Towards Mysteries of the Cosmos with Johannes Kepler

on the 450th Anniversary of His Birth

☉

… iter

Planetae in Coelo

non esse circular

sed viam Ovalem

perfecte Ellipticam

Cracow 2022

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Editors

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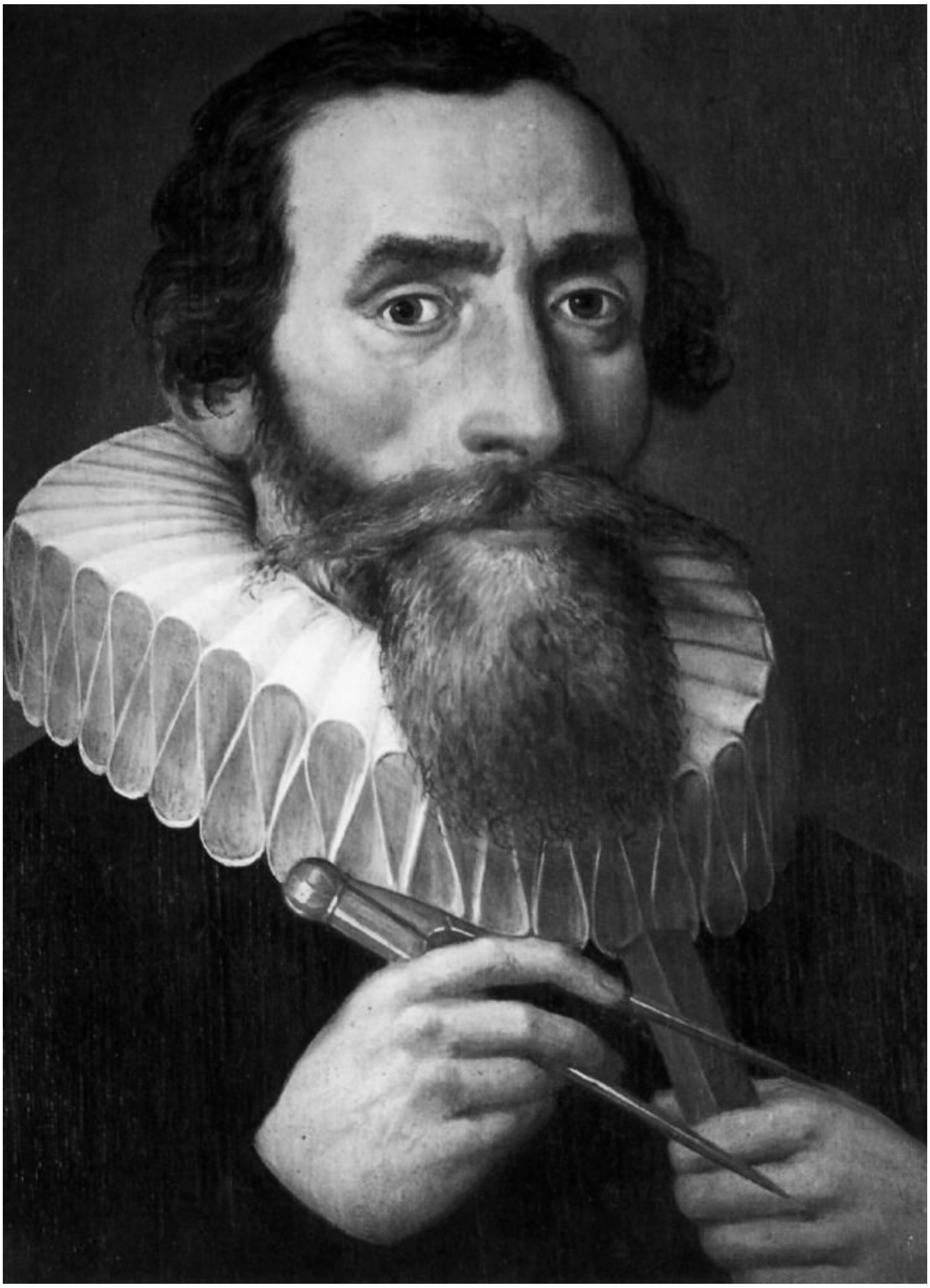

Johannes Kepler
(Weil der Stadt, 27 December 1571 – Regensburg 15 November 1630)

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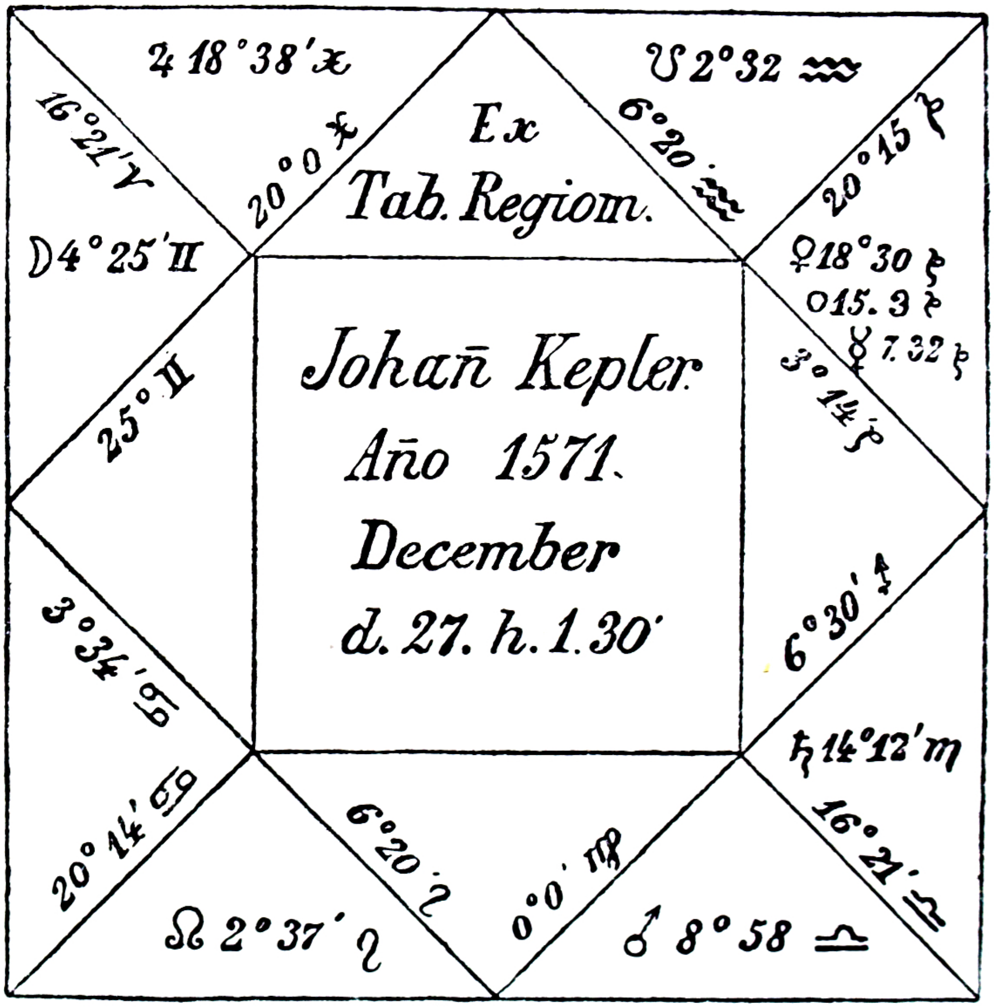


Kepler's auto-horoscope.

Prologue

A contemplative disposition and the fruits of deep reflection made Kepler immortal. Therefore, let everyone who finds eternal life an attraction, join that eternal community of spirit from which the Great Kepler and his great predecessors and successors were deriving and enriching it.

Mental decisions in terms of seemingly completely impractical matters taking place in the skies always have practical consequences and are often causing a new course of civilization. Kepler is a beautiful example of an in-depth thinker. People like Kepler are born on Earth no more often than the supernova stars in the sky. Therefore, people who are able to grasp and appreciate the colossal and unprecedented Kepler's intellectual legacy are also unique in every generation and anywhere in the world. Copernicus was lucky that Kepler understood him and brought the noblest achievements of his thoughts to daily light and masterfully "polished" them. Newton was also fortunate to read the works of Kepler. Based on them, he created his *Principia*, in which he published already quite practical "recipes" to be used for the technological progress of humanity. All people on Earth are lucky today because they experience a lot of favors, the sources of which should be sought in Kepler.

The great gratitude of posterity is due to Kepler for revealing in his works not only the essence of his thoughts but above all the intricate and deceptive lines of reasoning that must be tried before they fail. Hence the optimistic message that you don't need to be afraid of thinking, that you should not give it up at the first failure. It's necessary for the thinker to "push" a mystery on all sides until it succumbs. You have to do that to know that a secret often "breaks" under the pressure of relevant observations. Human effort, individual and collective, is, therefore, necessary for the penetration of truths of nature. Many truths about man and the world around him are waiting for recognition, but it cannot be done with "shortcuts". Reaching them always requires honesty and enormous intellectual effort.

Kepler, a mathematician with a head full of beautiful mathematical rules, was very anxious to find the “imprint” of these rules in nature. When none of the many invented ideal patterns were reflected in observations of the Cosmos, the now mature Kepler realized that there was a need for a radical change of approach. You have to look at the Universe with the greatest seriousness, compose observations in numbers, and then analyze them with full mathematical accuracy. The “ordering” method, whether to the Universe or its Creator, what chasubles are to be dressed in, and how they are supposed to dance, is not in line with the attitude of a true researcher or philosopher of nature.

Kepler is said to have physically made astronomy. He also made physics itself more physical! He gave it the right tone and secured the directions for its further development. From the existing physics, he took little but gave it a great deal. Kepler approached physics from the intellectual heights. This top-down approach must have led to great things for physics. The mature Kepler did not have to learn physics anymore, he created it. Moreover, he was forced to create new physics of the Universe. Math itself, though by thousands of years was enough to decide things in the sky, it turned out to be insufficient for Kepler. In this sense, physics was raised over math by Kepler. At some point, it came to the consciousness of mathematical Kepler that the Universe is physical (not mathematical) and a physical approach is necessary for its understanding. Even if somewhere the matter seems to visually apply to geometry rules (e.g. hexagonal snow stars, inflorescences, bee slices, regular crystallization patterns, spherical shapes of planets and stars, various symmetries in the structure of plants and animals), under the influence of which Kepler will express his own “Ubi materia, ibi geometria” (where is matter, there is geometry), this external geometry is for the mature Kepler only the effect of some physical cause; a cause that must be found and not explained “lazily” with some kind of metaphysics. Mathematics itself should be seen as a first-rate tool, born under the pressure of the need to quantify natural processes. If you want to continue to treat math as some kind of “crown” or “sacrum” it’s not because she is “God” herself, only because it is a wonderful fruit of human thought. The Universe, in turn, can be viewed as a harmonious system of matter having the inherent capacity for the most varied transformations in harmony with fundamental laws governing this matter. Matter is probably the source of these and she is faithful to them by this very fact.

Kepler really wanted to understand the Universe. He found that it was not an easy task to take. He has won many "wars" including the war against Mars itself! Early on he noticed that although this Universe is very demanding, it is also tremendously inspiring. It is "the great answer" for whatever possible questions one can think about. As long as you have the will and daring to ask and be curious about the answers of the "Old Man-Universe".

Many of Kepler's questions have yet to be answered. If the naturalist is consistently and honestly looking for an answer to the question "why?", he will go much further in his inquiries than if he only asked, "how?" This confirms greatly with Kepler. If the philosophers of nature want to pursue true causes of natural phenomena, the attitude represented by Kepler is a worthy role model for them. What characterizes it is the mental attitude of the researcher to the reception of subtle signals of nature, and not to persuade her by the force of what she is or what she should be.

