consequences of this. The postulates are the conditional outcomes, or solutions to conceptual problems, encountered as a consequence of this primary supposition or hypothesis. The sun-centred hypothesis thus functions for Copernicus in accordance with its original Greek meaning, ὑπόθεσις/hipothesis, meaning 'that which is placed under': it is the conceptual basis underlying the postulates.

For example, Postulates 1-3 deal with the immediate conceptual problems arising as a consequence of positing the Sun at the centre of the universe: 1) If the sun replaces the earth as the centre of all the celestial rotations, why does the moon quite evidently orbit the Earth? 2) If the earth is not the centre of the universe, why do objects fall perpendicularly towards the earth? 3) If the sun is at the exact centre of the universe, why do the planets still appear to orbit the sun at irregular speed? The postulates answer these questions: there are multiple centres of orbit, the earth is the centre of the lunar sphere and gravity, the sun is near the centre, but not in the exact centre.

Postulate 4, which asserts that the universe is far larger than had previously been estimated, is clearly put forward to counter the toughest objection to the sun-centred hypothesis, i.e. the absence of observed stellar parallax. Postulate 4 actually depends on Postulate 6, which asserts the earth's orbit of the sun, and is

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[14] N. Copernicus, G. R. Joachim, E. Rosen, *Three Copernican Treatises*, p. 28.

[15] T. S. Kuhn, *The Copernican Revolution: planetary astronomy in the development of Western thought*, Cambridge 1957, pp. 138, 171.

also a response to observational evidence: if it is supposed that the earth orbits the sun, then the stars should appear in different positions relative to each other as the earth goes through its orbit; in other words stellar parallax should be observed, but it is not. Instead of abandoning his heliocentric hypothesis in response to what appeared to be falsifying data – as Popper expected rigorous scientists to do – Copernicus tenaciously followed the consequences of his hypothesis: stellar parallax would only be observed if the universe is a relatively small place; but stellar parallax is not observed, therefore the universe must be many times vaster than previously supposed. If the universe is so large that the distance from the earth to the sun is practically imperceptible when compared with the distance of the earth to the stars, then stellar parallax would be imperceptible to the naked eye. Postulate 4 is adduced before Postulate 6 because Postulates 1-4 deal with the arrangement and scale of the universe, while Postulates 5-7 address the issue of motion.

Postulates 5-7 account for the discrepancy between the regularity perceived in the movement of the stars, and the irregularities observed in the movement of the Sun and planets. Postulate 5 asserts the earth's diurnal movement to account for the regular motion of the firmament, Postulate 6 posits the earth's annual orbit to account for both the irregularities in the sun's motion, and Postulate 7 accounts for the retrograde motion of the planets.

Conditional Reasoning in Aristotle and Ptolemy

Copernicus was, of course, not the first thinker to employ conditional reasoning to extrapolate the consequences of a hypothesis. His originality lay in the tenacity and rigour with which he pursued his deductions, and in his willingness to abandon assumptions, common sense and sensory evidence in the process.

Aristotle

Aristotle's *On the Heavens* is riddled with hypothetical thinking, but this hypothetical thinking is determined by absolute binary distinctions and is typically employed to bolster unquestioned assumptions and unverifiable qualitative assertions.

For example, in Book II, Part 6, Aristotle seeks to demonstrate that the movement of 'the heaven' is regular rather than irregular. He distinguishes between the movements of 'the first heaven' and 'the lower spheres.' Movement in the lower spheres has starting points and goals (Aristotle provides the motion of missiles as an example), and is therefore characterised by acceleration, maximum speed and retardation, which means this movement is uneven and irregular. In contrast, the movement of the heaven is circular (emphasis added):

> But circular movement, having no beginning or limit or middle in the direct sense of the words, has neither whence nor whither nor middle: for in time it is eternal, and in length it returns upon itself without a break. If then its movement has no maximum, it can have no irregularity, since irregularity is produced by retardation and acceleration.[16]

At first sight, Aristotle's reasoning may seem counter-intuitive. We can imagine (and even observe) a sphere beginning to rotate, then rotating with increasing velocity, before finally slowing and coming to rest. However, Aristotle's reasoning is driven by a more powerful common sense observation that overrides such considerations. The heaven (or celestial sphere) appears to rotate with perfect regularity, whereas all motion on the earth and in the earth's atmosphere appears uneven and irregular. Thus Aristotle's argument idealises circular movement: the potential for circular motion to have uniform velocity is seized on and asserted as its defining, absolute characteristic. Aristotle then provides further support for his argument (emphasis added):

