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THE DIALOGICAL ROOTS OF THE COPERNICAN REVOLUTION: IMPLICATIONS FOR THE CONTINUITY THESIS

1. The Multicultural Roots of Modern Science

It is generally taken for granted that modern science is mainly founded on the achievements of the philosophical, mathematical and scientific discoveries made by ancient European thinkers. The role of Asian contributions, even when it gets acknowledged, is seen as having only marginal significance. This is especially the case when attempts are made to account for the seminal event that led to the birth of modern science – namely, the Copernican Revolution[1]. The Copernican Revolution refers to the dramatic changes in astronomical theory proposed by Nicholas Copernicus in 1543 in which he argued against the geocentric theory taken for granted in his own timem, that is that the earth was at rest and that the sun, together with the other planets, revolves around it. Instead Copernicus proposed the idea, incredible at the time, that the massive Earth was actually rotating on its axis at great speed every twenty–four hours, while at the same time revolving around the sun together with the other planets[2].

But removing the earth from the center, and replacing the sun as the center of the universe, also came to require an entirely new physics and astronomy to explain why bodies near the earth fell to the earth but those near the sun fell to the sun, and why the planets went around the sun while the moon went around the earth. Before Copernicus scientists had explained why bodies fell to the earth, and why heavenly bodies revolved around it, by

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[1] Such oversight is understandable with early writers, such as T. Kuhn, *The Copernican Revolution* ... , who developed their ideas in a context that only later came to be reshaped by the pioneering researches of Joseph Needham, but it surprisingly continues with more recent works on the Copernican Revolution. Although Needham's contributions have led to some acknowledgement of the technological contributions of Chinese civilization, there continues to persist a reluctance to admit that some contributions from China also had a theoretical impact. See H. F. Cohen, *The Scientific Revolution* ... . However, recent studies, such as M. Kokowski, *Copernicus's Originality* ... , A. Bala, *The Dialogue of Civilizations in the Birth of Modern Science* and G. Saliba, *Islamic Science and the Making of the European Renaissance* have begun to take into account theoretical contributions from non–European cultures.

[2] Some writers tend to separate the Copernican Revolution from the Scientific Revolution by associating the former with the proposal of the heliocentric theory by Copernicus and the latter with the changes that led to a new physics and cosmology as a consequence. However, we will use the expression Copernican Revolution to include both. In his study T. Kuhn, *The Copernican Revolution* ... distinguishes them as the narrow and wider Copernican Revolution.

appealing to the fact that the earth was at the center of the universe. It then became possible to argue, as Aristotelians did, that heavy bodies tend to fall to the center of the universe at the center of the earth, and heavenly bodies to revolve around this center since they were made of a special substance *quintessence*[1]. This new physics and astronomy came to be completed through the work of a series of seminal pioneering thinkers – Tycho Brahe, Galileo Galilei, Johannes Kepler, and Isaac Newton. In an important sense Newton brought the changes to a completion by uniting physics and cosmology in one framework with his laws of motion and the theory of gravitation[2].

In the past most historians of science have generally taken the revolution that Copernicus initiated and which Newton completed to have been built mainly on contributions of mathematical, scientific, and philosophical ideas rooted in ancient European science – both Greek Hellenic and later Hellenistic science. However, the pioneering discoveries of Joseph Needham showing the seminal contributions of Chinese science to modern science and the efforts of those who followed him in documenting wider Asian influences on modern science show this assumption to be untenable. They reveal how the Copernican revolution came to be completed only because European scientists were able to draw upon a reservoir of discoveries and ideas from Arabic, Indian, and Chinese sciences, and combine these ideas with others rooted in ancient European Greek science. Consequently it is more accurate to see the Copernican Revolution that gave birth to modern science as the outcome of influences from many different cultural traditions of science[3].

2. The Continuity Thesis

However, such multicultural influences are often marginalized, even when they get acknowledged, because their contribution is seen as something quite dispensable. This follows from what can be characterized as *the continuity thesis* connecting ancient Greek science and modern science. According to the continuity thesis ancient European Greek thought already contained all the necessary philosophical, mathematical, astronomical, and scientific ideas needed to produce the Copernican revolution, because Copernicus, Galileo, Kepler and Newton were merely taking off from where ancient European Greek science had left off. Hence, if some ancient Greek Copernicus, say, had

[1] See A. F. Chalmers, *What is This Thing Called Science?* for a more comprehensive discussion of these issues. What makes Chalmers study significant is that he links the changes by drawing out their implications for the philosophy of science.