Kepler had to face the whole world. Expose himself to everyone. Shake the world at its best. Stand on the side of the truth which the world feared and did not want at all! Kepler had to fight for every scrap of truth. He also had to fight himself. He was from this Earth, after all, and everything that civilization had earned on it built his awareness through years of intellectual growth. You had to take it all underneath mature judgment and either reject or improve. And everything in times when stakes were still burning, and it was very easy to become a martyr for unconventional views or behavior.

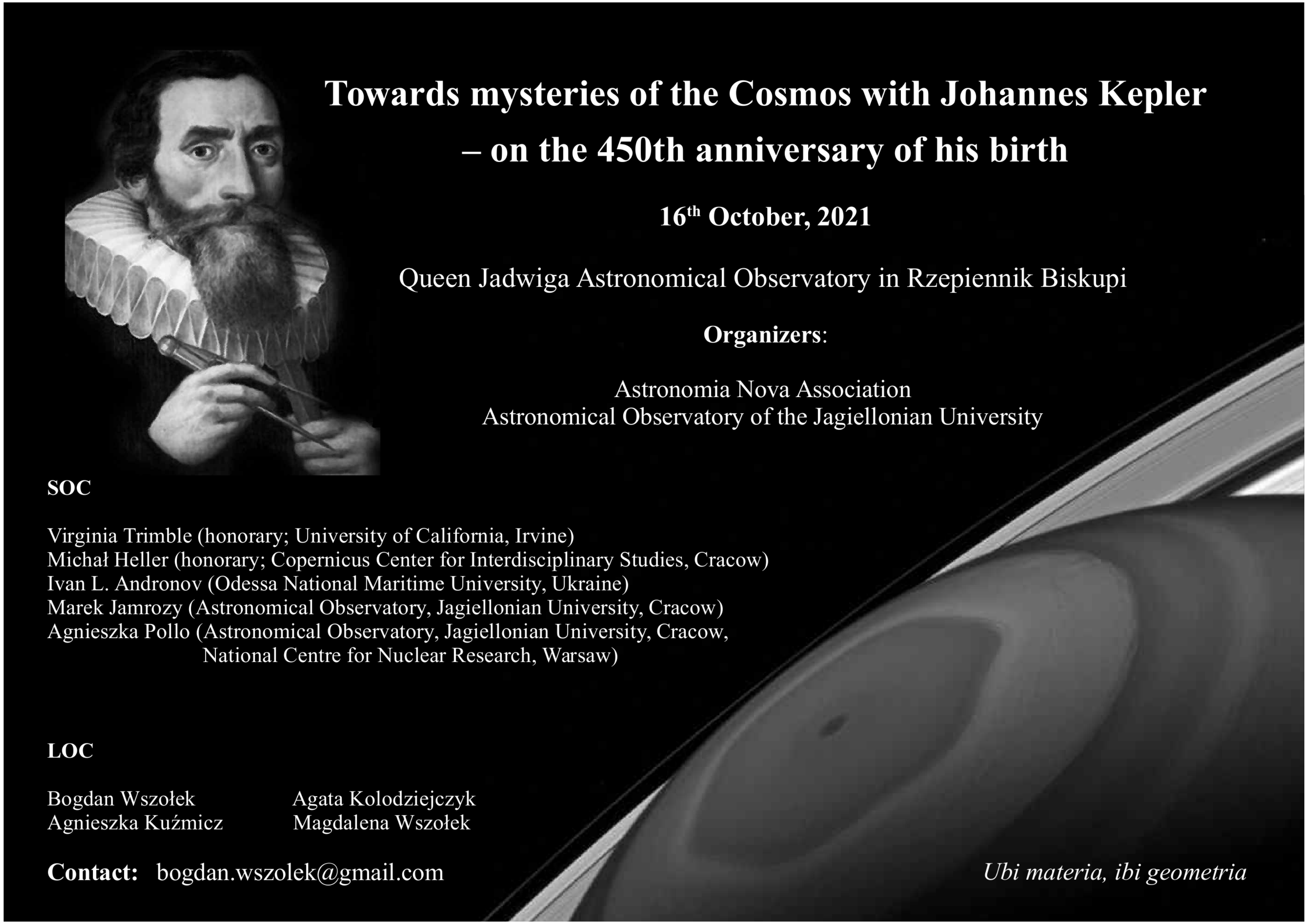
Kepler has long remained a poorly understood and little-known scientist. Chosen Kepler's scientific achievements were early appropriated by Isaac Newton and published, among others in his famous *Principia.*

However, Kepler's legacy is many times richer than Newton could understand. If modern physics is about to get out of today's troublesome state of stagnation, it probably cannot be done other than by leaving Newton's methodology of practicing science aside and going back to the sources worked out and published by Kepler. Many very basic considerations of nature have been started by Kepler, but never ended by anyone. From Kepler, you can constantly learn methods of effectively penetrating the secrets of nature.

On the anniversary of Johannes Kepler's birth, the attention of contemporaries should be drawn to the immortal fruit of the intellect that Kepler created for the general good of humanity. The occasional conference "Towards Mysteries of the Cosmos with Johannes Kepler – on the 450$^{\text{th}}$ anniversary of his birth" (Rzepiennik Biskupi, October 16, 2021) and this book prove that Great Kepler still has faithful friends in the world. Some participated in the conference in person, others brought their contributions to the book dedicated to Kepler. I want to thank all Kepler's friends sincerely.

In a special way, I would like to thank Prof. Virginia Trimble of the University of California (Irvine), also an honorary member of the Astronomia Nova Society (AN) and a member of the Honorary Staff of the Queen Jadwiga Astronomical Observatory in Rzepiennik Biskupi, for disseminating through her channels the information about our initiative to honor the anniversary of Johannes Kepler's birth. The fact is that this book was made largely thanks to the involvement of Virginia Trimble. Considering her various previous contributions to astronomy, including her cordial memory of astronomers in Poland, the General Assembly of AN decided to honor her with the *Keplerus Ellipsis*, a medal established by AN on the occasion of the anniversary of the birth of Johannes Kepler, the patron of AN.

Bogdan Wszołek
(President of Astronomia Nova Association)



The Kepler conference poster.

Conference participants (in person). From left to right: Jerzy Krzesiński, Kamila Świda, Agnieszka Pollo, Kinga Kijańska, Marek Jamrozy, Michał Służalec, Artur Kuźmicz, Agata Kołodziejczyk, Agnieszka Kuźmicz, Magdalena Wszołek, Bogdan Wszołek.

Keplerus Ellipsis

The Keplerus Ellipsis Medal was conceived as a material sign of friendship with Johannes Kepler. In any culture, anywhere on Earth, and at all times there are astronomers with the purest of intentions and in-depth friendly thinking about the Cosmos. We have created this medal for such people. The central graphic symbol on the obverse is the only symmetrical drawing posted by Kepler in his *Astronomia Nova*. This is drawing No. 56 which depicts the Sun and fragments of the orbits of Earth and Mars. Drawing content, showing the two positions of the Earth, orbiting the Sun faster than Mars, and two positions of Mars in its orbit, surrounded by two close auxiliary lines, served Kepler to illustrate the reasoning in command of the laws of planetary motion. The I and II laws of planetary motion were discovered by Kepler by analyzing the data observations about Mars. Kepler paid a superhuman effort for the discovery of these laws, which almost drove him, as he writes, insane. In the end, he could boast about, what he himself called, winning the war on Mars.

Obverse and reverse of the Keplerus Ellipsis medal.

The phrase *Sol omnia regit* symbolizes Kepler's insight that the Universe is physical, not mathematical. The shape of the medal has a slightly truncated cone. The obverse is therefore in the shape of an ellipse, and the physical sun is at its focal point. The shape of the medal is to symbolize the fact that truths about nature are sometimes found in millennia. Apollonius of Pergia (c. 260 - c. 190 BCE) cutting a cone with the plane resulted in an ellipse, but he had no idea what career it would do in the future. Alexandrian Hypatia (355/370 - 415 CE) wearing an ellipse in the heart and drawing it often with a stick in the sand, timidly sensed that if the Earth would circle the Sun, as Aristarchus of Samos (c. 310 - 230 BCE) wanted, it would be rather in an ellipse than a circle. Eventually, Kepler in 1609 in his work *Astronomia Nova* elevated the ellipse to the rank of a cosmic *sacrum*. The ellipse also reigns on the reverse of the medal, but already in a form that imitates its sketches in *Astronomia Nova*. The original Kepler's notation of "ellipse laws" and the Kepler equation are only visible after the medal has been flipped over. Let this also be a reflection of the regularity that the thinker looking for the truth has sometimes to overturn something upside down!

Bogdan Wszołek

Was Johannes Kepler a Great Astronomer?

Keplerus Ellipsis Presentation

Virginia Trimble[1,2]

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What sort of silly question is that, you may ask? It is not, I think, silly or pointless if it leads us to ask ourselves what is meant by "a great astronomer", or, indeed, pretty much "a great anything else". This is where the question has led me, to the thought that "greatness" is a function of there being some community of people who can say with confidence: (a) what the person did that we should remember, (b) approximately where and when, (c) why, that is, what was the situation before the crucial work, and (d) why it matters, that is, what came after that could not have happened without the crucial contributions. Two other traits that seem likely to be part of greatness: (1) we, of that admiring community, tend to forget or not mention other work of the person that was later recognized as not contributing to the progress of the field, and (2) the person was, accidentally or deliberately, the founder of a "school" of followers who worked later along the same lines and developed the crucial contribution(s).

From this point of view, Kepler then unquestionably belongs to a chronological Pantheon beginning with Copernicus and continuing to Tycho, Kepler, Newton, Halley, Herschel, and perhaps onward to Shapley and Hubble. And if we include "history of science" in what we teach

at all, it is generally this stepping-stone pattern. Astronomers are not unique in doing things this way. A sketched history of Western music is quite likely to have as its stepping stones Mozart, Bethoven, um, maybe Stravinsky. Let's make sure we can check all the boxes for Kepler before looking further afield.
(a) What: Laws of planetary motion; (b) When: Well his supernova was 1604, so early 17th century. Where: well, somewhere where they spoke German (and indeed his life was a bit peripatetic); (c) Why: At least partly because he wanted more accurate predictions of just where the planets would be visible in the sky in order to improve his astrological predictions, and, strangely, his weather forecasts (this is one of the items that we tend to forget, along perhaps with his views on musical aspects of the motions of the planets); (d) What came after: The recognition that elliptical orbits, sweeping out of equal areas in equal times, and $P^2 = a^3$ would happen only if there was a central, $1/r^2$, force, and we are in such a hurry to get to Newton, that we may not ask whether anyone else contributed to that recognition.

Is, or was, there "a school"? Certainly in at least the sense that up until the development of electronic computers, the method of actually finding orbital elements from observation of, for instance, a new comet or asteroid, followed the methods Kepler had developed and was computationally very intensive. Improvements were introduced, for instance, by Jacobus Kapteyn (who was "great" to his contemporaries, but is now remembered, if at all, for putting the solar system too close to the center of the Milky Way). Kapteyn himself emphasized that he tried to work as nearly as possible after the fashion of Kepler, giving primacy to the observations. This attitude, in turn, influenced that of Jan Oort, whom we remember for all the things that carry his name, and surely counts at least as "near great".

Now, what about the issue of "a community"? In these days of instant e-everything, one can ask distant colleagues what they think and expect an answer in hours. So, I asked a friend in India who did he think had been the greatest astronomers. And winging back came the answer, Newton and Aryabhata. And, of course, at this point I had to cheat and look him up! Born in 476 CE, he accepted the possibility that the

Earth might rotate, devised a system of epicycles different from those of Ptolemy, and perhaps discovered the precession of the equinoxes.

A Chinese colleague provided Guo Shoujing (Kuo Shou-ching in earlier spelling convention), who flourished around 1300 CE and contributed to calendric reform, a driver for astronomical investigations nearly everywhere and everywhen. For the Arabic-speaking and Moslem community, the obvious choice seems to be al-Haytham (Alhazen, 965 – c. 1040 CE), a true polymath, though my own private favorite is Nasir al-Din al-Tusi (1201 – 1274 CE), who recognized that you can use a point on one circle rotating inside another to trace out a straight line (the Tusi couple, also used by Copernicus). And with a combination of pieces of circles and straight lines, you can come pretty close to an ellipse.