> It follows then, further, that the motion cannot be irregular. For if irregularity occurs, there must be change either in the movement as a whole, from fast to slow and slow to fast, or in its parts. That there is no irregularity in the parts is obvious, since, if there were, some divergence of the stars would have taken place before now in the infinity of time, as one moved slower and another faster: but no alteration of their intervals is ever observed.[17]

Further proof that circular movement is regular is provided by conditional reasoning that appeals to observational evidence: if the circular movement of the heaven were irregular, we would have observed variation in the speed at which the stars move (but this has not been observed, so the movement of the heaven must be regular). This brief appeal to observation is followed by a return to more typical assertions:

> Retardation is always due to incapacity, and incapacity is unnatural. The incapacities of animals, age, decay, and the like, are all unnatural, due, it seems, to the fact that the whole animal complex is made up of materials which differ in respect of their proper

[16] Aristotle, *On the heavens*, transl. J.L. Stocks, Adelaide 2009.

[17] Ibidem.

> places, and no single part occupies its own place. If therefore that which is primary contains nothing unnatural, being simple and unmixed and in its proper place and having no contrary, then it has no place for incapacity, nor, consequently, for retardation or (since acceleration involves retardation) for acceleration.

Here Aristotle's conditional reasoning employs unverifiable, qualitative statements (retardation is due to incapacity, incapacity is unnatural, that which is primary is purely natural) to arrive at the sought after conclusion (the heaven is primary, its movement is natural, and therefore it cannot slow down or accelerate, so its movement must be regular).

After further qualitative reasoning on the impossibility of perpetual acceleration and retardation, and the impossibility of alternating acceleration and retardation, Aristotle concludes the section:

> Further, irregularity of this kind would be particularly unlikely to pass unobserved, since contrast makes observation easy.
> That there is one heaven, then, only, and that it is ungenerated and eternal, and further that its movement is regular, has now been sufficiently explained.[18]

Throughout this section of *On the Heaven*, Aristotle rests his arguments on the fundamental assumption of his cosmology: the absolute, binary distinction between the irregular motion of the sub-lunary sphere and the apparently regular rotations of the celestial sphere. The conditional reasoning employed in his arguments (e.g. *If then its movement has no maximum, it can have no irregularity*) merely supports the underlying assumptions, and is thoroughly determined by the binary distinctions generated by the two-sphere cosmology. The set of assumptions underlying the cosmology constitute a binary conceptual machine that is determined by – and at the same time generates – binary opposites (celestial-terrestrial, regular-irregular, natural-unnatural, eternal-temporal). When trapped within such a conceptual apparatus, and with such wholehearted trust of common sense, conditional reasoning or hypothetical thinking was restricted to confirming the dictates of the underlying assumptions.

Ptolemy

Like Aristotle, Ptolemy also employed conditional reasoning in the *Almagest*, particularly in Book 1, where he outlines the 'theoretical philosophy.' However, Ptolemy's rea-

[18] Ibidem.

soning is far more grounded in observational evidence and is therefore more methodologically similar to Copernicus' *petitiones*.

For example, in Book 1, Section 4, Ptolemy begins his proof that the earth is 'sensibly spherical' by referring to accumulated observations: the sun, moon and stars are seen to rise and set earlier in the east than in the west, the hour recorded in the east is always later than that recorded in the west, and the differences in the hour are proportional to the distances between the places of observation. Ptolemy claims that on the basis of these observations "one can reasonably conclude that the earth's surface is spherical." Having already established that the heavens move like a sphere in the previous section (Book 1, Section 3), Ptolemy concludes that observers on the earth are on the surface of an 'evenly curving surface' of a sphere, and this is why observers see the heavenly bodies come in and out of view 'in a regular fashion.'[19]

Ptolemy then employs conditional-hypothetical reasoning to strengthen his argument:

> If the earth's shape were any other, this would not happen, as one can see from the following arguments. If it were concave, the stars would be seen rising first by those more towards the west; if it were a plane, they would rise and set simultaneously for everyone on earth; if it were triangular or any other polygonal shape, by a similar argument, they would rise and set simultaneously for all those living on the same plane surface. Yet it is apparent that nothing like this takes place.[20]

Each antecedent considers a hypothetical possibility (that the earth's shape is concave, a plane, a triangle or any other polygonal shape); while each consequent deduces the observable consequences of the antecedent (e.g. the stars would be seen rising first by those more to the west). All the conditional statements are falsified by a simple conclusion that appeals to evidence from observation (it is apparent that nothing like this takes place).

