

DISCOVERY IN THE NEW COSMOLOGY OF COPERNICUS, KEPLER AND GALILEO

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INTRODUCTION

I would like to suggest three components contained in the notion of discovery: newness, an opening to the future and, in the case of astronomical discovery, a blending of theory and observation. Discovery means that something new comes to light and this generally happens suddenly and unexpectedly. While I would not exclude that one can plan and even predict what is to be discovered, this is generally not the case.

According to this description Copernicus truly discovered. With one stroke of genius he resolved what for centuries had been a most puzzling feature of Ptolemaic astronomy, namely, that the annual motion of the sun was coupled to the motion of any other planet. In all the planetary theories there was a decisive parameter equal to precisely one solar year. In Ptolemy this strange coincidence appears as a simple fact which is neither explained nor commented upon, and before Copernicus very few astronomers had paid attention to it. Now it found a simple explanation in Copernicus' rearrangement of the celestial orbits. The sun was placed in the center of the universe and the earth revolving around it as a planet with a period of one solar year. Although Aristarchus, for instance, had long ago proposed a heliocentric universe, Copernicus' discovery was truly new in that his insight resolved a centuries long puzzle and paved the way to the future, to Kepler and Galileo and eventually to Newton. He was truly a revolutionary.

For all of his life Kepler remained convinced that the secrets of nature can only be disclosed by mathematical methods. However, when, using only mathematics he failed to determine a circular orbit for Mars that would satisfy Tycho Brahe's and his own observations, he changed his

method to an attempt to derive the motion of a planet from its cause. Assuming that the motive force comes from the sun and is inversely proportional to the distance from it, Aristotle's dynamical law of the proportionality of force and velocity showed immediately that the 'area velocity' of the planet is the same at both the apogee and the perigee. In the *Astronomia Nova* (1609)¹ Kepler made the assumption that it is constant all over the orbit. This is now known as Kepler's Second Law, a true discovery, since for the first time in the history of science, an intuited theoretical cause, i.e., a sun centered force, linked to observations had yielded a new result. This discovery plus that of the other two famous laws of Kepler looked to the future for a discovery of the ultimate cause. Kepler was surely one of the principal spans in the bridge from Copernicus to Newton.

Galileo was the first true observational astronomer² but he was also an experimentalist. In fact, it was precisely through his dedication as an experimentalist, and in particular through his studies on motion that he had come to have serious doubts about the Aristotelian concept of nature. What he sensed was lacking was a true physics. The world models inherited from the Greeks were purely geometrical and the geometry was based upon preconceived philosophical notions about the nature of objects in the universe: all objects had a natural place in the universe and consequently they had a natural motion. But there was no experimental justification for these preconceptions. They were simply based upon a philosophical idea of the degree of perfection of various objects. And then he came to know of the telescope. Did he have expectations that he would with the telescope find out for certain whether the world was Copernican? I expect not. His expectations were not that specific. He simply knew that the small instrument he had worked hard to perfect, if he had already convinced his patrons of its value for military purposes, was surely of some value for scientific purpos-

¹ *Astronomia Nova*, in M. Caspar (ed.), *Gesammelte Werke*, München, 1937, III.

² My claim that Galileo was the first true observational astronomer requires some justification. Galileo did not invent the telescope; he improved it for the precise purpose of astronomical observations. Nor, it seems, was he the first to use the telescope to observe the heavens. There is evidence that Thomas Digges of England, using a rudimentary reflecting telescope invented by his brother Leonard, saw myriads of stars about thirty years before Galileo's first observations. Even if this is true, the observations of Digges did not become known and had no scientific impact. Galileo not only observed; he intuited the great importance of his observations and he communicated them rapidly to the whole cultured world of his day. It is for that reason that I feel justified in naming him the first true observational astronomer.

es. That in itself, although it may seem trite to us, was a major discovery.³ He truly discovered; he contributed by his telescopic observations the first new data about the universe in over 2,000 years. He was the first of many to follow. They are 'the people with long eyes'.⁴