Have there (we must ask in these days of equal whatever) been any great women astronomers? There have "always" been women astronomers – indeed the European Southern Observatory recently launched its Hypatia Project, an opportunity for early-career researchers to present their work to a varied audience. About half the applicants were young women (a larger fraction than in the current student-postdoc pools). Names we remember are of women who worked with husbands, brothers, or fathers (Caroline Herschel, Elizabeth Hevelius, Maria Mitchell), and still closer to the present, a small number of independent scholars, or nearly so – Henrietta Swan Leavitt, Cecilia Helena Payne Gaposchkin, Beatrice Muriel Hill Tinsley, Vera Florence Cooper Rubin ... And if we cannot all quite answer those what, where, when, why etc. questions, perhaps this means that the relevant community has yet to be assembled!

So, yes, of course, Kepler was a great astronomer, but thinking about just what we might mean by the phrase might enlighten our general thinking about the history of astronomy and other sciences. As for the rest of us, let me quote from yet another tradition, in which a wise man said to a worrier, that, when you come to the last judgment, God will not ask you why you were not Moses or not Maimonides. He will ask you why you were not Mendel Kirschbaum, that is, your own best.

If there is to be such a reckoning (most probably only in our own minds), we need not ask ourselves, "Why was I not Kepler? Or Why was I not Mozart?" but only "Why was I not the best astronomer, or musician, or ... . that I knew how to be?".

And, of course, I would not be the best colleague I know how to be if I failed to thank heartily my friends at Astronomia Nova for the great honor of their first *Keplerus Ellipsis* Medal!

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Virginia Trimble (Rzepiennik, 2015)

Kepler and Copernicus

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[Text reprinted from Vistas in Astronomy – Vol. 18. Edited by Arthur Beer and Peter Beer, Pergamon Press – Oxford and New York, 1975, private archives of Professor Jerzy Kreiner]

Kepler's attitude towards Copernicus may be best characterized by his widely known statement: "Because I am absolutely convinced of the Copernican theory, a solemn awe prevents me from teaching anything else, be it for the glory of my mind or for the pleasure of those people who are annoyed at the strangeness of this theory. I am satisfied to use my discovery to guard the gate of the temple in which Copernicus celebrates at the high altar." [M. Caspar, Kepler 1571-1630 (translated and edited by C. Doris Hellman), p. 23, New York, 1962.]

We find in this statement an expression of a great admiration for Copernicus and I take it as a starting-point of this my article.

Kepler learned the Copernican theory from Michael Mästlin, professor of mathematics and astronomy at Tübingen University, when Kepler was a student of the Faculty of Arts there. This theory could not be supported in the official lectures in the University, which was controlled by Protestant Theologians, and therefore the heliocentric theory could be only a subject of critical discussion. Nevertheless students were informed on its principles. Mästlin was a secret adherent of the Copernican theory, and he could convince Kepler of its correctness. Kepler at once became an ardent follower of Copernicus, whose work gave an inspiration to his main astronomical investigations, and this attitude towards Copernicus was maintained by Kepler lifelong without deviation. He had no opportunity during his university studies to read either *De Revolutionibus* or even the *Narratio Prima* of Rheticus. He did so later on, when he worked in Graz. From a thorough study of Copernicus there arose the first scientific publication of Kepler entitled "Prodromus dissertationum cosmographicarum continens Mysterium Cosmographicum de admirabili proportione orbium coelestium" – in short *Mysterium Cosmographicum.*

On the title-page of the first edition of the *Mysterium Cosmographicum* was based numerically on the greatest astronomical achievements of Copernicus, namely the determination of the relative distances of planets from the Sun, as was stated by Kepler on the title-page in the words "... de Libris Revolutionum, atque admirandis de numero, ordine et distantiis Sphaerarum Mundi excellentissimi Mathematici totiusque Astronomiae restauratoris D. Nicolai Copernici."

The basic assumptions of the Copernican theory – the stationary nature of the Sun and of the sphere of fixed stars, and the resulting rotation of the Earth and its revolution about the Sun – formed the unchanging foundation of the evolution of Keplerian astronomy.

In the preface to *Mysterium Cosmographicum* Kepler wrote that he ascribed the apparent yearly solar motion to the orbital motion of the Earth about the Sun owing to physical or rather metaphysical causes, while Copernicus had done so on geometrical principles. Such an approach to the motions of celestial bodies formed an essential extension of the Copernican theory and Kepler thus became the first interpreter of the physically extended Copernican ideas.

From the very beginning a conviction about world harmony formed the principal assumption of Keple's astronomical research. Copernicus also searched for such a harmony. He was proud that his heliocentric theory of the structure of the World was more harmonious than geocentric one. This harmony was in Copernicus' opinion an essential argument for his theory, because in no other way could the harmony be attained. Copernicus was satisfied with such a statement, but Kepler wanted to know much more, namely how such harmony might be attained. Kepler was convinced that God, a perfect mathematician, had built the Universe on geometrical principles. Such a perfect geometrical construction might be attained if the Universe were built of regular solids. There are only five such solids and therefore on their framework six planetary spheres might be fitted, if the solids were appropriately arranged. The Sun is to be placed at their common center and each planetary sphere was inscribed in a solid, to which the sphere of the next planet should be circumscribed. The solids are to be arranged in such a way that the radii of the spheres would conform to the relative distances of planets from the Sun according to the values given by Copernicus. Thus the sphere of Saturn is to be circumscribed to a cube in which the sphere of Jupiter is to be inscribed, and for the remaining planets there follow: tetrahedron, dodecahedron, icosahedron and octahedron. Such an order of regular solids was regarded by Kepler as a proof that the planetary distances are not accidental. The gist of the geometrical structure of the world was thus apparent for Kepler.

There arose, however, a difficulty with the eccentricities of planetary orbits. To take them into account Kepler assigned to particular spheres a finite thickness: nevertheless a satisfactory agreement with the numerical data given by Copernicus could not be attained. Besides, Kepler found that the eccentricities, as given by Copernicus, were inaccurate and even quite wrong, and therefore he desired to have access to the rich observational material which had been assembled by Tycho Brahe. This would enable Kepler to base his theoretical considerations on the most recent and accurate observations. It formed the starting-point of Keplerian astronomy. The results obtained by Kepler after coming into close contact with Tycho Brahe are too well known to be treated here in detail.

In his will, Tycho Brahe called on Kepler to elaborate Tycho's observations on the Tychonic system and not on the Copernican one. Kepler complied in general with this last request, but in his work *Astronomia Nova* he applied simultaneously the method of Copernicus too. His computations, based on the ecliptical latitudes as measured for Mars, at a time of opposition, led Kepler to the very important conclusion that the plane of Mars' orbit passes through the Sun and that its inclination is constant. In this way any oscillations of the inclination which resulted from Copernicus' investigations disappeared. Such oscillations were inevitable if the orbital plane passed through the center of the "great orb", i.e. the center of the circular orbit of the Earth, as Copernicus erroneously accepted following Ptolemy. After the statement that such oscillations do not occur when the planes of the planetary orbits pass through the Sun, Kepler stated that Copernicus did not know his own richness: "Copernicus divitiarum suarum ignarus, Ptolemaeum sibi experimendum omnino sumsit, non rerum naturam, ad quam tamen omnium proxime accesserat" – Copernicus was very near the truth, but he needlessly tried to correct Ptolemy instead of accepting the natural truth.

The assumption that the Sun is a real center of planetary orbits led Kepler to the rejection of the generally accepted axiom that all celestial motions should be circular only. Such a bold rejection could not be done at once and needed an essential evolution of Copernican ideas in Kepler's mind. It seemed inadmissible to him to consider centers of planetary motions other than the Sun and he subordinated all features of planetary motions to this principle, even if the principle of the uniform circular motion had to be sacrificed.

Astronomers had long known that the motion of the planets is not uniform. Ptolemy saved his theory by assumption of equants. Although Copernicus rejected equants, he was, however, obliged to apply more complex circular motions, similar to those which had been applied in the fourteenth century by Ibn Shatir. In this intricate set of circles the center of the planetary system was put by Copernicus into the center of the "great orb", a mathematical point void of matter. Such an assumption could not be accepted by Kepler.

Though, according to the principles expressed by Copernicus in Book I of his *De Revolutionibus*, the Sun should be regarded as a stationary center of the world system, he was compelled to put this motionless body outside the center of the Earth's orbit and outside the centers of the orbits of the remaining planets. The geometrical Copernican system became thus not exactly a heliocentric but a heliostatic one only.

On the contrary, Kepler in his endeavor to explain the motions of planets by the forces emanating from the Sun as a central material body of the Universe established a genuine heliocentric system. At first he discovered the law of areas, his second law of planetary motions. This law explains the non-uniform motion of the planets in their orbits. All attempts at reconciling the observed motion of Mars with a motion in a circular orbit were unsuccessful. There remained a certain maximum deviation, amounting to $8'$, in comparison with the observed positions of Mars; such a difference, however, was duly regarded by Kepler as inadmissible on account of the high accuracy (about $1'$) of Tycho Brahe's observations. He tried at first to replace circles by ovals and finally he proved that only the assumption that the orbit of Mars was an ellipse, with the Sun at its focus, led to a full accordance with the observational data. This discovery was applied afterwards to all the planets, and Kepler could formulate his famous first low of planetary motions. Epicycles vanished irrevocably from astronomy and the planetary motions lost their geometrical intricacy. It initiated such a radical change in the basic views on planetary motions that even the most active followers of Copernican theory, like Galileo, did not accept Kepler's innovations and continued to regard circular motions as the fundamental mathematical principle of all considerations on planetary motions.

The break with the principle of circular uniform motion of the planets enabled Kepler to look for physical forces causing planetary motions. Such forces, in accordance with the principles of heliocentrism, ought to emanate from the Sun only. Kepler made, however, the false assumption that they are in operation in the orbital planes only. It should be stressed that the forces assumed by Kepler had no gravitational features, like those considered later by Newton, but were tangential ones and displaced the planets along their orbits, as Kepler wrote in his letter to Mästlin of 5 March 1605: "Solis corpus est circulariter magneticum et convertitur in suo spatio, transferens orbem virtutis suae, quae non est attractiva, sed promotoria."

Though Kepler is to be regarded as a precursor of planetary dynamics, he cannot be reckoned as a forerunner of Newton, because in Keplerian celestial mechanics there is no place for gravitation; we find there only "magnetic forces", not too clearly formulated, emanating from the Sun.

In Kepler's *Harmonice Mundi* Copernicanism is not so largely represented, but it should be taken into account that Kepler's third law, formulated there, had become a cornerstone of the modern heliocentric theory. In this law the harmonious structure of the planetary system came into prominence.

In discussing the topic "Kepler and Copernicus" we should pay more attention to Kepler's great work *Epitome Astronomiae Copernicanae*, not only because it bears Copernicus' name in its title, but because it constitutes a synthesis of Copernican astronomy in the light of Kepler's discoveries and his views on heliocentrism.

The *Epitome* was printed in three parts in the years 1618, 1620 and 1621, respectively. The title may be somewhat misleading because the work is not a summary of Copernicus' astronomy, as expounded by him in *De Revolutionibus*, but it is a presentation of astronomy as it evolved from the basic Copernican principles, namely the immobility of the Sun and of the sphere of fixed stars, and the resulting motions of the Earth. Kepler would have been justified if he had given his work the title "Epitome Astronomiae Keplerianae", but he consciously put here the word "Copernicanae". He never gave titles which did not correspond to his intentions as well as to the contents. His book was really a textbook on Copernican astronomy, if we take it as a synthesis of its evolution, promoted mainly by Kepler's discoveries and statements.

