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The Copernican Hypotheses
Part 1

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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Kuhn's Paradigm

In *The Copernican Revolution*, Thomas Kuhn was at pains to construct an image of Copernicus as a decidedly non-revolutionary astronomer. Kuhn's model of scientific revolutions, first embodied in *The Copernican Revolution* and then generalised to the status of a theory in *The Structure of Scientific Revolutions*, conceives of science as being, for the majority of the time, a deeply conservative activity. In Kuhn's model, scientists who are engaged in the business of doing every day scientific work do so at the behest of of a reigning paradigm that completely dictates their field of enquiry and functions as an imperceptible intellectual strait-jacket.

Kuhn's historical approach was explicitly revisionist, as it challenged the orthodox images of science and the history of science disseminated by science textbooks, popularisations, and the philosophy of science. According to Kuhn, these diverse texts exercise the authority of the latest paradigm to perpetuate the image of science as a stable process of knowledge accretion. Scientific revolutions are envisaged as rare upheavals brought about by paradigm crises, and the emergence of a new paradigm, effected and embodied by widely-comprehensible, non-specialised scientific texts, compels science textbooks to be rewritten. However, the new textbooks and popularisations swiftly render the revolutionary crisis 'invisible.' The new paradigm simultaneously updates and is written into 'the completed body of scientific knowledge.' Once the crisis is over, the new paradigm guarantees the stability and authority of Science, and scientists return to their non-revolutionary, specialised, paradigm-driven research. One can perhaps detect here a 'meta-paradigm': scientific paradigms may come and go, but the Enlightenment image of Science as a stable tradition of truth-gathering prevailed (or at least it still prevailed in 1962, until the appearance *The Structure of Scientific Revolutions*).[1]

This image of science as essentially conservative is also at odds with Karl Popper's heroic image of science and scientists, constructed in *The Logic of Scientific Discovery* and *Conjectures and Refutations/The Growth of Scientific Knowledge*. In Chapter 3 of *Conjectures and Refutations*, entitled 'Three Views Concerning Human Knowledge,' Popper invokes Copernicus as a forerunner of 'the Galilean tradition.' Scientists in this tradition (such as Galileo, Newton and Einstein) made bold, 'genuine conjectures' which ultimately aimed at finding a true description of the world. Popper contrasts the Galilean tradition to the instrumentalist position (represented by Osiander, Cardinal Bellamine, Berkley, Mach, Duhem, Bohr and Heisenberg) which treats scientific theories as mere computational devices. While 'genuine conjectures' can be tested and falsified, and thus can be said to 'touch reality,' Popper argues that the instrumentalists cannot truly falsify their hypotheses, predictions or theories; indeed, instrumentalists can quite happily continue using theories after they have been refuted, if they have practical application. For Popper, such intellectual bankruptcy contrasts starkly with the revolutionary power of true or pure science. Pure science

[1] T. S. Kuhn, *The Structure of Scientific Revolutions*, Chicago 1962, pp. 136-144.

is a 'liberalising force,' that has 'immeasurably extended the realm of the known,' in the 'intellectual conquest of our world by our minds.'[2]

Kuhn explicitly criticises Popper's conception of falsification in *The Structure of Scientific Revolutions*. He politely allows that there are some similarities between the role of Popper's falsification and the role of 'anomalous experiences' in his model, before suggesting that 'falsifying' experiences probably do not exist[3]. Kuhn points to the case-study evidence previously supplied in his essay to repudiate the idea that scientists abandon theories if the data does not support them:

> On the contrary, it is just the incompleteness and imperfection of the existing data-theory fit that, at any time, define many of the puzzles that characterize normal science. If any and every failure fit were ground for theory rejection, all theories ought to be rejected at all times.[4]

The notion that scientists consciously and deliberately attempt to falsify the dominant paradigm could not be further from Kuhn's view of how science and scientists work.