[2] The process took over a hundred and forty years to complete. This is not surprising since the accumulation of new more accurate data on planetary motions by Brahe, the synthesis of these in terms of three planetary laws by Kepler, and the discovery of the laws of free fall by Galileo, all involved monumental achievements without which Newton could not have completed his revolution.

[3] This multicultural perspective has been developing over many decades since Needham's pioneering studies of Chinese science began in 1954. However, most studies of multicultural contributions have followed Needham by adopting what can be described as a binary orientation, which takes one civilization – Chinese, Arabic, or Indian – and documents its contribution to modern science in the West. It is only recently that some writers such as G. G. Joseph, *The Crest of the Peacock* ... , J. M. Hobson, *The Eastern Origins of Western Civilization* and A. Bala, *The Dialogue of Civilizations in the Birth of Modern Science* have looked at how contributions from a plurality of cultures combined in Europe at the dawn of modern science.

proposed the heliocentric theory in the second century, at the time of the decline of ancient Greek science shortly after Ptolemy, it would have been possible for Greek scientists to have followed the steps of Galileo, Kepler, and Newton to give birth to modern science more than a millennium earlier. That it didn't actually happen is seen as being beside the point – it could have happened because Greek science had all the relevant conceptual tools to make this transition. Hence, even if ideas came to be drawn from cultures outside Europe, these did not constitute anything essential that could not have been easily extended out of Greek science to making modern science possible. It gives strong grounds for supposing that Greek science, so the argument goes, can be treated as the direct precursor of modern science[1].

However, in this paper I shall attempt to demonstrate that the continuity thesis is untenable. Ancient Greek science could not have led to modern science sooner even if Copernicus had been born at the time of the decline of ancient Greek science. Much of the mathematics as well as the theoretical and empirical ideas needed for Newton's achievement were discovered by Arabic, Indian, and Chinese mathematicians, scientists, and astronomers long after the decline of ancient European science. Moreover, since dialogue with these Asian traditions of science made possible the birth of modern science, it is not possible to sustain the continuity thesis. We will now illustrate the importance of such multicultural impacts on modern science by looking at three crucial influences on the Copernican Revolution – Arabic optics, Indian mathematical atomism, and Chinese empirical astronomy.

3. Arabic Optics and Mathematical Realism

One of the main characteristics of modern science is its belief that the laws of nature are mathematical laws faithfully obeyed by natural phenomena. Ancient European scientists and astronomers did not believe that such an embodiment of mathematical laws in nature is possible. For ancient European thinkers mathematical forms could not be embodied in the world because even within the realm of geometry they considered it impossible to find perfect triangles, circles, or straight lines exemplified by concrete physical objects. It led empirically oriented thinkers, such as Aristotle, to incline toward a non–mathematical approach to natural phenomena, and more mathematically inclined thinkers, such as Plato, to turn away from the empirical realm in order to study perfect intellectual forms. As a result ancient European astronomers were satisfied if their theories could, as far as reasonably possible, *save the phenomena*, i.e. allow them to predict the results of observation with more or less reasonable mathematical precision. But they saw any demand to show that the world reflected perfect mathematical order as a request for the impossible[2].

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[1] T. Kuhn, *The Copernican Revolution* ... makes such an argument. Another historian adopting this position is E. J. Dijksterhuis, *The Mechanization of the World Picture*, pp. 288–289 who writes: *barring the application of trigonometric methods of computation one finds nothing [in Copernicus] that might not just as well have been written in the second century CE by a successor of Ptolemy*.

[2] The notion of *saving the phenomena* was very much a part of Ptolemaic astronomy. It made it possible to view the heavenly motions as regulated by spheres moving in spheres without too much concern about the

However, the idea that heavenly phenomena were merely to be approximated by mathematical models did not appeal to modern European astronomers in contrast to their ancient counterparts. What brought about this dramatic change? One plausible answer is that it came about because modern European thinkers had inherited from Arabic science a physical theory in which the phenomena of nature seemed to embody perfect mathematical order. This was the optical theory of the Arabic scientist ibn al–Haytham.