The *Epitome* consists of seven books, written in the form of questions and answers, as was then usually done in textbooks. The first three books contain mainly spherical astronomy. In particular the arguments in favor of the rotation of the Earth were quoted there. The remaining books are more important, because Kepler there explains his theoretical astronomy. He emphasizes the great merits of Copernicus in the determination of relative distances of the planets by quoting the system of regular solids which determine these distances according to the exposition in *Mysterium Cosmographicum*. The motions of planets were explained in accordance with principles of Copernicus, i.e. that all the planets run around the Sun in one direction, except the Moon, which revolves about the Earth. All inequalities in the motion of the Moon have been enumerated by Kepler without any application of epicycles. In the fifth book of the *Epitome* Kepler explains the motions of the planets according to his first two laws. The last book contains a discussion of the apparent motion of the sphere of fixed stars.

We must admire the great courage of Kepler, who edited his *Epitome* at a time when Copernicus' work was since a few years registered by the College of Cardinals in the *Index Librorum Prohibitorum*, while Kepler lived and worked in Austria – a largely Catholic country. This fact should be regarded as a manifestation of a great tribute from Kepler to Copernicus.

In conclusion, the cosmological attitude of Kepler should be briefly mentioned. The Copernican learning in its development led to the conception of an infinite Universe. Copernicus began Book I of *De Revolutionibus* with the statement that the Universe is spherical, but in another passage of the same book he stated that the question whether the Universe is finite or infinite he rather leaves to philosophers of Nature ... ("Sive igitur finitus sit mundus sive infinitus, disputationi physiologorum dimittamus ..."). It seems that he was not sure about an answer to that question.

Kepler, who considered the Sun as a real material center of the Universe, could not accept the assumption of infinity because such a Universe could not have a center. He did not agree with Giordano Bruno, who propagated not only the idea of an infinite Universe, but also the idea of a multitude of inhabited worlds. Kepler discussed the question of the infinity of the Universe in his work *De Stella Nova in Pede Serpentarii*, rejecting such a thesis as inadmissible from the philosophical point of view. Though he considered in *Epitome Astronomiae Copernicanae* the problem whether the Sun may be regarded as a star such as those shining in the night sky and appearing to us merely as faint points of light, because they are very distant – he rejected such a conception. He believed the stars to be relatively near, because he assumed that the distance of the farthest planet, Saturn, is the geometrical mean between the Sun's radius and that of the sphere of fixed stars. For the latter radius he derived the value of 60,000,000 diameters of the Earth, on the assumption that the geocentric parallax of the Sun amounts to $1'$. If the Sun were transferred to such a distance, it would be very much brighter than the brightest stars, and therefore, according to Kepler, it cannot be regarded as a star. Obviously Kepler's inferences were wrong, because he assumed too small distances of the stars.

Summing up the general attitude of Kepler towards Copernicus we may say that Kepler regarded his own astronomy as a development and continuation of that of Copernicus. We know that Keplerian astronomy should be regarded as a great progress in comparison to the results obtained by Copernicus, mainly because the Sun became a real physical center, from which the forces moving the planets in their paths emanate. The demonstration by Kepler that the orbital planes of the planets pass through the Sun was a further important step in the development of the Copernican theory. The rejection of the principle of uniform circular motion caused the epicycles to disappear finally from the theory of planetary motions, and simultaneously the centers of motion at points devoid of matter have been removed from theoretical consideration. The Copernican system lost its geometrical intricacy, whereas the location of the Sun at the common focus of all planetary ellipses and the suggestion that the forces steering the planets in their paths are to be searched for in the Sun, made the Copernican system in fact a heliocentric one. In this way Kepler laid a foundation on which the Newtonian celestial mechanics could be erected.

Copernican Ideas in Kepler's Epitome Astronomiae Copernicanae*

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Introduction

The most comprehensive and at the same time relatively rarely commented upon work of Kepler is his textbook of astronomy entitled *Epitome astronomiae Copernicanae*[1]. Kepler conceived the idea to write this textbook immediately after publication of his essential work *Astronomia nova*, in order to provide a synthesis of astronomical knowledge resting on Copernicus' basic theses within the framework of his own achievements. *Epitome* in by no means a summary of Copernicus' *De revolutionibus*: it is an exposition of astronomy resulting from the Copernican revolution.

This article represents an attempt to find those places in the *Epitome* where Kepler either directly states Copernican thoughts or develops the problems posed by Copernicus.

It is possible that Kepler received the impulse to write the *Epitome astronomiae copernicanae* because Michael Mästlin, his teacher at the University of Tübingen, authored a textbook *Epitome astronomiae*

[1]Volume VII of Johannes Kepler, *Gesammelte Werke* (Minich, 1953) contains the *Epitome astronomiae copernicanae* and its commentary ("Nachbericht"). I would like to express my gratitude to Martha List of the Kepler Commission at the Bavarian Academy of Sciences at Munich for sending me the "Nachbericht".

which appeared many times during the years 1582-1624. Mästlin's textbook rested on geocentric foundations, despite the fact that he had a very high regard for Copernicus' teachings. To counterbalance Mästlin's textbook, a new synthesis of the heliocentric astronomy was required, and this was done by Kepler.

Basic Assumptions of Copernican Teachings

The foundation on which Copernicus' model of the Universe rested was the assumption that the Earth is a planet which moves together with the rest of the planets around the sun, while at the same time it rotates around its axis from west to east. These assumptions properly explained the observed yearly motion of the Sun, and the daily motion of the celestial sphere; the retrograde planetary motion found its explanation in the fact that we observe it from the moving Earth.

Another essential Copernican postulate was his interpretation of the precession of the equinoxes as a slow change in the direction of the Earth's axis in relation to the stars. In this way that phenomenon was detached from the sphere of the fixed stars and attached to the Earth.

In addition, Copernicus postulated that the movements of the planets are composed of uniform circular motions, while the stationary Sun is situated inside the main planetary orbital circles, near but not in the exact geometrical center of the system.

As a result of his assumptions, Copernicus was able to calculate the dimensions of the planetary orbits in reference to the orbit of the Earth. It was impossible to perform such a computation on the basis of the geocentric theory.

The adherents to the geostatic theory maintained that the Earth, being a heavy body, can neither revolve like a planet nor rotate around its axis, since in the latter case all of the objects in the air would move to the west. In order to refute these objections, Copernicus postulated that gravity is an inherent attribute of all the planets, each of which for that reason coalesces into spheres. As far as the air is concerned, it adheres to the Earth and participates in the axial rotation: on account of that fact the objects in the air do not fly away.

The above theses, except the one dealing with the uniform circular motions, were accepted by Kepler, who believed the Sun to be located at the common focus of the elliptic planetary orbits. Assuming the Sun to be the physical center of the Universe, he postulated that the forces which lead the planets on their circumsolar paths are emanating from it. Paying close attention to the heliocentric assumptions, I will attempt to point to those places in the *Epitome* where basic Copernican thoughts appear either in their original version, or in a version modified by Kepler's achievements.

Editions of the *Epitome*

The first edition of the *Epitome* was printed in three parts. It was arranged in a form of questions and answers. The first part, "Doctrina sphaerica", consisted of Books I-III and was printed in the shop of Johannes Plancus (Linz, 1618). Books IV-VII, containing a review of physical problems arising from the motions of the planets, were scheduled to appear as "Doctrina theorica". However, the, politically and personally, stormy years 1618-1621 were responsible for the fact that Book IV appeared in 1620 in Linz as "physica coelestis". Later, Books V-VII, with the Linz printed sheets of Book IV, were published by G. Tampach in Frankfurt/Main as "Doctrina theorica"[2]. The second and full edition of the *Epitome* was printed in Frankfurt in 1635[3], and also as a portion of the complete works of Kepler during nineteenth[4] and twentieth centuries.

The individual books of *Epitome* bear the following titles:
Book I: De principis astronomiae in genere, doctrinaeque sphaericae in specie
Book II: De sphaera et circulis ejus
Book III: De doctrina primi motus, dicta sphaerica

[2] "Nachbericht", p. 547.
[3] *Ibid.*, p.548.
[4] Johannes Kepler, *Joannis Kepleri astronomi opera omnia*, ed. Christian Frisch (Frankfurt/Main and Erlangen, 1866), vol. VI

Book IV: Doctrine theoricae primus: De partium mundaranum situ, ordine et motu, de systemate mundano
Book V: Theoricae doctrinae secundus: De circulis eccentricis, seu theoriis planetarum
Book VI: Theoricae doctrine tertius: De apparentibus motibus planetarum, seu ipsa doctrina theorica
Book VII: Ad sphaericam simul et theoricam doctrinam pertinens.

As is clear from the titles cited, the most important part of the *Epitome*, dealing with the planetary movements, are Books IV-VI. We must, therefore, search for the Copernican thought there. However, Kepler invokes the name of Copernicus also in the other books, most frequently in Book I.

Copernican Thoughts in Books I-III of the *Epitome*

In the introduction to Book I, Kepler, announcing the content of his work, said that it explains primarily the hypothesis of Copernicus and of Tycho Brahe[5].

In the first chapter of Book I Kepler cites the same arguments for the sphericity of the Earth as we find in Book I of *De revolutionibus*. However, he treats them more extensively than Copernicus, for he dedicates 24 questions to the problem of the sphericity of the Earth[6].

In the lengthy third chapter of Book I of the *Epitome*, Kepler states that the air is light only by comparison with water, and that air gravitates toward the center of the Earth[7]. He enlarges here Copernicus' well-known thesis from Book I of *De revolutionibus* to the effect that the air adheres to the surface of the Earth and participates therefore in her rotation. Only above it is situated the "aura aetherea" which is not attached to the Earth.

Kepler expands the basic Copernican thoughts in the fourth chapter of Book I, were he discusses Earth's place in the Universe. He points out

[5] *Gesam. Werke*, VII, 26-27.
[6] *Ibid.*, pp. 32-41.
[7] *Ibid.*, p. 56: "... queo iam de Aere, qua figura superficies eius terminetur? Terminatur multo perfectus, quam Oceanus, superficie Sphaerica, ijsdem de causis; quia scilicet vt in densitate sic etiam in gravitate post Aquas proximo est loco, nec alter nisi in comparatione ad Aquam levis dici meretur".

clearly that the Earth is outside of the center of the Universe, and that the axis of the daily rotation of the heavenly spheres until the sphere of the fixed stars is identical with the axis of the daily rotation of the Earth, as was maintained by Copernicus. This statement contains the basic thesis of Copernicus' teaching dealing with the nature of daily motion of the heavens[8].

Next, Kepler raised the problem of gravity, which was treated by Copernicus as an inherent attribute of all the heavenly bodies. Kepler took an analogical position, maintaining in addition that a heavy body does not fall toward the center of the Universe but toward the center of its own body, whether it is in the center of the Universe or anywhere else[9].

Kepler dedicated the extensive fifth chapter of Book I to the rotational motion of the Earth around its axis. This chapter opens up with the statement that according to the Copernican astronomy the perceived phenomenon of the first motion is deceitful. The stars do not travel over the mountains but rather the mountains on the surface of the Earth rotate together with the entire globe from west to east. Likewise the stars do not cross the vertex, but a vertical point moves under the motionless stars[10]. This picturesque description constitutes for Kepler a point of departure to develop the fundamental thesis of Copernican teaching, in support of which Kepler cites seven arguments, each of which he explains fully.

In this exposition Kepler repeats numerous arguments given by Copernicus in the first book of *De revolutionibus* but he develops them better. While analyzing the first argument for the rotation of the Earth,

[8] *Ibid.*, pp. 74-75: "In specie vero si terram COPERNICUS extra Mundi medium ponti, eoque et motum ei geminum attribuit, de quo in parte sequente ... Ideo namque Terra est in axe Mundi, quia axis mundi nihil est aliud quam axis corporis Terrae, circa quem illa diurno motu circumagitur turbinis instar, continuatus per imaginationem nvtrique vssque ad fixas".

[9] *Ibid.*, p. 75: "Non est enim haec natura gravium, vt ferantur ad centrum Mundi, quatenus centrum: sed haec, vt ferantur, quodlibet ad centrum sui Corporis, sive in Mundi centro illud sit, sive alibi; et hoc tunc, si grave propositum vicinum sit illi Corpori, et minus illo".