Ptolemy's conditional reasoning is an invaluable tool for falsifying theoretical possibilities that are not supported by observational evidence. However, his reasoning is less rigorous when it confronts hypotheses that are at variance with common sense, even if they can account for the appearances.

For example, in Book 1, Section 7, Ptolemy attempts to demonstrate that the earth does not move.

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[19] Ptolemy, *The Almagest*, transl. G. J. Toomer, New York 1984, p. 40.

[20] Ibidem.

His first argument concerns whether or not the earth is falling, like other heavy objects. His reasoning rests firmly on on the principles of Aristotelian physics and can be summarised thus: the earth is in the centre of the universe, which is evident from the fact all heavy objects fall perpendicularly towards the surface of the earth. If the surface of the earth did not arrest their movement, falling objects would continue to the centre of the earth. If the earth were not in the centre of the universe, it would fall faster than all falling objects towards the centre, due to its greater size, and drop out of the heavens as it was carried down. This is clearly not happening, because if it were, "living things and heavy objects would be left behind, riding on the air." Ptolemy concludes that "such things are utterly ridiculous to think of."[21]

His second argument deals with the possibility of the earth's rotation. Ptolemy probably had Heraclides and Aristarchus in mind when he mentions those who "supposed the heavens to remain motionless" and posited the daily revolution of the earth from west to east to account for the apparent movement of the celestial sphere. Once again, Ptolemy dismisses this as a ridiculous idea:

> However, they do not realise that, although there is perhaps nothing in the celestial phenomena which would count against this hypothesis, at least from simpler considerations, nevertheless from what would occur here on earth an in the air, one can see that such a notion is quite ridiculous. [...] They would have to admit that the revolving motion of the earth must be the most violent of all motions associated with it, seeing that it makes one revolution in such a short time; the result would be that all objects not actually standing on the earth would appear to have the same motion, opposite to that of the earth: neither clouds nor other flying or thrown objects would ever be seen moving towards the east, since the earth's motion towards the east would always outrun and overtake them, so that all other objects would ever be seen moving towards the west and the rear.[22]

Ptolemy has to acknowledge that the hypothesis of the earth's diurnal rotation accounts for the celestial phenomena; in other words, it is consistent with the observations of astronomy. The hypothesis is refuted by conditional reasoning based on the common sense principles of Aristotelian physics. Ptolemy shies away from giving an astronomical hypothesis serious consideration, even though is is quantitatively consistent, because common sense and the authority of Aristotelian physics got the better of him.

[21] Ibidem, p. 44.

[22] Ibidem, p. 45.

Copernicus' *De revolutionibus*

The Copernican revolution was borne of cultural factors and, perhaps more importantly, Copernicus' willingness to think his way through the obstacles encountered by conditional reasoning, to accept the consequences, and to adapt his assumptions, no matter how contrary they were to common sense.

As both Kuhn and Gingerich noted, the period of upheaval that Copernicus lived through was conducive to bold scientific thinking. However, as Gingerich also noted, there was something very untimely about the Copernican revolution. The *petitiones* of the *Commentariolus* and the scientific hypotheses presented in *De revolutionibus* (1543) were at least one hundred years ahead of their time, and would not be fully assimilated into European culture until long after the publication of Newton's *Principia* in 1687.[23] As we have seen, Kuhn laid part of the blame for the slow assimilation of the heliocentric revolution at Copernicus' feet, due to the obscurity of Copernicus' style and the lack of an alternative to Aristotelean physics. Yet the Copernican revolution was not readily accepted in many quarters even when the new paradigm was expressed with Galileo's polemical clarity, or when techno-scientific advances such as the telescope enabled widespread confirmation, or even when Newton provided the alternative physics.