Al–Haytham's work, *Optical Thesaurus*, was translated into Latin in the 12th or early 13th centuries and had an enormous impact on European optics from that point on. It came to influence nearly all the major medieval European thinkers who worked on optics including Robert Grosseteste, Roger Bacon, John Pecham and Witelo. Through them Alhazen – as al–Haytham's name came to be latinized – influenced optical thinkers into the 17th century, including Galileo and Kepler. Galileo appealed to the *Optical Thesaurus* when he had to demonstrate that moon was not a polished mirror as maintained by some of his Aristotelian critics and Kepler took off from the point where Bacon, Pecham and Witelo had developed Alhazen's optical paradigm[1].

Alhazen had developed his optical theory by carefully examining the scope and limits of the different theories that Arabs had inherited from the ancient Greeks. These followed three quite different approaches to understanding optical processes inspired by either Aristotle, Plato, or Galen[2]. The Aristotelian theory assumed that perception occurred by virtue of the fact that the perceived object disturbed the transparent medium between the object and observer – a disturbance that came to be instantly transmitted to the observer's eye where it generated sensation. David Lindberg, the historian of science, labels the Aristotelian theory as an *intromission* theory of perception since we perceive an object because something enters the eye from the outside. Although the Aristotelians could apply the theory to physically account for many aspects of vision, the Aristotelian intromission theory could not give a mathematical account of the way the image in the eye was formed. It remained simply a qualitative theory.

By contrast Platonic optics offered a mathematical account of perception. This came to be possible because Plato held the view that perception occurs because the eye sends out an emanation that gets intercepted by the object. The shape, size and location of the object can be inferred by the pattern and location of the intercepted rays. Since this theory views perception to occur by virtue of an emission from the eye, rather than something entering the eye, Lindberg labels it an *extramission* theory of perception. Plato's theory was subsequently refined by the mathematician Euclid. In Euclid's optical theory radiation emanates from the eyes in the form of a cone – the visual cone – and an object is perceived when the rays forming the cone get interrupted by it.

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physical impossibility of such motions since they were treated as purely conceptual devices that permitted the correct calculation of observed results.

[1] For a more detailed account of Alhazen's influence on medieval European optics see D. Lindberg, *The Beginnings of Western Science* ... .

[2] D. Lindberg, *The Beginnings of Western Science* ... , pp. 308–309.

This approach made it possible for Euclid to give a mathematical, more precisely geometrical, theory of perception.

The third Greek theory was derived from medical practitioners and rooted in a tradition pioneered by the physicians Herophilus and Galen. It was base upon studies involving the physiology of sight and the anatomy of the eye. Galen had become the dominant authority in this area after he had described in detail the structure of the eye, the various organs that constituted the visual pathways and showed how they combined to facilitate vision. However, Galen's physiological theory was, like Aristotle's intromission theory, a non–mathematical account of perception more concerned with describing how mechanisms in the eye made vision possible.

Alhazen's great achievement was to integrate the virtues of these different theories. He combined the mathematical sophistication of the extramission theory and the physical plausibility of the intromission theory by drawing on the physiological account of perception given by the medical practitioners. In effect he created a new synthesis of the different optical theories derived from the ancient Greeks. To accomplish his task he began by showing the implausibility of the extramission theory. He argued that an emanation arising from within the eye cannot by its very nature harm the eye. But very bright objects can injure the eye. Hence the injury must be caused by something entering the eye from the outside. He also argued that since our perception extends even up to the stars in the heavens the extramission theory implies that material emanated by the eye fills the whole of space that we reach by vision. But this is highly implausible. Hence, he concluded, the extramission theory must be rejected.

However, Alhazen also appreciated the mathematical power of the visual cone associated with the extramission theory. Hence he wished to retain it even after he rejected the extramission theory on the grounds of its physical implausibility. He found a plausible approach to achieving this objective through his studies of the *camera obscura* – the pinhole camera. He conjectured that an image of an object before the camera forms on the back of the screen because every point on the object – although it radiates light in all directions – only has a single ray that reaches the pinhole from any point on it. It is this ray that contributes to the formation of the image. Alhazen argued that a similar process occurred with the eye by virtue of the fact that only rays which fall perpendicularly on the eye lens are sensed. The others are not felt since they become weakened by being refracted and their contribution to vision can be ignored. However, following Galen, Alhazen still treated the crystalline humor or lens of the eye as the primary sensing organ in facilitating the process of vision. Alhazen's synthesis of the mathematical virtues of Platonic optics, the physical plausibility of Aristotelian optics, and insights of Galenic physiology of the eye was so powerful that his theory came to dictate thinking about light and perception once it entered Europe through translations[1].