Each of these three great figures was in his own unique way a discoverer. Let us examine now in more detail what unique contribution each made through his discovery to development of cosmology.⁵

COPERNICUS, THE REVOLUTIONARY

Up until Copernicus arguments about cosmology were located within a mathematical and descriptive discourse on celestial phenomena without any significant reference to their immediate causes. In fact, because of that long historical antecedent, when in 1543 the great work *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Orbs)⁶ by Copernicus appeared its purpose was immediately misunderstood. It was provided with several prefaces, one of which was a letter from Cardinal Nicholas Schönberg written in 1536 CE and urging Copernicus to publish his new theory of the world. Another preface by Copernicus himself dedicated the work to Pope Paul III to whom the author explained his reasons for his drastic change of the traditional views on cosmology, hoping that the work might 'make some contribution also to the Church' by furthering the efforts to reform the Gregorian calendar, adding that *Mathematica mathematicis scribuntur*.⁷ This appeal to a certain autonomy of the mathematical

³ It indeed was a major discovery to intuit the importance of the telescope for investigating the universe. In Note 2 I have remarked that Thomas Digges may have actually been the first to observe with a telescope but it appears that he did so in a rather perfunctory fashion and without an appreciation of its value for science, or at least he did not communicate that science to the world.

⁴ This description of astronomers is due to the Tohono O'Odham Indians of the southwestern United States who, not otherwise having a word for astronomer in their language, constructed this phrase to describe those who came to build telescopes in collaboration with them on their sacred mountains.

⁵ I am very much indebted to the lifelong research of Olaf Pedersen (deceased in 1997) for much of this historical survey. I am preparing the posthumous publication of his voluminous work, *The Two Books*, a brief presentation of which is given in *The Book of Nature*, Vatican City, Vatican Observatory Publications, 1992.

⁶ Reprinted in the edition of Nicholas Copernicus, *Complete Works* published in several volumes by the Polish Academy of Science, Warsaw-Cracow, 1973.

⁷ 'Mathematical matters are written for mathematicians,' Copernicus, *Complete Works*, 1978, II, 5.

discourse on nature made him forestall incompetent objections: 'Perhaps there will be babblers who claim to be judges of astronomy although completely ignorant of the subject and, badly distorting some passage of Scripture to their purpose, will dare to find fault with my understanding and censure it. I disregard them even to the extent of despising their criticism as unfounded'.⁸ This premonition of coming disaster was perhaps the reason why the book contained also a third preface by a Lutheran Minister, Osiander, in which the serious nature of the Copernican reform was explained away as a purely abstract, mathematical game, just more of the same as throughout the previous centuries, that would not disturb the established order of the universe. It is the duty of the astronomer, it is said, to study the celestial motions and to 'conceive and devise the causes of these motions or hypotheses about them. Since he cannot in any way attain to the true causes, he will adopt whatever suppositions enable the motions to be computed correctly from the principles of geometry for the future as well as for the past. The present author [Copernicus] has performed both these duties excellently. For these hypotheses need not be true nor even probable. On the contrary, if they provide a calculus consistent with the observations, that alone is enough'.⁹

The very wording of this anonymous preface shows that it could not stem from Copernicus' own hand,¹⁰ nor did it express his own view of the ontological status of his now hypothesis, although a first reading of the work might easily suggest that the opposite were true, since there is no more physics in the *De Revolutionibus* than in Ptolemy's *Almagest* which Copernicus tried to revise, removing from it some of its less satisfactory features. Among these were Ptolemy's use of circular motions that were not uniform with respect to their own centers. Copernicus got around this aesthetic difficulty by devising a new system of planetary epicycles that was at least as complex as Ptolemy's own. However, as we have seen in the introduction, Copernicus' great revolution was to solve the long-standing puzzle of the one solar year dependence of all former planetary theories with a simple rearrangement of the celestial orbits. The sun was placed in the center of the universe with the earth orbiting it. Consequently, any position of a star must change with this period according to the changing position of

⁸ *Ibid.*

⁹ Copernicus, *Complete Works*, 1978, II, xvi.