A reading of *De revolutionibus* can unearth a Copernicus who was obviously influenced by his revolutionary historical-cultural context, but who was also uniquely able to transcend it, through combining the conclusions of conditional reasoning (arrived at in the *Commentariolus*) with a nascent scientific method based on the use of hypotheses.

The most lucid expression of method appears in Copernicus' *Preface and Dedication to Pope Paul II.*[24] The first two paragraphs of the Preface explain why he decided to publish his 'opinion' at all. He informs the Pope that he was inclined to follow the Pythagoreans and hide his opinion from all but a select group of relatives and friends. However, these friends – and he makes a point of naming a Cardinal and a Bishop – persuaded him to overcome his fear, stop hesitating and publish his 'luminous demonstrations,' so as to dissipate the 'fog of absurdity' which engulfs the general opinion.

[23] The uncensored version of *De revolutionibus* was finally removed from the Index of Prohibited Books in 1835.

[24] N. Copernicus, *De revolutionibus orbium caelestium*, transl. C. G. Wallis, New York 1995, pp. 4-7.

This explanation provides a strikingly clear description of how, borrowing the terminology of Ludwik Fleck , Copernicus' private opinion made the transition from a supportive esoteric circle to the exoteric testing ground of public opinion. The shift from *The Commentariolus* manuscript to the printed book form of *De revolutionibus* entailed the adoption of different strategies to deal with different types of reader. In the Preface, Copernicus anticipates hostile responses from general common sense, from mathematically proficient astronomers and from innumerate scriptural literalists, and he incorporates pre-emptive arguments and tactics into his text to defend and communicate his opinion. Copernicus is acutely aware that presenting his new model to the public is fraught with danger; that the printing and dissemination of his opinion necessitates a degree of popularisation for an audience who are intuitively and theoretically ill-disposed to his assertions.

The third paragraph of the Preface merits particularly close attention, because it is here that Copernicus gives a concise and conceptually intense account of the factors which drove his 'nocturnal study' and writing. This paragraph also adds support to the generous interpretation of Copernicus' introduction to the *Commentariolus*, mentioned earlier, which suggests that Copernicus rejected the traditional distinction between cosmology and astronomy, and the subordination of the latter to the former.

At the outset, Copernicus acknowledges that his work both breaks with the prevailing wisdom and defies common sense:

> [...] you will be eager to hear from me what came into my mind that in opposition to the general position of mathematicians and almost in opposition to common sense I should dare to imagine some movement of the Earth.[25]

He then goes on to explain that this daring arose through frustration. He has come to the conclusion that these mathematicians are fundamentally inefficient – they are incapable of calculating phenomena which really ought to be basic, especially considering their practical utility:

> For in the first place mathematicians are so uncertain about the movements of the sun and the moon that they can neither demonstrate nor observe the unchanging magnitude of the revolving year. Then in setting up the solar and lunar movements and those of the other five wandering stars, they do not employ the same principles, assumptions, or demonstrations for the revolutions and apparent movements.[26]

[25] Ibidem, p. 5.

[26] Ibidem.

Crucially, Copernicus then focuses on the problems of method:

> For some make use of homocentric circles only, others of eccentric circles and epicycles by means of which however they do not fully attain what they seek. For although those who have put their trust in homocentric circles have shown that various different movements can be composed of such circles, nevertheless they have not been able to establish anything for certain that would fully correspond to the phenomena. But even those who have thought up eccentric circles seem to have been for the most part to compute the apparent movements numerically by those means, they have in the meanwhile admitted a great deal which seems to contradict the first principles of regularity of movement. Moreover, they have not been able to discover or to infer the chief point of all, i.e. the form of the world and the certain commensurability of its parts.[27]

His argument structurally echoes the critique of the Ptolemaic system at the start of the *Commentariolus* – i.e. that in the Ptolemaic system computational models can only correspond to the phenomena if the first principles of regularity of movement are violated – but he is also clearer about the ultimate aim of mathematics (i.e. quantitative astronomy): the vague reference to being 'sufficiently absolute' from the *Commentariolus* has become discovering 'the form of the world and the certain commensurability of its parts.'