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[1] D. Lindberg, *The Beginnings of Western Science* ... , p. 309.

However, Alhazen's achievement had an impact on epistemology that went beyond its significance for theoretical optics. It profoundly reoriented the goal of science modern European scientists set themselves in contrast to the ancient Greeks. Greek science had always assumed that ideal mathematical forms could not be embodied in the world – e.g. even Archimedes worked with weightless pulleys that could not be found in the real world. However, light rays in Alhazen's optics were real rays he considered to travel in perfect straight lines. Hence, Alhazen's optical theory did not separate the physical object studied and the mathematical laws it obeyed by mediating calculations through an ideal object. Thus his optics showed that mathematics could be applied to physical phenomena by assuming that the phenomena themselves embodied perfect mathematical relations. It constituted the archetypal mathematical realist theory of the world. This served to inspire early modern European scientists when they came to articulate mathematical models in astronomy and physics many centuries later. Moreover, many of the developments in optical instrumentation that led to the telescope which played such a crucial role in generating new evidence for the Copernican theory were rendered possible by Alhazen's optical theory[1]. Hence, those who assume the continuity thesis, that ancient European science alone could have given birth to modern science, are ignoring the impact of the Alhazen optical paradigm.

4. Indian Mathematics and Atomic Modes of Analysis

The role of Indian mathematics is another reason for thinking that the birth of modern science could not have taken off from Greek science. To a large extent the success of modern science is crucially dependent on the new number system Europeans inherited from India without which it is hardly likely that scientists could have managed the far greater complexity of computations required in the new mathematical conception of nature. Indeed, given the limitation of the mathematical instruments available to them, Greek scientists could not have completed the Copernican revolution with sufficient mathematical precision to render it a credible alternative to the earth–centered world–picture. They simply did not have adequately powerful computational tools.

To appreciate this claim let us look at the way numbers are represented in the Indian place–value decimal number system with zero. In the Indian mathematical representation every number is represented as a power series – e.g. $4567 = (4 \times 1000) + (5 \times 100) + (6 \times 10) + 7 = 7 + 6.10 + 5.10^2 + 4.10^3$. The central principle built into such a representation is that that every number can be written as a sum of parts. The notion that a whole is no more than the sum of its parts is key principle for seventeenth–century modern physics. Most of the important concepts and laws of physics discovered at that time embody this summative principle – the mass of a body is the sum of the masses of each of its parts; the momentum of a body is the sum of the momenta of each of its parts; the volume, distance moved, force upon, and so on, of any body is the

[1] See S. B. Omar, *Ibn Al–Haytham's Optics* ... for a greater discussion of the practical and experimental impact of Alhazen optics.

sum of the volumes of its parts, the separate small intervals it traverses or the different forces acting upon it. Consequently, the mathematical system inherited from the Indians served as a powerful computational tool for the atomic mode of analysis that constituted a key pillar of 17th century science.

It is crucial to note that the atomic approach did not apply to physical bodies alone since properties such as volume, mass, momentum, force, and so on could be subjected to the same atomic dissection and reassembly. Even space and time could be divided and recombined as the sum of separate spatial and temporal intervals. The expression *mathematical atomism* could be used to characterize such a flexible atomic notion which goes beyond the narrower physical or material atomism associated with Democritus in ancient Greece. The mathematical atomism of the Indian number theory came to serve as the foundation for the study of a vast range of physical phenomena in modern physics.

Thus it is not surprising that the historian of science Alexandre Koyré came to doubt that modern atomism can be treated simply as a revival of ancient Greek atomism. He thought that, without the adoption of a mathematical approach to nature, atomism could not have offered a proper foundation for physics[1]. But Koyré does not explain why mathematical methods and techniques could not have been adopted by the ancient Greeks. However, it is the Indian number system – the decimal place–value system with zero that we currently use – which made the combination of mathematics with atomic theory possible. Hence, even if the ancient Greeks had considered combining mathematics with atomism they could not have succeeded.