¹⁰ In fact it was written by the Lutheran minister Andreas Osiander who saw the book through the press at Nuremberg. This was first discovered by Kepler.

the terrestrial observer. This solved the riddle of the Ptolemaic theories at the same time as it gave rise to the new question as to whether the fixed stars would also show an annual variation (or parallax) of a similar kind. An observational answer to this question would provide a deciding argument in favor of the Copernican system. Since no such parallax was discovered, Copernicus assumed, correctly so as we now know, that the sphere of the fixed stars, which was to him still the outer boundary of the universe, must be much further away than previously suspected.

Copernicus, contrary to Osiander and almost all cosmologists in the previous centuries, clearly realized that, even if various astronomical theories would save the same celestial phenomena, they might have different physical implications. This is obvious from his remark that it would be necessary to change the concept of gravity. Terrestrial gravitation could no longer be construed as a tendency to move towards the center of the universe, for the earth was no longer there. Instead he declared his belief 'that gravity is nothing but a natural desire, which the divine providence or the Creator of all things has implanted in parts, to gather as a unity and a whole, by combining in the form of a globe. This impulse is present, we may suppose, also in the sun, the moon, and the other brilliant planets, so that through its operation they remain in that spherical shape which they display'.¹¹ The only possible inference is that Copernicus believed his celestial kinematics to be a true account of the planetary system, even if, and this is the important point here, it was developed without consideration of the possible causes of the motions of its parts. Nonetheless, he also believed that this would lead him to true insights into reality as it had been shaped by the Creator. However, this passing reference to creation is practically the only point at which Copernicus referred to theological matters.

KEPLER, THE BRIDGE TO THE FUTURE

In fact, it is not until Kepler appeared that a scientist of the first order seriously considered his research in the light of his religious faith. Being always a convinced Copernican he tried in his first work, the *Mysterium Cosmographicum* (1596) to calculate the relative radii of the planetary orbits from the geometrical properties of the five regular polyhedra.¹² This

¹¹ Copernicus, *De Revolutionibus*, I, 9; in *Complete Works*, 1978, II.

¹² See the figure in *Mysterium Cosmographicum*, in M. Caspar (ed.) *Gesammelte Werke*, München, 1938, I.

was an attempt to derive information on the universe from purely geometrical structures that were known a priori. As such it clearly belonged in the Platonic tradition. In a similar vein the ratio of the orbits of Jupiter and Saturn seemed to appear from a special geometrical construction in the plane to which Kepler was led by considerations of astrology in which he was always an ardent believer. However, the results did not answer to the standard of accuracy which Kepler demanded and he had to admit his failure. He also failed, as we have seen in the Introduction, by his sheer mathematical method to determine a circular orbit for Mars. When he changed his method from pure mathematical analysis to a search for the cause of the motions he discovered the law of areas and armed with this result, he returned to the problem of the shape of the orbit which he attacked by making no *a priori* assumptions. He succeeded after very much numerical work in showing that Mars moved in an ellipse.¹³ The generalized assumption that all planetary orbits are elliptical expresses Kepler's First Law.

Kepler's Third Law appeared in a later work called *Harmonices Mundi* (1619) in a rather unexpected context. The book begins with a very long exposition of the mathematical theory of music in the tradition going back to the Pythagoreans. And so it has often been thought that the Third Law came to light by applying musical theory to Copernican astronomy, and it is possible that Kepler himself regarded his work as a kind of updated version of the 'Harmony of the Spheres'. Nevertheless, a closer examination of the text reveals that Kepler subjected the planetary periods of revolution 'T' and their mean distances from the sun 'a' to trial and error calculations and was fortunate enough to realize that the ratio T^2/a^3 is the same for all the planets.¹⁴ So here again it really was an a posteriori method which led to the result.

No previous scientist had ever been able to carry this type of mathematical approach to nature to a similar perfection with such a methodological freedom and open-mindedness. More than anyone else it was Kepler who became the herald of a new era in which mathematical physics would go from strength to strength, and his works remain a source of wonder and admiration for all who have the patience to follow all the turnings of his mind and to repeat all his computations.