The heliocentric revolution as reconstructed by Kuhn in *The Copernican Revolution* constitutes a perfect, prototypical example of a Kuhnian paradigm shift. Kuhn devotes the first half of the book to providing detailed explanations for why the Aristotelian-Ptolemaic geocentric paradigm had such a hold over the human psyche. The weight of these sections lends support to Kuhn's account of why the geocentric paradigm faced no serious challenge for over 1300 years, and of why it took so long for the Copernican Revolution to become accepted as the new paradigm.[5]

Kuhn outlines the two components of the geocentric paradigm: qualitative 'Aristotelian' cosmology and quantitative 'Ptolemaic' astronomy.

The uniform, circular motion of stars in the celestial sphere, first posited by Eudoxus and then sanctioned by Aristotle, was readily confirmed by the sensory evidence of naked-eye observations. Common sense also fully concurred with the descriptions of celestial and terrestrial motion outlined in Aristotelian physics. Lastly, the Earth's central position in the two-sphere 'cosmological scheme' satisfied 'the psychological craving for at-homeness': humans stranded in the ever-changing sub-

[2] K. R. Popper, *Conjectures and refutations: the growth of scientific knowledge*, New York 1968, p. 102.

[3] T. S. Kuhn, *The Structure*..., p. 146.

[4] Ibidem.

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

lunary sphere could take solace from a cosmology that placed their home at the centre of the perfect, regular celestial rotations.

Kuhn demonstrates how this cosmology was both underpinned by and reinforced by the observations and calculations of qualitative astronomy. Following Apollonius and Hipparchus, Ptolemy offered astronomers computational devices that could efficiently account for observed data and enable accurate predictions. Ptolemaic astronomy was sufficiently flexible to cope with serious anomalies in the data without – for the most part at least – betraying the fundamental assumptions underlying the Aristotelian cosmological scheme.

In their attempts to predict future celestial movements, astronomers were forced to deal with evidence of past movements that seemed to clash with the principles underlying the conception of the two-sphere universe. In contrast to the stars in the outer celestial sphere, which regularly rotate westward every night, the planets were known as 'wandering stars' because, in addition to the nightly westward rotation, they could also be observed slowly moving eastward against the celestial backdrop throughout the course of a year. To make matters worse, naked-eye observation detected that there were irregularities in these wandering motions. One irregularity – known as the first or zodiacal anomaly – concerned speed: for example, the sun seemed to move faster through some parts of the zodiac than others. The second anomaly concerned observations of retrograde motion: when in opposition to the sun, Mars, Jupiter and Saturn were observed to reverse their usual eastward motion and move westward before returning to normal eastward motion.

Kuhn provides a detailed demonstration of how ancient astronomy devised geometric models of motion to account for both these anomalies. For example, Ptolemy accounted for the first anomaly (irregular speed) by placing the sun on a circle "whose centre is displaced from the centre of the earth,"[6] a device known as an eccentric. Small circles that moved around the circumference of larger circles, i.e. epicycles on deferents, could also be used to account for the first anomaly. The second anomaly (retrograde motion) could be accounted for by means of more complex epicycles on epicycles.[7]

Neither the eccentric nor the epicycle violated the underlying assumptions underlying the Aristotelian two-sphere universe: the motion of the planets on eccentric circles or on epicycles was constant and regular. However, in order to reconcile interaction between the two anomalies, and to make observations of the outer planets (particularly Mars) more accurate, Ptolemy employed a geometric device,

[6] Ibidem, p. 70.

[7] Ibidem, p. 69.

the equant, which did violate the principle of uniform motion.[6] The equant device enabled the rate of planetary rotation on an epicycle to *appear* non-uniform, if the observer viewed the rotation of the deferent from an off-centre equant point, rather than from the geometric centre.

Kuhn indicates that it was the equant, introduced in order to account for anomalous data, that inspired Copernicus to begin questioning the Aristotelian-Ptolemaic paradigm:

> Observed from the geometric center of its deferent, the planet seems to move at an irregular rate or to wobble. Because of the wobble, Copernicus felt that the equant was not a legitimate device for application to astronomy. For him the apparent irregularities of the rotation were violations of the uniform circular symmetry that made the system of epicycles, deferents and eccentrics so plausible and attractive.[8]

Yet, in accordance with Kuhn's model of scientific revolutions, Copernicus' rejection of the equant is far from a conceptually bold move – it is rather cast as an example of the decidedly non-revolutionary discomfort with 'trivial mathematical details' or 'technical minutiae' that tends to underlie paradigm shifts.[9]

Apart from Copernicus' abhorrence for the monstrous equant, Kuhn adduces other factors that contributed to his rejection of the geocentric paradigm.