The Indian role might have been even more than what has been suggested above if we take into account the claim that even the notion of infinite series – a seminal idea connected with the development of the mathematics of the calculus – could have been transmitted from India. Indeed, integral calculus is the outcome and natural extension of the mathematical atomism embodied in the Indian number system. Without the computational powers provided by the Indian number system calculus could not have developed. The number system allowed areas to be computed by dividing them into infinitesimal parts and summing them together and gradients of curved lines to be computed as the limits of a series of infinite terms. Indeed, it is acknowledged that Indian mathematicians of the Kerala School beginning with Madhava in the 14th century had anticipated modern discoveries in infinite series expansions for trigonometric functions and circular functions and many of the early methods of differentiation and integration[2]. These discoveries are generally seen as

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[1] A. Koyré, *From the Closed World to the Infinite Universe*, p. 278, n. 7 explains the failure of ancient Greek atomism as follows: *The explanation of this sterility lies, in my opinion, in the extreme sensualism of the Epicurean tradition; it is only when this sensualism was rejected by the founders of modern science and replaced by a mathematical approach to nature that atomism – in the works of Galileo, R. Boyle, Newton, etc. – became a scientifically valid conception, and Lucretius and Epicurus appeared as forerunners of modern science.*

[2] See G. G. Joseph (ed.), *Kerala Mathematics* ... for articles addressing the epistemological, historical, and sociological contexts of the origin and development of Kerala mathematics and its impact on modern mathematics.

being made independently by European mathematicians, leading to culminating achievements by Newton and Leibniz. However, there is now circumstantial, albeit not conclusive, evidence that Indian ideas in these areas could have reached European mathematicians via Jesuit scholars, who had reached India more than a century before such discoveries were made in Europe[1].

The mathematical compatibility of the Indian number system with atomic modes of analysis raises the question of how this could have come about. One possible answer is that the Indian number system developed in close association with atomic ideas over long historical periods. Unlike Europe and China where atomism never achieved any prominence until modern times, the atomic idea in India goes back to the times of the Buddha in the 6th century BCE. It became a dominant thema in all the major Indian schools of thought – Hindu, Buddhist and Jain.

The Hindu *Nyaya–Vaisesika* considered the four elements earth, air, fire and water to be composed of atoms both indivisible and indestructible. All atoms are also taken to have a spherical shape and to be in constant motion. The combinations of such atoms are seen to follow strict rules – they first combine as dyads and the dyads can in turn form triads where each component is itself a dyad. By adopting such concepts, similar to the way atoms in modern chemistry combine to form molecules and these more complex molecules Nyaya–Vaisesika thinkers were able to account for the physical and chemical properties of many different compounds they dealt with[2].

The Jains had quite a different atomic model which treated all atoms as identical. It was not the properties of atoms that shaped the differences between things but the way they combined together. Furthermore, the Jains also attributed properties like attraction and repulsion to atoms. The different properties of the elements were the result of different combinations of atoms which both attracted and repelled each other. Their view was quite sophisticated because they not only saw free atoms as traveling in straight lines, but also considered atoms bound in objects as capable of vibrating in a fashion analogous to how they are seen by chemists today.

Buddhist thinkers envisaged atoms as bundles of forces or energy with no permanent existence, but which appeared and disappeared continually to be replaced by other similar atoms. This conformed to their core metaphysics of process and incessant change. Like the Jains, the Buddhists also considered atoms to be centers of repulsive and attractive forces for other atoms. Despite the complexity of the processes involved, with atoms interacting with each other and being continually subject to decay and birth, they did not see the changes themselves as random chance events. Instead they were held to follow the Buddhist law of dependent origination – a rigidly regulated causal process where each appearance is conditioned by the context in which it appears[3].

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[1] For a discussion of the possible modes of transmission see A. Bala, *Establishing Transmissions* ... and D. Almeida & G. G. Joseph, *A Report of the Investigation on the possibility of the transmission* ... .

[2] See S. Goonatilake, *Aborted Discovery* ... , p. 17.

[3] See S. Goonatilake, *Aborted Discovery* ... , p. 17.