¹³ *Astronomia Nova*, IV, 49, in M. Caspar (ed.) *Gesammelte Werke*, München, 1937, III, 367, ff.

¹⁴ *Harmonices Mundi*, V, 3, in M. Caspar (ed.) *Gesammelte Werke*, München, 1940, VI, 302.

But Kepler was also unique in another way. Despite their mathematical character his works were written in a highly personal style which faithfully explained all the mistakes he had made and all the blind roads he had explored before the final result turned up. This makes them difficult reading; but it also provides a rare psychological insight into the hopes and fears of his research, revealing both his frequent despair and his final jubilation when the goal was reached and a new property of nature disclosed. Recapitulating his work in the *Mysterium Cosmographicum* he wrote: 'How intense was my pleasure at this discovery can never be explained in words! I no longer regretted the time wasted day and night. I was consumed by computing in order to see whether this idea would agree with the Copernican orbits, or if my joy would be carried away by the wind'.¹⁵ This excitement was caused by an idea which failed and was in a way carried away by the wind. No wonder that a success made him even more jubilant as when he told about the discovery of the Third Law: 'Since the dawn eight months ago, since the broad daylight three months ago, and since a few days ago when the sun illuminated my wonderful speculations, nothing holds me back! I dare frankly to confess that I have stolen the Golden Vessels of the Egyptians to build a tabernacle for my God far from the bounds of Egypt [...]. The die is cast, and I am writing the book, to be read now or by posterity, it matters not! It can wait a century for a reader, as God Himself has waited 6000 years for a witness'.¹⁶

This text deserves a close reading. In particular the reference to the Golden Vessels is highly significant. As told in the story of the Exodus¹⁷ these vessels were stolen or borrowed by the people of Israel when they left Egypt. They were sacred treasures, not of their own making, but acquired from a foreign country. This clearly reminded Kepler of the manner in which his most spectacular discoveries had emerged. Every time he had tried to impress a mathematical structure of his own choice upon nature he had failed. The laws he found were not of his own making. Success always came a posteriori and in unexpected ways. Thus the discovery of the Third Law convinced him that 'the whole nature of harmonies in the celestial movements does really exist, but not in the way I previously thought, but in

¹⁵ *Mysterium Cosmographicum*, Praef., in M. Caspar (ed.) *Gesammelte Werke*, München, 1938, I, 13.

¹⁶ *Harmonices Mundi*, in M. Caspar (ed.) *Gesammelte Werke*, München, 1940, VI, 290.

¹⁷ *Exodus* 12, 35.

a completely different, yet absolutely perfect answer'.¹⁸ His results came as delightful surprises, precisely because they were not really fruits of his own intellect. Despite all the mental energy he had spent unraveling them, they were actually stolen from a foreign country outside his own mind.

Kepler gave this insight a deeply religious interpretation, realizing an inner harmony between his scientific and his spiritual vocation. And in his last great exposition of astronomy the same idea was still alive and prominent in his thought about the study of astronomy: 'For it is precisely the universe which is that Book of Nature in which God the Creator has revealed and depicted his essence, and what he wills with man, in a wordless [*alogos*] script'.¹⁹ This looks like a rather traditional instance of how the metaphor of the Book could be used with the backing of the Epistle to the Romans. But Kepler drew from it some personal consequences which shows how intense was his feeling of touching the Divine by means of his research. First it shed a revealing light upon his own self. Having undertaken to praise God in his works in the *Mysterium Cosmographicum*, he continued as if he suddenly realized the seriousness of what he had just put on paper: 'Therefore I am so stupefied that I must exclaim with Peter: "Go away from me for I am sinful man!"'.²⁰ And a couple of years later the same sense of being close to God in his work caused him to use a daring expression which had never before been heard in Christendom: 'Since we astronomers are Priests of the Most High God with respect to the Book of Nature, it behoves us that we do not aim at the glory of our own spirit, but above everything else at the Glory of God'.²¹ Twenty years later he had found no reason to abandon this understanding of the vocation of the scientist. In a preface to the Emperor he explained that 'I understand myself as a priest of God the Creator, appointed by your Imperial Majesty'.²²