[10] *Ibid.*, p. 80: "Astronomia Copernicana docet, visum falli circa motum primum: non enim sidera vere ascendere supra montes, attollive versus nostrum verticem: Sed è contrario, montes qui sunt nobis circumjecti, stantes in superficie globi telluris, partes quippe cum toto globo, circa axem illius converti à plaga occasus in plagam orientis; eaque conversione stellas orientis immobiles, alias post alias nobis detegi, stellas occidentis tegi; itaque non stellas per verticem transire, sed punctum verticale transire per stellas immobiles, quantum ad motum primum".

entitled by Kepler “a subjecto motus”, he writes, similarly as Copernicus in *De rev.* (Book I, Chapter 6), that it is impossible for the whole world machine to move while only the Earth remains stationary[11].

Further in the fifths chapter of Book I of the *Epitome*, Kepler writes about the relativity of motion and cites the same place in Vergil’s *Aeneid* which we find in Book I of *De rev.* “Provehimur portu terraeque, recedunt”[12].

After the arguments for the Earth’s rotation around its axis, Kepler, like Copernicus in *De rev.*, refutes the objections posed by the defenders of the old stationary Earth thesis. In particular he concerns himself with the objection that if the Earth were to move around its axis, the clouds and birds would move in the opposite direction, that is westward in relation to the earthly observer. Kepler, echoing Copernicus, answers the objection by saying that the objects are in the air which moves around the axis together with the Earth[13]. This is also true of the wind, which, if it were not for its participation in the axial rotation of the Earth, would constantly blow with a great force from the east.

In the fifth chapter of Book I of the *Epitome* there are references to Copernicus’ statements of a general nature. Kepler refers in particular to the utterances of Copernicus in his Preface to *De revolutionibus* addressed to Pope Paul III, even though he does not cite them exactly. For example, he repeats Copernicus’ well-known statement where the latter says that philosophers’ opinions are remote from the judgments of the common people and that some idle talkers shamelessly distort certain passages in *Holy Scripture*. Here Kepler mentions, after Copernicus, the name of the Church Father Lactantius. Finally Kepler states that Copernicus repeated after Cicero the name of Nicetas[14], and after [pseudo] Plutarch the names of Philolaus, Ecphantus, and Heraclides of Pontus as the supporters of the rotation of the Earth[15].

[11] *Ibid.*, p. 81: “Atqui non potest moveri tota Mundi machina motu diurno, quiescente sola terrâ; ergo necesse est, terram moveri motu diurno.” Also, *Nicholas Copernicus’ Complete Works*, Vol. I (Macmillan: Warsaw-London, 1972), fol. 6r, lines 2-4: “Neque enim sequitur: in medio mundi terram quiescere oportere. Quin magis etiam miremur: si tanta mundi vastitas sub XXIIII horarum spatio revolvatur potius; quam minimum eius, quod est terra”.

[12] *Gesam. Werke*, VII, p. 94.

[13] *Ibid.*, p. 98.

[14] Hicetas.

[15] *Gesam. Werke*, VII, p. 100.

Copernicus' name appears twice at the end of the Book I where Kepler states that at present most eminent philosophers and astronomers "Copernico astipulantur". Strictly speaking, Book II and III of the *Epitome* do not contain any Copernican thoughts. Book II deals with the problems in spherical astronomy, especially with the great circles on the celestial sphere, and the Copernican theses concerning the motions of the Earth are unnecessary for that purpose. To be sure, Book III discusses the diurnal rotation of the celestial sphere mainly from the point of view of problems in spherical astronomy. It is only worthwhile to note that while writing about the "natural days" (defined as a time period between successive sunrises) Kepler mentions the names of Mästlin and Copernicus[16]. For in computing the "natural day" Mästlin was relying on the computational data contained in the *Tabulae Prutenicae* which were based on the results of computations given by Copernicus in *De revolutionibus*. Moreover, it should be observed that in the same place in Book III of the *Epitome* Kepler uses the term "praecessio aequinoctiorum" coined by Copernicus.

Copernican Ideas in *Epitome* Concerning the Motion of the Planets

Whereas Kepler, in contrast to Copernicus, introduced relatively few concepts while discussing the rotational movement of the Earth around its axis, in explaining the second Copernican thesis concerning the orbital motion of the Earth he greatly expanded Copernicus' thoughts. This was done not only by introducing changes in the kinematics of the planets, where the circular motion was replaced by the elliptical motion, but also by recognizing the Sun as a source from which emanate the forces that drive the planets on their orbits. For that reason the Copernican ideas in Books IV-VI of the Epitome, containing, as Kepler puts it, the theoretical doctrine, should be examined from another angle as was done above, in the analysis of Books I-III.

Kepler and Copernicus were united in their search for harmony in the structure of the Universe. Both of them held on to the principle

[16] *Ibid.*, p. 183.

that the stationary and central Sun is the point of reference of the planetary motions. However, they differed in their geometrical approach. While Copernicus – in a manner similar to the one adopted by Ptolemy in the geocentric system – chose for the center of the planetary orbits the center of the "great circle", that is the center of the Earth's orbit, Kepler, who did not approve of empty, devoid of matter, central point of motions, placed the Sun in that center. In Copernicus the planes of the planetary orbits passed through the center of the "great circle", in Kepler, through the Sun. We must keep the above in mind while presenting the Copernican ideas contained in Kepler's Books IV-VI of his *Epitome astronomiae copernicanae.*

Book IV should be considered as the central part of the *Epitome*, since it presents the basic theses of Copernican astronomy, as formulated by Kepler. In the beginning of Book IV Kepler cites five basic principles of Copernican astronomy. They are:

1. The Sun, immovable in place, is located at the center (or near the center) of the sphere of the fixed stars.
2. Single planets move indeed around the Sun in their separate systems, composed of the most uniformly revolving perfect circles.
3. The Earth is one of the planets; it describes in a year a circle around the Sun between the orbits of Mars and Venus.
4. The ratio of this circle to the diameter of the sphere of the fixed stars is imperceptible and thus the diameter resembles the boundless.
5. The sphere of the Moon is arranged around the Earth as its center, so that the annual revolution around the Sun ... is common to the entire sphere of the Moon together with the Earth[17].

In these five points Kepler faithfully reproduced the principles on which Copernicus built his system of the world.

Kepler divided Book IV into three parts, the first dealing with the

[17] *Ibid.*, p. 257: "1. Solem in centro sphaerae fixarum, (vel quasi) collocatum esse, immobilem loco. 2. Planetas singulos moveri revera circa Solem in singulis systematibus, quae ex pluribus circulis perfectis, aequabilissimo motu conversis, componantur. 3. Tellurum esse unum ex planetis, sic vt orbem inter orbes Martis et Veneris medium annuo motu circa Solem describat. 4. Proportionem Orbis hujus collati ad diametrum sphaerae fixarum, esse insensibilem, adeoque immensae similem. 5. Sphaeram Lunae ordinari circa terram vt centrum suum, sic vt motus annuus circa Solem (et sic de loco in locum) toti sphaerae Lunae cum Tellure communis sit".

principal parts of the world, the second with the movements of the celestial bodies, and the third with the real and true inequalities of the planetary motions and their causes[18]. In the first part he enlarged upon the Copernican attribute of the Sun as the central body of the world by saying that in respect to its light the Sun is most beautiful, in respect to heat it is the hearth of the world, while in respect to movement, the Sun is the first cause of planetary motion[19]. All this may be regarded as an exposition of the famous statement of Copernicus dealing with the Sun's position in the center of the world[20].

The essential contribution of Copernicus was his detachment of the planetary spheres from the sphere of the fixed stars, which he pushed to an indefinite distance. In his work Copernicus did not yet abandon the concept of planetary spheres which enjoyed great popularity during the medieval period. Kepler and Brahe maintained that Copernicus accepted the existence of the crystalline spheres, according to the theory of Peurbach with which he became acquainted during his studies at the University of Cracow. Following Brahe, Kepler in *Epitome* abandons that concept. Of great importance in his widening of the Copernican outlook was the statement that planets move freely in the "aura aetherea" of the Universe.

In Book IV, part 1, ch.2 of the *Epitome*, Kepler discusses the place of the Sun in the center of the world. He repeats the characterization of the Sun as the most precious and most excellent of the heavenly bodies[21] which, on that account, should be located in the center of the world. In support of this statement Kepler invokes the authority of Copernicus

[18] "Nachbericht", p. 561.

[19] *Gesam. Werke*, VII, pp. 259-260: "Nam quod locum attinet, eâ cum Sol ipse pulcherrimus est, et quidam veluti oculus mundi, tum verò mundi reliqui corpora ipse vt fons lucis aut clarissima fax, illuminat, pingit, exornat ..." [...] "Quoad calorem, Sol focus mundi est; ad hunc focum Globi in intermedio sese calefaciunt; fixarum sphaera continet calorem, ne diffluat, veluti quidam mundi paries, pellis aut vestis, vt Psalmi Davidici flosculis vtar .." [...] "Quò ad motum, Sol est prima causa motus planetarum vniversi, primusque motor, etiam ratione sui corporis".

[20] N. *CCW* I, fol. 10r : "In medio vero omnium residet Sol. Quis enim in hoc pulcerrimo templo lampadem hunc in alio vel meliori loco poneret: quam vnde totum simul possit illuminare. Siquidem non inepte quidam lucernam mundi: alij mentem: alij rectorem vocant. Trismegistus visibilem deum, Sophoclis Electra intuentem omnia. Ita profecto tamquam in solio regali Sol residens circumagentem gubernat astrorum familiam".

[21] *Gesam. Werke*, VII, p. 262: "Iam vero Solem quidem ... digniorem esse Tellure, totiusque mundi preciosissimum et dignissimum ...".

who pointed out this position of the Sun in the Universe[22].

At the end of his chapter Kepler noted with disapproval that Copernicus did not place the Sun exactly at the center of the world, but that he put this center at a distance from the Sun equal to the Sun's eccentricity assumed by the ancients. According to Kepler "nodus systematum planetariorum" should be in the Sun[23]. This is an important correction of Copernicus' cosmological geometry.

In the next (3rd) chapter entitled "De mobilium sphaerarum ordine" Kepler presented the most important astronomical achievements of Copernicus, that is the establishment of the succession of the planets and their relative distances from the Sun. Answering the question: "Quondam est hic discrimen inter veterum et inter COPERNICI ratiocinationem?" he summarizes the results of Copernican teaching in comparison to the theses of the astronomers of antiquity. In reference to the planetary succession, Kepler shows that whatever was only probable in the ancients became a necessity in Copernicus. In addition, Copernicus, on the basis of his observations, calculated the distances between the planets, and enormously enlarged the sphere of the fixed stars, which was formerly considered to be not much greater than the sphere of Saturn. Finally, while the earlier astronomers, despite their desire to do so, were unable to prove their layout, Copernicus proved his in a most splendid manner[24]. Here Kepler concisely describes the Copernican cosmology and shows not only its superiority over the views of the astronomers of antiquity, but also the superiority of Copernicus' argumentation over those of his predecessors.

In his further exposition Kepler presented the individual Copernican achievements in the field of cosmology, citing especially the numerical

[22] *Ibid.*, p. 263: "Quem Solem dum quaerimus, quo mundi loco sit situs, COPERNICUS coeli peritus, nobis medium indicat: caeteri qui alium ejus ostendunt locum, non coguntur ad hoc argumentis astronomicis, sed alijs quibusdam ad speciem meta-physicis, ex terrae ejusque loci contemplatione ductis: quorum argumentorum aestimatio nobis cum illis est communis, et quibus non indicant, sed quaerunt ipsi quoque Solis locum".

[23] *Ibid.*, p. 264.