Given the pervasive significance of the atomic theory in most important schools of Indian thought it is not surprising that the Indian number system came to be designed to suit atomic conceptions. The number system enabled Indian scientists to work with very small numbers when they dealt with the dimensions of atoms, and very large numbers when they came to computing the numbers of atoms in large bodies. It became an ideal instrument for dealing with computational problems raised by the atomic conceptions of nature in all the major Indian traditions of thought. It also came to serve 17th century European scientists who developed modern science when they, like the Indians, came to deploy atomic ideas, infinite series and methods of the calculus, in dealing with natural phenomena.

If Alexandre Koyré is right then we must suppose that the atomic idea became dominant in early modern Europe only because the mathematical apparatus inherited from the Indians made it possible to fully exploit its potential. This suggests that modern science could not have simply morphed from Greek science as a natural continuation of it, because the latter did not have the necessary mathematical apparatus to make this possible.

5. Chinese Astronomy and a Universe of Change

Another reason for doubting the continuity thesis is the role of Chinese astronomical contributions to the Copernican revolution. The primary carriers of the Chinese influences into Europe were the Jesuits who arrived as missionaries to China in the 16th century. Having better and more accurate techniques for calendar calculations and predictions of eclipses they soon had established themselves in dominant positions within the Chinese astronomical bureau, which had always been closely linked to the imperial court. Their position gave them ample motivation and opportunity to study Chinese astronomical ideas at first–hand. Since they also maintained continuous and close communication with their superiors and colleagues in Europe, they were ideally placed to contrast Chinese views with established European beliefs about the cosmos.

Despite their established role in the Chinese court the Jesuits found many Chinese cosmological ideas quite incredible. In a letter sent back to Europe in 1595 the Jesuit missionary astronomer Matteo Ricci referred to a number of *absurdities* – as he called them – which the Chinese believed. He lists them as follows:

i. The earth is flat and square, and the sky is a round canopy.

ii. There are not many skies (as the Europeans held by taking each planet to be carried by a solid rotating sphere), but only one sky.

iii. The space between the planets and the stars is not filled with air – it is a void.

iv. There are five elements – earth, water, fire, wood and metal, and not four – earth, water, fire, and air as the Europeans held. Moreover, contrary to European views, the Chinese thought the elements could be transformed into each other.

v. The eclipse of the sun is caused by the moon which dims its light as it approaches the sun.

vi. During the night, the sun hides under a mountain near the earth[1].

It is surely noteworthy that half of the absurdities listed by Ricci have now become a part of modern science. Thus we would concur today that the Chinese correctly maintained that there is only one sky and not ten as European medieval astronomers thought, that the space between the planets and stars is a void and not filled with air, and that elements can be transformed into each other as the Chinese supposed. Of course we would concede that Ricci is right to think that earth is not a square or that the sun does not hide behind a mountain at night. These are indeed absurd for us today as they were for Ricci then. But what is significant is that we would reject Ricci's view that statements 2, 3 and 4 are absurd and only agree with him that statements 1 & 6 are absurd. However, it is difficult to see what we should make of statement 5. Did the Chinese see the moon as diminishing the light from the sun by some mysterious influence at a distance or by blocking it from our view? If they held the latter position we would be inclined to agree with them. But then Ricci would not have seen their position as absurd. So probably they held the view of a mysterious influence from the moon. However, even if we make this concession it is still the case that half the absurdities Ricci lists in Chinese cosmological ideas at the time have now become a part of mainstream modern science.

The Chinese impact on European astronomers did not lie within their mathematical sophistication but in their cosmological views. These were developed over long historical periods and in isolation from the astronomical traditions of the Indians, Greeks, Arabs and Europeans who were all much more historically interconnected by shared influences. In particular the Chinese had developed three distinct theories of the universe during the Han dynasty which had undergone articulation over a long time: the hemispheric dome theory, the celestial sphere theory, and the infinite empty space theory. We shall present them in brief below[2].

The hemispheric dome theory, developed in the first century BC, is the earliest of the three theories. According to it the sky is a semi–spherical dome which covers the earth. But the earth itself is a square which is elevated in the center so that it forms an inverted plate surrounded by water. The sky dome is attached to an axis which passes through it near the pole star and around which it rotates, thereby carrying all the heavenly bodies with it. The sun also rotates with the dome of the sky, but in addition it also moves towards and away from the central axis. It is nearest the axis during the summer and furthest in winter.