This audacious notion of the scientist as a priest calls for two brief comments. Firstly, in Kepler it was not based on any sort of pantheism. He was not a priest of nature, but a priest of the Book of Nature; and the author of

¹⁸ *Harmonices Mundi*, V, Proem., in M. Caspar (ed.) *Gesammelte Werke*, München, 1940, VI, 189.

¹⁹ *Epitome Astronomiae Copernicanae* (1618) in M. Caspar (ed.) *Gesammelte Werke*, München, 1953, VII, 25.

²⁰ In the letter to Maestlin, 1595 October 3, quoted above.

²¹ Letter to Herwath von Hohenburg, 1598 March 26, in M. Caspar (ed.) *Gesammelte Werke*, München, 1945, XIII, 193.

²² *Epitome Astronomiae Copernicanae* (1618) in M. Caspar (ed.) *Gesammelte Werke*, München, 1953, VII, 9.

his book was a God who was not an immanent force in nature but a true Creator. He was even more; for to know him did not mean that man would see himself as a little spark of the Divine or an element of the great unity of everything. It meant that man saw himself as a sinner. Secondly, it is worth noticing that Kepler here took a significant step beyond Aristotle who had denied that any wisdom could be found in any kind of mathematics, and who had based his natural knowledge of God on the idea of causality in nature. Kepler was of a different opinion. The student of nature can realize the Glory of God even if he knows nothing about the causes of its phenomena. Kepler knew that he had found the three laws without really knowing the causes of planetary motion, even if he vaguely suspected it to be of a magnetic nature. And from a religious point of view it was enough to know that the relations or 'harmonies' of nature did really exist. This interpretation is supported by his brief meditation in the *Astronomia Nova* on King David the Psalmist who praised God for the wonders of the heavens even if he was 'far removed from speculating about physical causes, being completely at rest with the Greatness of God who made all this'.²³ Also for Kepler the mere 'givenness' of the constant relations in nature was the decisive point. Therefore, his intellectual conquests did not lead him to pride and vainglory, but to the humility of a man who was drawn out of himself to be at rest in that which was not his own.

GALILEO, EYES ON THE UNIVERSE

With Kepler the Book of Nature reached the summit of its metaphorical life as the vehicle of the self-understanding of a first rate scientist who was deeply committed to the Christian Faith. But with Galileo the Book of Nature was confronted with the Book of Scripture in a dramatic encounter which has ever since been regarded as one of the most decisive interactions between the world of science and the world of belief. Many polemicists have even taken it as the final proof of the alleged incompatibility of these two worlds and evidence of an essential enmity between the Catholic Church and the scientific attitude.²⁴ It became Galileo's fate to shake the

²³ *Astronomia Nova*, Dedic., in M. Caspar (ed.) *Gesammelte Werke*, München, 1937, III, 31.

²⁴ An excellent up-to-date study of the Galileo affair up until the most recent statements of John Paul II is: A. Fantoli, *Galileo: For Copernicanism and for the Church*, Vatican City, Vatican Observatory Publications 2002, Third English Edition; distributed by the University of Notre Dame Press.

foundations of the inherited discourse on nature. In this he was not alone, but in the course of the events he came to occupy a more conspicuous position than that of the other great pioneers of modern science. Copernicus had lived and worked almost unseen and unnoticed in a remote corner of Poland, and even if Kepler was the Imperial Mathematician his works were much too technical to draw the attention of more than a few experts. But, after many years of quiet work at Pisa and Padua, Galileo suddenly rode to European fame in 1610 when he published the first results of his epoch making astronomical observations with the telescope he had constructed (but not invented). All the world was amazed at the mountains on the moon, the innumerable fixed stars, the resolution of the Milky Way into separate stars, and the four satellites revolving around the planet Jupiter.²⁵ The framework of traditional cosmology had no room for such discoveries and would collapse under their weight.