Copernicus's rejection of the status and remit traditionally assigned to astronomy could hardly be clearer. His mathematics will not be restricted to being a mere computational device and, consequently will not be given free rein to think up any ad hoc devices just as long as they aid efficient calculation and 'save the appearances.' Copernicus informs the Pope that his mathematics is going for the big prize hitherto reserved for Aristotelian cosmology – 'the form of the world.' Copernicus hungers for the real and aims to provide a mathematical description the universe as it really is.

At the end of this third paragraph, Copernicus identifies the problem of method as a problem with basic assumptions and hypotheses:

> And so, in the process of demonstration which they call "method," they are found either to have omitted something necessary or to have admitted something foreign which by no means pertains to the matter; and they would by no means have been in this fix, if they had followed sure principles. For if the hypotheses they assumed were not false, everything which followed from the hypotheses would have been verified

[27] Ibidem.

> without fail; and though what I am saying may be obscure right now, nevertheless it will become clearer in the proper place.[28]

There a slight shift in Copernicus' language from the *petitiones* ('postulates' or 'assumptions') of the *Commentariolus*. Throughout *De revolutionibus* Copernicus tends to use the term '*hypothesis*' to refer to both implicit assumptions about the physical universe that underly geometric models and explicit suppositions which purport to describe the physical universe. Examples of the former can be found when Copernicus criticises Ptolemaic models,[29] while examples of the latter can be found when Copernicus outlines his own system.[30] Edward Rosen, a translator of *De revolutionibus*, states that Copernicus uses the terms *principium*, *assumptio* and *hypothesis* interchangeably[31]. Copernicus himself admits to a certain amount of obscurity on this point ('what I am saying may be obscure right now'), but I think the shift from 'petitiones' to 'hypothesis' is tied up with Copernicus' new notion of testing. The *hypotheses* of De revolutionibus are *tested* against the data, whereas the *petitiones* of the Commentariolus were laid down as the foundations for the construction of a heliocentric system. Later in the Preface, Copernicus explains:

> [...] because I knew that others before me had been granted the liberty of constructing whatever circles they pleased in order to demonstrate astral phenomena, I thought that I too would be readily permitted to test whether or not, by the laying down the Earth had some movement, demonstrations less shaky than those of my predecessors could be found for the revolutions of the celestial sphere.[32]

I would suggest that when Copernicus replaced the hypothesis of the Aristotelian-Ptolemaic geocentric model with the alternative hypothesis of the Earth's movement (and the subset of hypotheses that followed as a consequence of this fundamental hypothesis) he also introduced a nascent method to accompany the hypothesis: a method in which the accuracy of computations based on the hypoth-

[28] Ibidem, pp. 5-6. The Latin original: "Itaque in processu demonstrationis, quam μέθοδον [methodon] vocant, vel praeteriisse aliquid necessariorum, vel alienum qiud, et ad rem minime pertinens, admisisse inveniuntur. Id quod illis minime accidisset, si certa principia sequuti [= secuti] essent. Nam si assumptae illorum hypotheses non essent fallaces, omnia quae ex illis sequuntur, verificarentur proculdubio. Obscura aute[m] licet haec sint, quae nunc dico, tamen suo loco fient apertiora."

[29] For example *De revolutionibus*, Book IV, Sections 1 & 2.

[30] For example in Book I.

[31] For an extensive list of Copernicus' use of the word 'hypothesis' in *De revolutionibus*, see E. Rosen's *Introduction* to *Three Copernican Treatises*, pp. 29-30 and especially footnote 93.

[32] N. Copernicus, *De revolutionibus*..., p. 6.

esis indicated the truth of the hypothesis. The 'Copernican Method,' briefly outlined in the Preface, would seem to claim that if hypotheses produce accurate calculations and are in agreement with certain axioms of physics, then they can be treated as true descriptions of physical reality. For Copernicus, hypotheses were the fundamental tools of a method which seeks optimal correspondence between concepts and physical reality.[33]

Conclusion: A Productive Blind Spot

Of course, when tested against the data, Copernicus' hypotheses were not verified in any simple or aesthetically pleasing way. Copernicus sought confirmation of his hypotheses, and when the data suggested the hypotheses were falsified, he resorted to *ad hoc* geometrical devices in order to fit the model with the data.