The second Chinese theory – the celestial sphere theory – was elaborated by Zhang Heng in 100 AD, although germinal versions of it could have appeared earlier. It assumes that the universe is shaped like an egg with the

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[1] See C. Ronan, *The Shorter Science and Civilization in China ...* , p. 213.

[2] An in–depth account of the various historically important Chinese astronomical theories can be found in P. Y. Ho, *Li, Qi and Shu ...* , pp.126–130. See also X. Sun, *Crossing the Boundaries Between Heaven and Man ...* , esp. pp. 437–443.

yolk at the center being the Earth[1].

In the 4th century Ge Hong describes the infinite empty space theory, but attributes it to Qi Meng who lived a couple of centuries earlier. This is the most philosophically sophisticated and intellectually revolutionary of the three theories considered. It assumes that the earth and other heavenly bodies are floating in an infinite empty space. Ge Hong writes:

> [The] *heavens were empty and void of substance* [...] *The sun, moon and the company of stars float (freely) in the empty space, moving or standing still. All are condensed vapor* [...] *It is because they are not rooted (to any basis) or tied together that their movements can vary so much. Among the heavenly bodies the pole star always keeps its place.*[2]

At the time the Jesuits first arrived in China the views embodied in the infinite empty space theory were radically at variance with European views. For example, the Chinese saw heavenly bodies as having a history and being subject to continual change. They also treated the sun, moon, and stars to be the outcomes of condensations from a vaporous substance *qi*. Such views closely resemble contemporary notions of stars and planets as formed from dispersed matter in empty space. It is an image of a cosmos that is in perpetual transformation – one distinctly different from the static heavens of European astronomers in the 16th century.

Moreover, unlike their European counterparts, the Chinese astronomers did not take the sun to be a perfect sphere and had surveyed, documented, and studied sunspot phenomena from as early as 28 BCE. Their official records document more than one hundred sunspots by 1638. Apart from sunspots they also kept records of comets, meteors and meteorites. These go back to 687 BCE. Chinese records of novae go back to oracle bone records – the first being as early as 1300 BCE. Indeed, of the four known supernovae in our local galaxy the two earliest are only given in Chinese records – the first in 1010 and the second in 1054. The latter is the origin of the Crab Nebula[3].

Despite the fact that comets, novae, and supernovae were observed by Greek, Arab and medieval European astronomers they were not treated as astronomical phenomena. Unlike the Chinese these astronomers explained them away as atmospheric events. Medieval Europeans, for example, saw comets as a hot dry exhalation from the earth that had ascended into the heavens. Hence they classified comet observations along with phenomena like lightning, thunder, shooting stars, and rainbows. Yet, shortly after contact with China and the entrenchment of the Jesuits in the Chinese astronomical bureau, European astronomers began to treat sunspots, comets and novae as part of astronomical data. Such data also became key elements that led Copernican astronomy to displace classical Ptolemaic astronomy. Since it is highly likely

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[1] See X. Sun, *Crossing the Boundaries Between Heaven and Man ...* , p. 441.

[2] C. Ronan, *The Shorter Science and Civilization in China ...* , pp. 86–87.

[3] P. Y. Ho, *Li, Qi and Shu ...* , pp. 150–152.

that the change was wrought by Chinese influence upon European scientists, can we still maintain the continuity thesis? Is it still credible to suppose that ancient Greek science was only a single step away from modern science?

6. Does Dialogical History Support the Continuity Thesis?

The arguments above suggest that the Copernican revolution – both the narrow revolution initiated by Copernicus when he proposed the heliocentric theory and the wider Scientific Revolution, as it is sometimes labeled, which terminated with Newton – could not have taken place without contributions from Arabic Indian, and Chinese scientific traditions. The mathematical realism of Alhazen optics provided the inspiration for the search for mathematical realist theories in modern astronomy. Indian mathematical ideas and techniques paved the way for the mathematical atomism that made it possible to complete the Copernican Revolution. Chinese cosmological ideas of a changing infinite universe populated by stars, comets and novae in incessant transformation furnished evidence against the Ptolemaic universe and paved the way for the success of the Copernican vision. But the continuity thesis assumes that Copernicus, Galileo, Kepler and Newton were more or less simply taking off from where ancient European Greek science had left off. But the multicultural contributions needed to make the revolution show that the continuity thesis is untenable – Greek science could not have paved the way for the birth of modern science without indispensable contributions from other non–European traditions of science.

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