During the very last year of what he himself described ‘as the best [eighteen] years of his life’²⁶ spent at Padua Galileo first observed the heavens with a telescope. In order to appreciate the marvel and the true significance of those observations, we must appreciate the critical intellectual period through which Galileo himself was passing at the time those observations were made. As we have noted in the Introduction, Galileo was the first true observational astronomer but he was also an experimentalist. It is impressive, indeed, to visit the *Istituto e Museo di Storia della Scienza* in Florence where one sees the many broken lenses from Galileo’s attempts to make ever better telescopes. He himself stated that ‘of the more than 60 telescopes made at great effort and expense [in his home in Borgo de’ Vignali in Padua] I have been able to choose only a very small number ... which are apt to show all of the observations’.²⁷ In that museum one also sees a display showing Galileo’s application of the pendulum to a clock and his experiments with an inclined plane in search of the law of falling bodies. Before he pointed his finest telescope to the heavens he had done his best to show experimentally that there were no serious ‘instrumental effects’. Again, in his own words: ‘In so far as I can truthfully state it, during the infinite, or, better said, innumerable times that I have looked with this instru-

²⁵ *Sidereus Nuncius*, Venice, 1610, in *Edizione Nazionale delle Opere di Galileo*, reprint-ed 1968, Florence, Giunti Barbèra, A. Favaro (ed.) III, 55-96. English translation in Stillman Drake, *Discoveries and Opinions of Galileo*, New York, 1957, 21-58.

²⁶ A. Favaro, *op. cit.* In Note 25, vol. XVIII, 209.

²⁷ *Ibid.*

ment I have never noticed any variation in its functioning and, therefore, I see that it always functions in the same way'.²⁸

Before we turn our gaze upon Galileo with his perfected telescope pointed to the heavens, I would like to attempt to recover his state of mind at that moment. This is admittedly a very tendentious thing to do, but I think it is important to attempt to do so for the sake of understanding what we might possibly mean by 'discovery'. He was nearing the end of a relatively long, tranquil period of teaching and research, during which he had come to question at its roots the orthodox view of the known physical universe. But he had as yet no solid physical basis upon which to construct a replacement view. He sensed a unity in what he experienced in the laboratory and what he saw in the heavens. For Galileo, the motion of falling bodies and the motion of the planets had something in common and geometrical explanations were not sufficient. Physics was required. But, in addition to his attachment to experiment and the sense for physics that derived from it, Galileo also nourished the idea that the true physical explanation of things must be simple in the richest meaning of that word. To be more specific, among several possible geometrical models the nature of the physical world would see to it that the simplest was the truest. But his view of the physical world was limited, although there was some expectation that, since with his telescope he had seen from Venice ships at sea at least ten times the distance at which they could be seen by the naked eye, he might go a bit beyond that limit. He was uncertain about many things in the heavens. He had seen an object suddenly appear as bright as Jupiter and then slowly disappear; he had been able to conclude that it must be in the realm of the fixed stars, but he could venture nothing about its nature.

Obviously not everything happened in the first hours or even the first nights of observing. The vault of the heavens is vast and varied. It is difficult to reconstruct in any detail the progress of Galileo's observations; but from October 1609 through January 1610 there is every indication that he was absorbed in his telescopic observations. From his correspondence we learn that he had spent 'the greater part of the winter nights under a peaceful open sky rather than in the warmth of his bedroom'.²⁹ They were obviously months of intense activity, not just at the telescope but also in his attempt to absorb and understand the significance of what he saw. At

²⁸ *Ibid.*

²⁹ *Ibid.*

times his emotional state breaks through in his correspondence. He makes a climatic statement in this regard in a letter of 20 January 1610, some weeks after his observations of the Medicean moons of Jupiter, when he states: 'I am infinitely grateful to God who has deigned to choose me alone to be the first to observe such marvelous things which have lain hidden for all ages past'.³⁰ For Galileo these must have been the most exhilarating moments of his entire life.