In *The Copernican Revolution*, after his summary of the latter books of *De revolutionibus*, Kuhn observes:

> The preface to the *De revolutionibus* opens with a forceful indictment of Ptolemaic astronomy for its inaccuracy, complexity and inconsistency, yet before Copernicus' text closes, it has convicted itself of exactly the same shortcomings. Copernicus' system is neither simpler nor more accurate than Ptolemy's. And the methods that Copernicus employed in constructing it seem just as little likely as the methods of Ptolemy to produce a single consistent solution to the problem of the planets. The De revolutionibus itself is not consistent with the single surviving early version of the system, described by Copernicus in the early manuscript Commentariolus. Even Copernicus could not derive from his hypothesis a single and unique combination of interlocking circles, and his successors did not do so. Those features of the ancient tradition which had led Copernicus to attempt a radical innovation were not eliminated by that innovation. Copernicus had rejected the Ptolemaic tradition because of his discovery that "the Mathematicians are inconsistent in these [astronomical] investigations" and because

[33] It is clear from these sentences that Copernicus uses the word 'hypothesis' in an entirely different sense from that employed by Andrew Osiander in his infamous letter of 1541, which was inserted into the first edition of *De revolutionibus*. Osiander treats the geometric figures of astronomy, such as epicycles and eccentrics, as hypotheses. These devices can describe or account for celestial movement adequately, but the method makes no requirement that they be true, i.e. correspond with physical reality. Consequently, for Osiander it makes no difference whether the irregular movement of the Sun is accounted for by an epicycle or by an eccentric. The sole criterion for evaluating hypotheses is their accuracy in accounting for the phenomena, and since both epicycles and eccentrics get the job done there is nothing to choose between them.

"if their hypotheses were not misleading, all inferences based thereon might surely be verified." A new Copernicus could have turned the identical arguments against him.[34]

In my view, in the Preface Copernicus' strongest indictment of Ptolemaic astronomy was not for its "inaccuracy, complexity and inconsistency," but rather for its violation of the principle of regularity (or uniformity), manifested in the widespread use of the equant. By his own account in the *Commentariolus* and the Preface to *De revolutionibus*, it was this feature of the ancient tradition that primarily led him "to attempt a radical innovation."

While questioning the assumptions underlying the Aristotelian-Ptolemaic universe, Copernicus tenaciously clung to just two of the fundamental assumptions: that celestial objects revolve in perfect circles and at regular, uniform speed. We have seen how difficult it was for Ptolemy to even entertain hypotheses that contradicted the principles of Aristotelian physics and went against the intuitions of common sense. Copernicus' loyalty and devotion to the principles of perfect circles and uniform motion actually seem to have enabled him to be so radical in his rejection of the other assumptions underpinning the geocentric paradigm: these principles were the bedrock that he stood on while hypothesising his new astronomical system. It is in this sense that Copernicus' blind spot with regard to these principles was a very productive blind spot.

Even so, Copernicus' allegiance to the principle of regularity lies behind some of the successes of *De revolutionibus*, such as the recognition that the phenomenon of precession is tied to the Earth's axial movement. As Copernicus progressed from the Earth's diurnal movement and the movement of the declination to the Earth's orbital movement, the principle of regularity did enable partial verification of his hypothesis (in the case of precession), but it also necessitated increasingly complex adjustments (i.e. minor epicycles). These adjustments ultimately rendered his system inaccurate in terms of its predictive capacity and made his hypothesis somewhat implausible as a description of physical reality.

However, it seems that Copernicus genuinely believed he had arrived at the truth with his system. His doubts concern the details, for example whether the Earth moves on an epicycle or an eccentric; not the fundamentals, such as the possibility that the Earth might move on neither of these perfect circles.

Kepler would eventually falsify these principles by finally accepting what Tycho Brahe's data on the movement of Mars was telling him – that the planets move in

[34] T. S. Kuhn, *The Copernican Revolution*..., p. 171.

elliptical orbits and at variable speeds. Kepler's revolutionary contribution to science and scientific method was that he abandoned these ancient principles, with great reluctance, in response to the data and formulated his new 'laws.' In contrast, Copernicus' revolution was first and foremost a conceptual revolution: the hypotheses were radical, but the geometric models were still *ad hoc* attempts to 'save the appearances,' appearances which were based on ancient and often inaccurate data.

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