[24] *Ibid.*, p. 265: "1. Veterum ratio probabilis saltem est, COPERNICI demonstratio ex suis orsa principijs, necessarium infert ... 3. ... COPERNICUS ex ipsis observationibus spatia singulis sua metatus, tanta inter binos interesse ostendit, vt incredibile sit, illa orbibus impleri ... 4... COPERNICUS contra mobilium regionem modice amplam, fixarum vero quiescentem immensam facit: quam veteres non multo majorem statuunt sphaera Saturni. 5. Veteres dispositionis suae rationem non, vt optant, explicant et comprobant: COPERNICUS in rationibus stat egregiè".

values of the radii of the planetary orbits as given by Copernicus in Book V of *De revolutionibus*.

In the second part of Book IV of the *Epitome* Kepler continued to develop Copernican ideas. He addressed himself to the question of the motion of the heavenly bodies, in his words, "De motu corporum mundanorum". Kepler began this part by asking: "Quid sentit COPERNICUS de motu corporum, quid illi movetur, quid quiescit?" In response to this question he cites Copernicus' thesis that the stationary Sun occupies the center of the world, and that the planets move in one direction without any retrogradiations[25]. Kepler elaborated on these ideas and explained in detail their numerical relations.

In Book IV, part 2, ch, 5 entitled "De Telluris motu annuo" we find again a number of Copernican ideas. Kepler began this chapter with a question pointing to the philosophical character of the Copernicus' thesis, namely to his recognition of the Earth as a planet[26]. Kepler proceeds by presenting a modified Copernican explanation of the motion of the inferior and superior planets, for he gives eight arguments to show that the planets of all the planetary orbits should pass through the Sun and not through the center of the "great circle".

Yet the most important Copernican ideas were given by Kepler in answering the question which arguments speaks for the system of Tycho Brahe, and which for placing the stationary Sun in the center of the planetary orbits, as was postulated by Copernicus. To answer this question Kepler presented no less than 18 arguments, all of them speaking for the Copernican thesis. In general, his arguments do not contain Copernican theses for they are so constructed as to show that Tychonic concept of a stationary Earth around which revolves the Sun which in turn is the

[25] *Ibid.*, p. 290: "... Solem igitur COPERNICUS ponit apud centrum mundi consistere, ratione totius, centro sic et axe, immobilem ... Iam vt quisque primariorum est Soli proprior, ita breviore periodo circum Solem fertur, sub eodem quidem communi circulo Zodiaco, et in plagam omnes eandem, in quam partes corporis Solis praecedunt; Mercurius spatio trium mensium, Venus sesqui-octo, Tellus cum coelo Lunae duodecim, Mars viginti duobus semis, seu minus quam duobus annis, Iupiter duodecim, Saturnus triginta annis ... Tellus interim circa suum etiam axem, et circa Terram Luna circumvolvitur, rursus in plagam vtraque, si ad exteriora mundi respicias, eandem, in quam omnes primarij. Omnes autem motus COPERNICO sunt tantum in directum et continuum, nulla penes illum statio in rei veritate, nulla retrogradatio".

[26] *Ibid.*, p. 308: "*Terram igitur haec COPERNICI philosophia facit unum ex planetis et inter sidera circumfert; quaero quid praeter dicta requiratur ad faciliorem dogmatis, argumentorumque perceptionem?*"

center of the planetary orbits is less probable than the heliocentric concept of Copernicus. In the forefront of his argumentation Kepler places the small size of the Earth not only in relation to the Sun but also in relation to the superior planets (Kepler assumed incorrectly that Mars is bigger than the Earth). According to Kepler, smaller bodies should revolve around larger ones, and in the Tychonic system, the Sun, despite its enormity in comparison with the planets, revolves around the Earth together with three planets, each one larger than our globe. Very fitting then is Kepler's conclusion: "Terrâ verò eunte, Solem necesse est quiescere"[27].

Later in the fourth book of the *Epitome* we will find few ideas directly borrowed from Copernicus; rather, we find there Kepler's own astronomical ideas. In particular, in part 3 of this book, in the chapter "De motu latitudinis", Kepler corrects the geometry of Copernicus' planetary orbits by placing the line of orbital nodes in the Sun.

The modification of Copernican ideas appears also in Book V of the *Epitome* which constitutes the second part of "Doctrina theorica". In this book Kepler gives a mathematical argumentation for his first and second laws of planetary motion be presented under the guise of the astronomy of Copernicus, who shared the views of the ancients that the planetary orbits consist of perfect circles. He answers that even though his hypotheses are non-Copernican, yet they arise from the basic theses of Copernicus' teaching: the immobility of the Sun and the motion of the Earth, and thus they may safely be regarded as Copernican[28]. In the same manner Kepler presents his theory of elliptical planetary motion, repudiating in this place Copernicus' use of two epicycles[29].

[27] *Ibid.*, p. 316.

[28] *Ibid.*, pp. 364-365: "*Quo iure hanc quoque partem facis Copernicanae Astronomiae; cum tamen is author manserit in sententia veterum de perfectis circulis?* Fateor formam hanc hypothesim non esse Copernicanam. At quia pars ista de Eccentrico servit Hypothesis vniversali, quae motu telluris annuo, et quiete Solis vtitur: fit igitur a potiori denominatio. Adde quod ista particula Hypotheseos, necessariis argumentis physicis ex illa quiete Solis et motu terrae, dogmatibus Copernicanis, nectitur; itaque bono titulo etiam haec ad COPERNICUM referti possunt".

[29] *Ibid.*, pp. 364-365: "*Quo iure hanc quoque partem facis Copernicanae Astronomiae; cum tamen is author manserit in sententia veterum de perfectis circulis?* Fateor formam hanc hypothesim non esse Copernicanam. At quia pars ista de Eccentrico servit Hypothesis vniversali, quae motu telluris annuo, et quiete Solis vtitur: fit igitur a potiori denominatio. Adde quod ista particula Hypotheseos, necessariis argumentis physicis ex illa quiete Solis et motu terrae, dogmatibus Copernicanis, nectitur; itaque bono titulo etiam haec ad COPERNICUM referti possunt".

Book VI the *Epitome* deals in a general way with movements as seen from the Earth. Kepler begins his exposition with the apparent motion of the Sun, stressing the fact that in agreement with Copernicus, the apparent solar movement mirrors only the motion of the Earth[30].

While explaining the problem connected with the apparent solar motion, Kepler gave the definition of the "great circle" which appears in the theory of Copernicus. He explains that by "great circle" Copernicus meant the orbital path of the Earth, which is very small in comparison with the dimensions of the sphere of the fixed stars[31]. The reason for labeling this circle as "great" is not its size but the unique place assigned to it in the Copernican system.

In the questions that follow Kepler occupies himself with the motion of the Earth's aphelion, or, as Copernicus following the ancient tradition calls it, the solar apogee. At this point it should be remembered that Copernicus believed the motion of the solar apogee to be nonuniform. Kepler, however, shows that by referring the motion of the Earth to the center of the Sun (and not to the center of the "great circle" as was done by Copernicus), and by making allowance for possible errors in the observations of the Arab astronomers used by Copernicus in computing the motion of the solar apogee, the motion of the "solar apogee" may be regarded as uniform[32].

In the second part of Book VI dealing with the movements of the superior planets, in chapter 2 entitled "De directione, statione, retrogradatione", Kepler explained why the Copernican astronomy, by assuming Earth's motion, accounts in a simpler way for the planetary movements

[30] *Ibid.*, p. 399: "*Quare fit initium a Theoria Solis?* Primum, quia motus Solis apparens, secundum placita COPERNICI non inest ipsi Soli, sed inest terrae, nostro domicilio: aequum igitur est, vt a nobis ipsis noscendis exordio sumpto, postea demum ad caeteros planetas noscendos progrediamur. Sequundò, quia hic Solis motus apparens, est multo simplicior et aequabilior, quàm motus reliquorum planetarum".

[31] *Ibid.*, p. 403: "*Quid est in Astronomiâ COPERNICI Orbis magnus?* Sic appellat Copernicus hanc ipsam Orbitam veram telluris circa Solem, sitam medio loco inter Orbitas Martis exteriorem, et Veneris interiorem: et Magnum appellat, non ob quantitatem cum superiorum Orbitae circulares sint multo ampliores: sed omnium planetarum primariorum". "*Quae est huius Orbis proportio ad sphaeram fixarum?* Copernicus ponit eam plane insensibilem, ob planetas reliquos. Itaque ... proportio probabiliter introducta, quia et ipsa insensibilis, et inobservabilis est, cum COPERNICI positione benè stat".

[32] *Ibid*,. p. 407.

than the geocentric theory. In two questions Kepler discussed the method of interpretation of the observed direct and retrograde motion of the superior planets as well as their stations, supporting his arguments with a suitable diagram[33].

In addition, we encounter the name of Copernicus in numerous places where there is a discussion concerning the motions of both inferior and superior planets. Here Kepler criticizes both Copernicus and Tycho for assuming motions around geometrical points devoid of matter. Copernicus is also mentioned in the fourth part of Book VI where Kepler makes a comparison between his own hypotheses dealing with the inequalities of the monthly lunar motion and those of Tycho Brahe and Copernicus.

Problems in Precession

The new astronomical ideas of Copernicus concerned not only the planetary motions but also the precession of the equinoxes. Kepler deals with these ideas in the last, seventh, book of the *Epitome*. We find in this book short reflections upon the eighth and ninth spheres that appeared in the pre-Copernican astronomy in connection with the explanation of various lengths of the sidereal and tropical year; further on, Book VII contains a discussion of the problems in precession, the changes in the obliquity of the ecliptic, and other questions connected to the above. Since Copernicus introduced fundamental changes in the theory of precession by connecting it to the third motion of the Earth, Kepler invokes his name several times.

In the beginning of Book VII Kepler mentions that before Copernicus the astronomers introduced as many as ten spheres, the last three of which, that is the eight, ninth, and tenth, pertained to the fixed stars. Kepler reminds the readers of the attempts to add two more spheres, namely eleventh and twelfth, for no one was able to solve all the problems concerning the fixed stars by means of three spheres only. He asks then what caused the astronomers to place additional starless spheres on top

[33] *Ibid*,. pp. 416 ff.

of the sphere of the fixed stars[34], and he supplies an extensive answer where he mentions trepidation.

While referring to the ecliptic longitude, Kepler stated that Copernicus used the star "prima Arietis" as his zero point. He repeats after Copernicus that the simple motion of the Sun is counted from the first star in the zodiacal constellation known as the Ram, while the composite consists of two parts: a simple motion in respect to a fixed point, and the motion of that point around the movable equinoctal point[35].

After discussing problems involving the calendar, Kepler ends his *Epitome* by stating that many problems will remain hidden in the book of eternal laws until it will please immortal God to let it be opened by mortals[36].

Final Remarks

In appraising the whole of *Epitome astronomiae copernicanae* in respect to the Copernican ideas that it contains, it must be stated that the basic tenets of Copernicus' teaching found here a proper presentation. The great piety that Kepler harbored toward Copernicus enabled him to make a correct evaluation of the contributions that Copernicus made in laying the foundation of new astronomy. For Kepler, who believed himself to be a guardian at the door of the temple where Copernicus celebrated the services at the high altar, presented in this work contemporary astronomy as it developed from the ideas of Copernicus.

The *Epitome* appeared about 75 years after the publication of *De revolutionibus*. During this time period many astronomical views changed.

[34] *Ibid*,. p. 515: "*Quam causam habuerunt sphaerae Fixarum superponendi sphaeras alias sine stellis?*"

[35] *Ibid*,. pp. 524-525: "*Quid vocat COPERNICUS motum Solis simplicem, quid motum compositum?* Simplex is dicitur, cuius initium sumitur a puncto fixo, scilicet à primâ stellâ Arietis ... Compositus motus est, qui constat ex duabus partibus, 1. ex motu à fixo puncto in consequentia, 2. ex motu medio principi Arietis ... hoc est, qui numeratur a puncto non fixo sed mobili, scilicet ab aequinoctiali".

[36] *Ibid*,. p. 530: "Verissimae igitur planetarum Inclinationes ad Regiam viam, causaeque et quantitates et plagae motuum, limitum et Nodorum, haec inquam et caetera huiusmodi latent in Pandectis aevi sequentis, non antea discenda, quam librum hunc Deus, arbiter saeculorum, recluserit mortalibus, immortalis ipse, cui sit laus, honor et gloria in saecula saeculorum, Amen".