But he will be very acute and intuitive when it comes to sensing the significance of his observations of the moon, of the phases of Venus, and, most of all, of the moons of Jupiter. The preconceptions of the Aristotelians were crumbling before his eyes. He had remained silent long enough, over a three month period, in his contemplations of the heavens. It was time to organize his thoughts and tell what he had seen and what he thought it meant. It was time to publish! It happened quickly. The date of publication of the *Sidereus Nuncius* can be put at 1 March 1610, less than two months after his discovery of Jupiter's brightest moons and not more than five months after he had first pointed his telescope to the heavens. With this publication both science and the scientific view of the universe were forever changed, although Galileo would suffer much before this was realized. For the first time in over 2,000 years, new significant observational data had been put at the disposition of anyone who cared to think, not in abstract preconceptions but in obedience to what the universe had to say about itself. Modern science was aborning and the birth pangs were already being felt. We know all too well how much Galileo suffered in that birth process.

Galileo's telescopic discoveries dramatically overturned the existing view of the universe. They looked to the future. Were there other centers of motion such as seen with Jupiter and its moons? Did other planets like Venus show phases and changes in their apparent sizes? And what to make of those myriads of stars concentrated in that belt which crosses the sky and is intertwined with bright and dark clouds? All of these were questions for the future. Although neither Galileo nor any of his contemporaries had a well developed comprehensive theory of the universe, Galileo clearly intuited that what he saw through his telescope was of profound significance. His discoveries were not limited to looking; they involved thinking. Henceforth no one could reasonably think about the universe in the tradition of Aristotle which had dominated thinking for over two millennia. A new theory was required.

³⁰ *Ibid.*

Did Galileo's telescopic discoveries prove the Copernican system? Did Galileo himself think that they had so proven?³¹ There is no simple answer to these questions, since there is no simple definition of what one might mean by proof. Let us limit ourselves to asking whether, with all the information available to a contemporary of Galileo, it was more reasonable to consider the Earth as the center of the known universe or that there was some other center. The observation of at least one other center of motion, the clear evidence that at least some heavenly bodies were 'corrupt', measurements of the sun's rotation and the inclination of its axis to the ecliptic and most of all the immensity and density of the number of stars which populated the Milky Way left little doubt that the Earth could no longer be reasonably considered the center of it all.

But Galileo was also wise enough to know that not everyone could be easily convinced. In a letter to Benedetto Castelli he wrote: '... to convince the obstinate and those who care about nothing more than the vain applause of the most stupid and silly populace, the witness of the stars themselves would not be enough, even if they came down to the Earth to tell their own story'. While he could not bring the stars to Earth, he had, with his telescope, taken the Earth towards the stars and he would spend the rest of his life drawing out the significance of those discoveries.

SUMMARY

At the beginning of this essay I suggested three components contained in the notion of discovery: newness, an opening to the future and, in the case of astronomical discovery, a blending of theory and observation. Copernicus, Kepler and Galileo, according to these criteria, were all discoverers in the search for an understanding of the universe, but each in his own unique way. Copernicus was truly a revolutionary. With one stroke of genius by rearranging orbits in the solar system he resolved what for centuries had been a most puzzling feature of Ptolemaic astronomy, namely, that the annual motion of the sun was coupled to the motion of any other planet. Kepler was truly a bridge to the future. With his unique combination of an intuitive idea about the force of the sun and

³¹ Historians debate endlessly as to when Galileo first became personally convinced of the correctness of Copernicanism. Judging from his statement of 'already for many years' and from other indications he must have certainly been leaning towards Copernicanism during the first years of his teaching at Pisa, which began in 1589.

a mathematical analysis of observations, he discovered the three laws of planetary motion named for him, thus leading the way to Newton and the law of universal gravity. Galileo can be rightly called the first 'person with long eyes'. He contributed by his telescopic observations the first new data about the universe in over 2,000 years. But he was also an experimentalist. He sensed a unity in what he experienced in the laboratory and what he saw in the heavens.