The first of these factors are the contributions of scholastic science: most notably Buridan's impetus theory, which reconsidered and added to Aristotelian dynamics, and Oresme's suggestion that the earth and heavens were subject to 'a single set of laws,'[10] a suggestion that undermined the essential dichotomy of the two-sphere universe.[11]

The second factor that Kuhn mentions was simply the time that Copernicus lived in. The years 1473-1543 were a time of tremendous upheaval, mainly due to Luther's assault on papal authority. With the suggestion being that this revolutionary atmosphere inevitably rubbed off on on Copernicus: "[...] stereotypes are most readily discarded during periods of general ferment."[12] These years were also a time of ground-shaking discovery, with the Portuguese explorations of the African coast and Columbus' voyage to America, which revealed how wrong Ptolemy's geography was and necessitated more accurate knowledge of star positions for navigational

[8] Ibidem, p. 71.
[9] Ibidem, p. 73.
[10] Ibidem, p. 121.
[11] Ibidem, p. 122.
[12] Ibidem, p. 124.

purposes. Copernicus' lifetime was also, of course, a time of great rediscovery, with the Renaissance recovery and reconstruction of classical texts, including Ptolemy's *Almagest* from Greek sources, which revealed that Ptolemy's errors were present in the original and were not purely due to problems of translation.

The last factor adduced by Kuhn is resurgent Neoplatonism, a scientific movement which developed alongside Renaissance humanism. Inspired by Plato and Proclus, this 'otherworldly' strain of thought inspired astronomers to look for the mathematical patterns at work behind physical appearances:

> [...] some Renaissance scientists, like Copernicus, Galileo, and Kepler, seem to have drawn two decidedly un-Aristotelian ideas: a new belief in the possibility and importance of discovering simple arithmetic and geometric regularities in nature, and a new view of the sun as the source of all vital principles and forces in the universe.[13]

Kuhn asserts that Copernicus had contact with the Florentine Neoplatonists during his sojourn in Italy, and identifies a distinctly Neoplatonic section in Book I of *De revolutionibus*.[14]

According to Kuhn, Copernicus was unwittingly carried along by these revolutionary 'philosophical currents.'[15] At the same time, Kuhn claims that it was these currents that enabled Copernicus to perceive the current state of Ptolemaic astronomy, with its accumulation of inaccuracies and complexity, as monstrous.

Kuhn claims that by the sixteenth century there were numerous versions of the Ptolemaic system in circulation, as numerous astronomers had made modifications to the models in order to save the appearances. Furthermore, inaccuracies in Ptolemy's data were compounded by the passage of time (i.e. thirteen centuries). However, according to Kuhn, this diffuseness and inaccuracy was not enough itself to make any other astronomers abandon the geocentric paradigm, "for the the tradition had been diffuse and inaccurate before."[16] Only Copernicus was able to see the Ptolemaic monster for what it was.

Kuhn's Copernicus was in the right place at the right time: exposed to upheaval, to radical questioning of authority, and to a powerful resurgence of a mathematical philosophy capable of rivalling institutionalised Aristotelianism. Copernicus was

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[13] Ibidem, p. 128.

[14] "In the centre of all rests the sun. For who would place this lamp of a very beautiful temple in another or better place than this wherefrom it can illuminate everything at the same time." N. Copernicus, *De revolutionibus orbium caelestium*, transl. C. G. Wallis, New York 1995, pp. 24-25.

[15] T. S. Kuhn, *The Copernican Revolution*..., p. 141.

[16] Ibidem.

also, Kuhn concedes, a very skilled mathematician and competent astronomer. In *The Copernican Revolution* it is the convergence of all these factors that is responsible for the beginnings of the heliocentric paradigm shift.