The greatest input in solving the problem of planetary motions was executed by Kepler himself; it was he who corrected the heliocentric system and placed it on a firm basis.

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Eugeniusz Rybka (1898-1988) – eminent Polish astronomer
(*Painted by Marek Genew*)

Johannes Kepler, His Supernova and His Astrometeorology

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Jan Oort (of the Oort cloud, Oort limit, and Oort rotation constants, van der Kruit 2001) once said that, when there was another astronomer as great as Kepler, there would be a supernova for him to see. Indeed SN 1987 was, briefly, a naked eye object, but only from the southern hemisphere, which Oort had last visited in Sydney Australia.

Given that Kepler was something like 9$^{\text{th}}$ person to see his supernova, owing to clouds and rain in Prague, it is not surprising that he also took an interest in weather forecasting. That he should apparently have thought that such forecasting could be improved by better predictions of locations of planets in the sky and methods of astrology, on the other hand, comes as a considerable surprise to modern minds (mine anyhow), and we will return to this.

So who did discover the new star in the foot of Serpentarii (Ophiuchus)? Immediately we encounter a difference in custom between east and west. Nearly all the early European reports have observers' names attached, while the records from China and Korea say things like "In the division of Wei, there was a star like a crossbow pellet." and "In the first watch of the night, there was a guest star; it was 10 du in Wei lunar lodge and its distance from the north pole was 110 du." The first Chinese sighting occurred on 1604 October 19 and the first Korean on 1604 October 13. There are at least 14 good Korean brightness estimates, covering the pre-maximum rise and portions of the decline.

The Europeans got in a day (actually about 18 hours) earlier, with two reports from Italy, from a physician (whose name is not known) who reported to Christopher Clavius in Rome (and later provided several good brightness estimates) and from Ilario Altobelli in Verona, who reported to Galileo (Stephenson & Green (2002)). Others who caught peeks before Kepler included B. Capra and S. Marius in Italy and J. Bronowsky in Prague, who passed the news on to Kepler on the 10^{th}, when clouds intervened. Thus Heck in Rome, Maginia in Bologna, Roeslin in Hagenau, and David Fabricius in Osteel, Frisia on 13 October, were also "pre-Keplerian" discoverers. Of these Fabricius is most significant, because, along with Kepler he started recording positions relative to comparably bright stars and estimates of the brightness of the new star itself (Baade 1943, Burke-Gaffney 1937).

So, what did our early 17-th century colleagues report, how did they measure things, why, what can we learn from these historic data, and what have we learned about Kepler's supernova and its remnant since?

First, what did they report? Both east and west recorded dates and generally times. European dates could be either on the old Julian calendar or the newer Gregorian one. Dates from China, Korea (and for other supernovae, Japan) were given as reign period (name or equivalent of the current emperor), year of the reign, month and day. Turning "Wanli reign period, 32^{nd} year, ninth lunar month, day yichou" into 1604 October 10 (Gregorian) is a highly specialized skill (and there have been a few disputes about correct readings of ambiguous signs, though none connected with the 1604 event). Next was position in the sky, relative to known permanent stars and perhaps planets. The Chinese and Korean ones were precise to a degree or so, Kepler and Fabricius to a few minutes of arc. Then a color (red-yellow from Chinea and orange or like Mars at least initially from Europe). Then finally an estimate of brightness, for which the Korean and Keplerian data continue on until the guest star had faded below detectability.

Second, just how were the various parameters measured? We tend to assume that scholarly colleagues back then knew what day it was, again with a few exceptions, none affecting 1604. The Eastern positions made use of existing areas on the sky, defined by conspicuous star patterns (only the Big Dipper and one or two others of our Babylonian to Greek constellations look the same) and/or divisions along the ecliptic and path of the Moon. A unit of distance was the du, the motion of the Sun in a day. Other mentions of position invoke something like the angular size of thumb or hand at arm's length. The European positions were angles from well known, relatively bright stars. Fabricius and Kepler used many of the same stars and agreed about the angles to a minute or two of arc. One problem was differential refraction in the atmosphere – the event, at declination 21°, never rose very high. The second was that Kepler tried also to use angular distances from nearly planets Jupiter and Saturn, whose positions, of course, changing through the days, and his theory of their motion was not good enough for his purpose. Baade (1943) and his successors have, therefore, agreed that the positions from Fabricius are to be preferred, though either set is more than good enough to say firmly that the remnant has been correctly identified at all relevant wavelengths. Kepler used a sextant, and similar devices were at the disposal of the other European observers. Those in the east were apparently eyeballing the situation. Both East and West reported brightnesses relative to Jupiter, Saturn, and Mars, which were conveniently near and stars in the constellations of Scorpio, Ophiuchus, Aquila, Libra, and Sagitta. The relationships were originally described in words that most naturally translate as "larger," "smaller," or "about the same as." Stephenson and Green have provided these as "brighter," "fainter," and "about as bright as." There are gaps in the data from when the Sun, Moon, or clouds were too close in the sky to the new star. With modern estimates of how bright the relevant planets would have been then and there (their proximity is part of our next item) and knowing that the comparison stars are not extreme variables, Stephenson and Green were able to plot a single light curve from the Korean plus Keplerian data (with that unknown Italian physician making an important contribution to the rapid rise in brightness from 10 to 15 October). Because many observers were watching that patch of the sky regularly just then, there are good upper limits on the possible brightness a few days before discovery. The Koreans last report a brightness close to that of Tau Sco on 22 April 1605 (and Yellow), while Kepler's last data point is fainter (smaller) or equal to Eta Oph (m = + 2.6) on 8 October 1605. His efforts to recover the new star when it came out from behind the Sun in 1606 failed.

Why Were They All Doing This?

The short answer is that it was part of everybody's "job description." The imperial courts of Korea, China, and Japan all maintained official court astrologers (the issue of the extend to which the systems in Japan and Korea were derived from the Chinese is way above my pay grades (see North 2008, chapter 5). Their jobs included observing, recording, and prognosticating. Under the circumstances, it is not surprising that both the appearance and fading of a new star could be interpreted as favorable to the emperor, described as a great worthy! Kepler's position, from 1601, as Imperial Mathematician to the Holy Roman Emperor Rudolph II, was not so very different. David Fabricius (1564-1617, Faber, Goldschmid etc) was employed as Lutheran clergyman, which carried a different set of responsibilities! He had discovered the variability of Mira in 1596; it was his son, Johann Fabricius (1587-1616) who published the first European observations of sunspots, associating them with the rotation of the Sun's surface, and not with transits of Mercury, Venus, or other unknown planets (a topic that also concerned Kepler).

Both, however, had additional "agenda items," connected with whether the trans-lunar cosmos could change. Assorted Greeks and churches had said no. Tycho's supernova of 1572 and the comet of 1577 in Tychonic data were both clearly well outside not only the Earth's atmosphere but also the orbit of the Moon, based on an absence of geocentric parallax. Accurate measurements of the position of 1604 event were important in this regard, as was the fact that it twinkled (reported also in the Eastern records) and so was a "star" not a planet or comet.

Kepler, at least, had an additional retrognostication at stake. Conjunctions of Jupiter and Saturn occur every 12 years, approximately. And these march around the Zodiac/ecliptic in a complicated pattern that, in turn, repeats approximately every 800 years (See Hoskin p. 200).

The conjunction shortly after 1600 CE was the first since about 800 CE to occur in a Zodiacal sign associated with the element fire. Many other European astronomers/astrologers of the period were interested in the details of conjunctions, and this guaranteed that the 1604 event would be caught quickly and that good limits could be put on its brightness just a day or two before discovery.

Burke-Gaffney's 1944 book focuses on Kepler's version of those 800-year periods and what happened at each "fiery" conjunction and the great man born at the time: 4000 BC Adama; 3200 BC Enoch; 2400 BC Noe (presumably Noah); 1600 BC Moses; 800 BC Isaias (presumably Isaiah); 0 BC/AD Christ. Kepler was also involved in discussions of Biblical and Roman evidence for the year of Christ's birth and whether the star of Bethlehem was associated with that conjunction; Kepler's view of the star, again following Burke-Gaffney (1037, 1944), is that it was a special miracle arising from the lower layer of the atmosphere – so that it could "lead" but somehow also he associated with the conjunction); 800 AD Charlemagne; and 1600 AD (don't hold your breath!) Rudolph II, his patron. By 240o, who knows! And would they remember us? The half-way-between conjunction of 2000 CE received a good deal of popular press attention, "Was it the Star of Bethlehem returned? And, if so, what did it mean?" Not, anyhow, all the computers failing because of the extra zeros in the year. Or perhaps, Kepler opined on another occasion, the nova, like comets, condensed out of the ether above the lunar sphere.

The diminutive Irish engineer-astronomer-priest Rev. Michael William Burke-Gaffney (1896-1979) was himself an exceedingly interesting character, better known in Canada than in Poland or the US, but this perhaps takes us too far a field.

Implications of the Historical Data

We learn, first, that there was a supernova there (in two dimensions anyhow) and then. Even this was not always so. The supernova-defining papers of Baade and Zwicky (1934), made use of data from 6 events in the Virgo cluster, 6 others outside the Local Group, S Andromeda (1885 in M31), Z Cen (1895 in NGC 5253), and Tycho's 1572 event. Neither Kepler's SN nor the 1054 (Crab Nebula) event were yet on their radar, still less the other Galactic historical events of 1006, 1181, and whatever made the radio source Cas A. Even with this somewhat larger sample, as per Stevenson & Green, its mere existence adds a bit to the statistical information on "rates, types, and parent populations." The additions are somewhat inconsistent!

What can the light curve tell us in comparison with the now very large sample of more recent events? Some normalization of the peak apparent magnitude of – 2.25 is needed. How far away was the exploding star? And how much light absorption was/is there along the line of sight? Vink (2017) makes the light curve look a bit like assorted Type Ia (nuclear detonation or deflagration) SNe by putting 1604 at 5 kpc from us, with 2.8 magnitudes of obscuration. Woltjer (1972) put it at 8 or even 10 kpc. He has very little else to say about 1604, though 1054 and 1572 appear k in his tables of energetic and X-ray SNRs and in his discussion of the evolution of radio SNRs. The assumption is Type I, but only for the Tycho event is there a spectrum of a light echo to establish the type. The Crab is a core-collapse event because we see the core (pulsar NP 0532), and a Type II because the present remnant has enough hydrogen that its presence would surely have been obvious if the Chinese and other observers in 1054 had thought to take a spectrogram.

What Have We Learned Since 1605?

There are, of course, now lots of nice images from the Very Large Array (radio), the Spitzer Space Telescope (infrared), HST (optical), and Chandra (X-ray). As is bound to happen where data pile up, many astronomers have entered the fray on how fast the remnant is expanding, what is it interacting with, and is it a typical anything?

But the outstanding SN Ia problem these days seems to be, are the progenitors binaries consisting of two white dwarfs that merge (double degenerate scenario) or of one white dwarf driven close to, or above, the Chandrasekhar limit by accretion from some less compact star (single degenerate scenario)? For the class as a whole, one could say "Some of each." That is not possible for a single event whether seen in 2021 in 2021 or 1604. So which was it? As Vink (2017) points out, there are observations inconsistent with each scenario. If there was only one white dwarf, where is the other star, which cannot have gone all that far in 400 years! If two merging white dwarfs blew themselves up completely, then why is there silicate dust around, and why is the remnant expanding into nitrogen-rich material like a wind from an AGB star?

Whichever scenario you favor (I'm a double degenerate person myself) somehow the progenitor system has to have left the galactic plane at something like 250 km/sec, the current bulk motion, about million years ago, to reach its present position (for d = 5 kpc). My own, not well thought, suggestion is that there were two stars in a tight orbit themselves orbiting a much more massive third star which disrupted (while still containing more than half the total mass of the system or in a highly asymmetric fashion) thereby ejecting two white dwarfs, the surface of at least one carrying a bunch of stuff from the original massive primary of the triple system. It's OK if this is rejected by Astrophysical Journal. I can't afford their new page charges anyhow.