Nevertheless, Kuhn's Copernicus, despite his skills and unique insight, is still no revolutionary. Motivated by dissatisfaction with 'trivial mathematical details,' Copernicus is presented as a blinkered specialist unable to transcend his own narrow field[17]. While he may have abandoned Ptolemy's system and been the first astronomer to attempt a mathematical description of the Earth's motion, and even though he quite clearly claimed his model represented the true reality of the universe, Copernicus left Aristotelian cosmology and physics almost completely intact:

> So far every one of Copernicus' arguments is Aristotelian or scholastic, and his universe is indistinguishable from that of traditional cosmology. In some respects he is even more Aristotelian than many of his predecessors and contemporaries. He will not, for example, consent to the violation of the uniform and symmetric motion of a sphere that is implicit in the use of an equant. [...] The radical Copernicus has so far shown himself a thoroughgoing conservative.[18]

This is the crux of Kuhn's argument: the Copernican revolution can hardly be found in *De Revolutionibus* because Copernicus only managed to reject and provide an alternative for one component of the prevailing paradigm. Copernicus rejected and replaced Ptolemy's quantitative geocentric system, but his replacement heliocentric system was still firmly situated in the same qualitative Aristotelian cosmos, with the same physics and underlying principles. For Kuhn, all the shortcomings of *De Revolutionibus*, i.e. its impenetrability, complexity and inaccuracies, are due to this residual Aristotelianism, and particularly his unswerving loyalty to the principle of uniform motion

Kuhn's commentary on Chapters 7, 8 and 9 of Book 1 of *De revolutionibus*, where Copernicus anticipates the arguments of physicists against the movement of the earth, depicts Copernicus as being woefully unaware of just how incompatible his system was with Aristotelian physics. For example, to ward off the argument that motion of the earth would be violent and lead to its disintegration, Copernicus counters that if the earth is a planet like all the others, then its motion would be natural and circular. Kuhn points out that if the earth is granted uniform circular motion, motion which in Aristotelian physics is reserved for the celestial sphere, then the distinction between the sublunary (terrestrial) sphere and the celestial sphere – an absolute

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[17] Ibidem, p. 145.

[18] Ibidem, p. 148.

distinction in Aristotelian physics – simply collapses.[19] Though Kuhn claimed not to 'discredit' Copernicus, the lack of a convincing physical explanation for the earth's motion is depicted as a kind of failure:

> [...] the inadequacies of Copernicus' physics do illustrate the way in which the consequences of his astronomical innovation transcend the astronomical problem from which the innovation was derived, and they do show how little the author of the innovation was himself able to assimilate the Revolution born from his work.[20]

In addition to facing resistance from common sense, Biblical authority and institutionalised loyalty to the prevailing geocentric paradigm, acceptance of the new Copernican heliocentric paradigm was thus, according to Kuhn, also hindered by poor delivery. The lack of a convincing alternative to Aristotelian physics in *De Revolutionibus* meant that the Copernican Revolution was not widely accepted until Newton (following the work of Galileo, Gilbert and Kepler) published his *Principia* – 143 years after the publication of *De revolutionibus*.

The 143 years between *De Revolutionibus* and the *Principia* fit nicely into Kuhn's model of scientific revolutions: it was a period of crisis and gradual assimilation of the new paradigm. Representatives of the old paradigm did battle with representatives of the new; the most public and dramatic being Galileo's confrontation with Cardinal Bellarmine and the Vatican. Incompatible theories competed publicly to replace the old paradigm, with Tyco Brahe's astronomy and Rene Descartes physics losing the consensus to Kepler's astronomy and Galilean-Newtonian dynamics. And once the weight and predictive power of Newton's *Principia* settled the matter, science returned to its default stable state: the specialised business of answering questions posed by the prevailing paradigm.

It is worth noting that the construction of the Copernican paradigm shift is far more sophisticated in *The Copernican Revolution* than the version Kuhn offers in *The Structure of Scientific Revolutions*, where he was at pains to emphasise the role of anomalies and crisis in triggering revolutions:

> But as time went on, a man looking at the net result of the normal research effort of many astronomers could observe that astronomy's complexity was increasing far more rapidly than its accuracy and that a discrepancy corrected in one place was likely to show up in another's. [...] By the early sixteenth century an increasing number of Europe's best astronomers were recognizing that the astronomical paradigm was

[19] Ibidem, pp. 150-155.
[20] Ibidem, p. 155.

> failing in application to its own traditional problems. That recognition was prerequisite to Copernicus' rejection of the Ptolemaic paradigm and his search for a new one. His famous preface still provides one of the classic descriptions of a crisis state.[21]

This section does not sit well with Kuhn's account in *The Copernican Revolution* of the factors that led Copernicus to reject the Ptolemaic system, where Kuhn stressed the role of the intellectual climate and philosophical currents in enabling Copernicus to see Ptolemy's system as a monster, and where he stressed Copernicus' unique insight: "for the the tradition had been diffuse and inaccurate before."[22]

In *"Crisis" versus aesthetic in the Copernican revolution*,[23] Owen Gingerich argued against Kuhn's assertion that the Copernican revolution was brought about by crisis caused by the accumulation of discrepancies and inaccuracies. Gingerich argues that in the early 16th century, rather than there being an increasing number of astronomers able to recognise the failures of the Ptolemaic paradigm, as Kuhn claims, late 15th and early 16th century astronomers were actually only just getting to the point where they could *understand* Ptolemy again, let alone improve upon his work.

Gingerich recomputed the data from the 13th Alfonsine Tables, which were based on pure Ptolemaic models to make 'a daily ephemeris for three centuries,' and then compared them with the data of Johannes Stoeffler (1452-1530), a professor of mathematics at Tübingen University and leading ephemeris-maker in the 16th century. Gingerich commented on the results of these computations:

> [...] these positions agreed so closely with those published by Stoeffler that I am forced to conclude he used the unembellished Ptolemaic system, as transmitted through the Alfonsine Tables.[24]

So, far from astronomers experiencing increasing discomfort as they added epicycles to epicycles *ad infinitum*, in a vain attempt to make Ptolemy's system agree with the data, as Kuhn's stereotype of pre-Copernican astronomy suggests, Gingerich's evidence suggests that competent astronomers were more than comfortable with Ptolemy's system and the data it generated.

Gingerich argues that Copernicus' innovation was a revolution born of aesthetic vision rather than of a widespread perception crisis in science. Referring to the *Preface* to *De Revolutionibus*, where Copernicus criticises the mathematicians' failure to

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21 T. S. Kuhn, *The Structure...*, pp. 68-69.

22 T. S. Kuhn, *The Copernican Revolution...*, p. 141.

23 O. J. Gingerich, *'Crisis' versus Aesthetic in the Copernican Revolution*, "Vistas in Astronomy" vol. 17, 1975, pp. 85-95.

24 Ibidem, p. 88.

deduce the principal thing, "namely the design of the universe and the fixed symmetry of its parts," Gingerich argues that Copernicus stumbled upon 'a profound simplification' when he put the earth in motion. In Ptolemy's system the orbits of the planets could be scaled arbitrarily, but in the Copernican system they are fixed in respect to each other. The mathematical simplicity and elegance of this system contrasts sharply with Ptolemy's monster.

The question Gingerich then asks is this: if the Copernican revolution was triggered purely by an aesthetic vision rather than crisis, why was there not a Copernicus before the 16th century? Theoretically, any astronomer after 150 AD could have rejected Ptolemy's system on the basis of its lack of aesthetic economy, and experimented with putting the earth in motion.

Gingerich's answer to this question is somewhat similar to Kuhn's explanation in *The Copernican Revolution* (though Gingerich makes no reference to Kuhn's more sophisticated account in this book). Gingerich attributes Copernicus' ability to make his innovation to the 'intellectual climate,' voyages of discovery, and the advent of printing, concluding:

> In many ways, the world was ready for an innovative view of the cosmos. Copernicus, with both the intellect and the leisure to fashion a new cosmology, arrived on the scene at the very moment when the increased flow of information could both bring him the raw materials for his theory and rapidly disseminate his own ideas.[25]

Whilst I fully agree that the cultural climate during Copernicus' lifetime was extremely conducive to scientific and philosophical innovation, I would also argue that Copernicus also availed himself a conceptual tool that was crucial for the unfolding of his unique insight, namely hypothetical thinking. The power of this thinking is particularly evident in Copernicus' *Commentariolus*, a text that Kuhn almost completely suppresses in *The Copernican Revolution*.

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[25] Ibidem, p. 91.