What might we still be able to learn about the 1604 event? Perhaps additional contemporary records might surface in "the provinces" though the gaps in the light curve due to the Sun being in the sky are unbridgeable (at least from earth-based data). Better determinations distance and obscuration seem to require better understanding of the present motions of all the different bits of the remnant and its emission mechanisms. Perhaps the best hope is that bigger, better (and more expensive) telescopes focal plane instruments, and computers might reveal a few extragalactic remnants of comparable age (again etc.) that could be more firmly associated with a particular type of progenitor, star formation region, explosive mechanism, and so forth. Some time around 2104 might be a good guess for that to happen.

The Kepler of the supernova is, at least in part, someone we might feel we could have a technical discussion with. Modern astronomers measure positions and brightnesses as accurately as they can, and sometimes colors. We sometimes do these things with the explicit goal of ruling out a hypotheses predating or in conflict with our own (as Kepler wanted to show that there was change in the trans-lunar cosmos). Can we at least completely reject the thought that the dance of Jupiter, Saturn, and Mars around each other in the sky would foreshadow a “new star” of some sort? Perhaps not quite. The recent shenanigans of Betelgeuse led some to expect a supernova, and some of the words published in recent years about Eta Carinae and hibernating novae appear to suggest predictive power.

As we go on to Kepler and meteorology, it is, for me at least, much harder to adopt a mind set in congruence with what he was apparently trying to do, except, perhaps, that the quest for a “theory of everything” is eternal, but the “things” to be included in “every” change. Both Schrödinger and Einstein in their later years mired down in efforts to find a “unified field theory” of gravitation and electromagnetism. Kepler’s idea of “everything” included not only laws of planetary motion, Biblical chronology, and horoscopes (he is said to have cast about 800 in his life), but also notions of musical harmony, and weather forecasting, to which was now turn.

Kepler and Astrometeorology

To all intents and purposes, I had never heard of astrometeorology, let alone Kepler’s contributions to it, until the April 2021 issue of Physics Today arrived, with an article entitled “Medieval weather prediction” by Anne Lawrence-Mathers (2021). To one-sentence precis of the article reads “Meteorological practices that developed in the first millenium did not die in the Middle Ages, but were radically improved with an international science of weather forecasting.” The early developments were Islamic, with the core idea that the planets and their movements around the Earth (center of the cosmos in those days) affected atmospheric conditions (perhaps via stirring the aether) and so determined or at least affected terrestrial weather. Further European development, we are told, included work by Tycho Brahe and Johannes Kepler, and other astronomers, particularly David Fabricius (variously Faver and Goldsmid). The article never quite says that what they were doing was simply not the right way to look at weather!

What could they possibly have been thinking of to suppose that better measurement of the motions of the planets, and thus better astrology, could possibly lead to better weather forecasts?! Well, just possibly, if a Creator was determining the motions of the planets, which swirled the aether, which swirled the atmosphere, but first, Kepler was confirmed Copernican from 1600 on or thereabouts, and, second, this does not quite seem to be what he had in mind. At this point, I mast pause and extend hearty thanks to James Voelkel (1999, 2001, 2021) for some insight into late sixteenth and early seventeenth points of view. He also put me in tough with Mary Ellen Bowden of the Science History Foundation, whose currently unpublished manuscript "The astrometeorological research of Johannes Kepler and David Fabricius" is a treasure-trove of detail about each of their publications on the topic and the exchange of letters between them.

Kepler was attempting a "theory of everything" though his "everything" was a very different inventory of phenomena from that of modern theoretical physicist, with strings and multiverses, or the early 20th century Einstein and Schrödinger, who just wanted to unify gravitation and electromagnetism (Halpern, 2015). It included all of the quadrivium – geometry, astronomy, arithmetic, and music – and much of what happened on Earth, both natural and driven by human behavior. You weren't supposed necessarily to think that the motions of the planets relative to the fixed stars caused the fall of rain or the fall of kings, but that God had created a harmonious whole, in which knowledge of what was going on in one sphere could yield insights into what was going on or about to happen in another sphere.

Thus in Kepler's cosmos, the spacing of the planets could be figured out by nexting the Platonic solids between spheres and their angular velocities corresponded to musical notes, or rather ratios of musical notes as produced by strings under tension and stopped or fretted off into lengths that are the ratios of small whole numbers, along the lines recommended by the Greeks. Under this "common cause" hypothesis, better knowledge of the motions of the planets could improve predictions of long and short term atmospheric changes. Kepler's early work had used tables of motions of the planets that predated Copernicanism, Tycho's work, and his own. Thus he expected to get better forecasts when he incorporated better astronomy or astrology. We will return in a few sentences to what aspects of the motions he thought most important.

Remember first, however, that Kepler and Fabricius and all were working just before thermometers, barometers, anemometers, and even well-designed rain gauges came into use, so that both the forecasts and weather reports accumulated afterwards spoke of conditions being warmer or colder than averages, violently windy and snowy, of gentle breezes from SSW, and so forth. The modern forecasts in The Old Farmer's Almanac J.S. (2021) are also of this form and also have some astrological input.

Just what celestial arrangements did Kepler regard as significant? Some of his early weather-remarks are of the form that a conjunction of the Sun and Saturn in February foretold cold weather. But he came in due course to attach great importance to what are called "aspects" (as a technical term), meaning the angular displacement along the ecliptic between two astronomical objects.

The specific angles have names and can be defined either by inscribing various polygons in circles are by cutting out "pie pieces" whose fraction of the circumference corresponds to those ratios of small whole numbers AND to (mostly) euphonious musical intervals. Ptolemy had defined the first four; Kepler added four more, as per our Table here (data from Bowden 2021).

One of the missing pieces in this "everything connects with everything" picture is Kepler's cosmic chord. Ferguson (2002) provides a brief, fairly comprehensible, explanation of how the ratios of angular velocities of the planets in their orbits, taken pairwise, correspond to musical intervals. The relative sizes of the orbits came from Kepler's use of the Platonic solids to space out their orbits, and the periods were, of course, measured.

Aspect name	Inscribed form	Angle	Ratio	As decimal	Interval	Note in C major
opposition	diameter	180°	2:1	2.00	octave	C
trine	triangle	120°	:2	1.50	fifth	G
quartile	square	90°	4:3	1.33	fourth	F
sextile	hexagon	60°	6:5	1.20	minor third	Eb or D#
quintile	pentagon	72°	5:4	1.25	major third	E
biquintile	5-pointed star	144°	5:3	1.67	major sixth	A
sexquadrate	8-pointed star	135°	8:5	1.60	minor sixth	Ab or G#
quincunx	12-pointed star	150°	12:7	1.74	sour seventh	B or Bb
not used	9-pointed star?*	40°	9:8	1.125	whole step	D
by Kepler	16-pointed star?	22.5°	16:15	1.067	half step	C# or Db

* The same method used to hand-draw a five-pointed star can be extended to yield stars with 7, 9, or 11 points with a little care. The easiest way to draw the 8, 12, and 16 pointed ones is probably to put a suitable number of dots equally spaced around a circle and connect them up after a bit of thought. For other numbers you are on your own.

Figure 1 shows, first, the six notes of the six planets known to Kepler. He wrote in a contemporary letter that he would have preferred to find the tonic note at the bottom, so, in part b, I've added two notes to accomplish this, "obviously" yielding a prediction of Uranus and Neptune. This much can be played on a harpsichord, organ (yes there still exist ones built before 1600, mostly in Italy), or a modern piano. But there is room for a bit more. Parts c and d fill in that gap with either an E ("mi") or G ("so") falling between Mars and Jupiter, to represent the asteroid belt, beginning with Ceres, discovered in 1800/1801.

If you happen to have a keyboard handy (no, the other sort), try the two and decide which sound you prefer. Oh? You don't have hands like Rachmaninoff to play all nine notes at once? Bend over and hit the E or G with your nose. On pianos dating from between about 1890 and 1939, I prefer the version with the G. On an electronic keyboard, the one with the E. If anyone should have access to a very old organ, I would be interested in a report on which sounds better there. Some of the classic organs were actually not tuned to equal temperament in which each half step is precisely (2)1/12 higher in frequency that the previous one, so that a full chromatic scale takes you exactly a factor of two up to the octave. Instead, his idea of tuning was the ratio of small whole numbers, as in the Table above, and a fixed-tuned instrument, piano, organ, strings with frets, made to be played in one key will sound perfectly awful in a distant key. Thus your "organ in C" may do for F or G major, but not for E major or a flat.

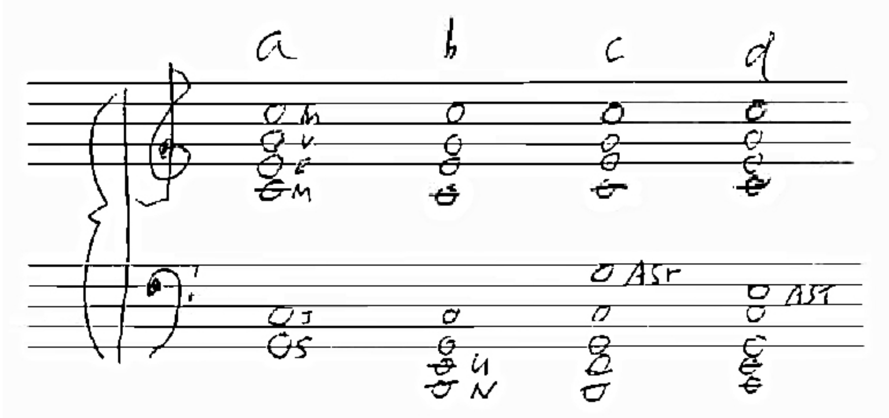

FIGURE 1. Kepler's "harmony of the worlds", (a) as shown by Ferguson (2002, p. 239), (b) with additional bass notes added to represent Uranus and Neptune, (c) and (d) with one more note added to represent the asteroid belt as either closer to Jupiter (d) or closer to Mars (c).

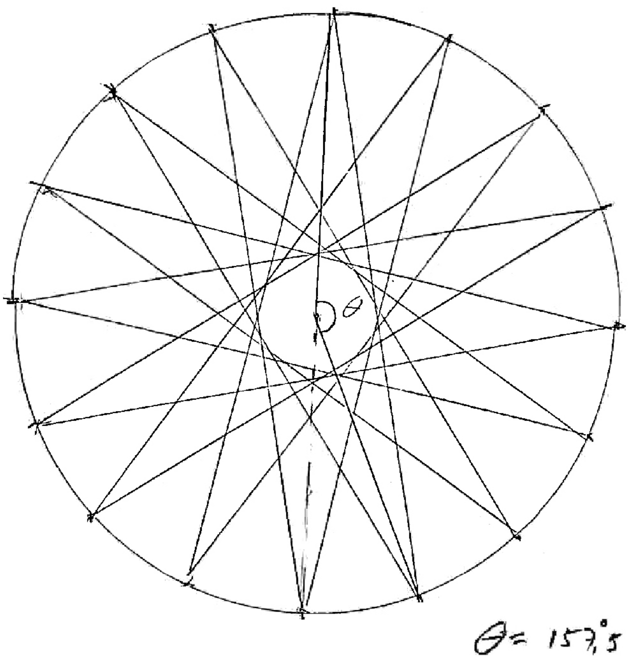

FIGURE 2. And here is our 16-pointed star, drawn by the methods just described, on my first try. Kepler did not use this; it would represent two planets getting fairly close to, or just leaving, opposition, with the unmusical interval of a half-step or major 7th.

Given that point of view, it becomes clear why Kepler and others should have thought accurate planetary position data was important. These will determine just when (random example) Mars and Saturn are at trine, and, if this leads you to expect icy rain on January 3rd, but the real aspect occurred on January 1st or January 7th, it is quite likely that there will have been icy rain in Prague at least one day in that period.

This brings us to the other key aspect of Kepler's (and Fabricius's) contribution to astrometeorology: the keeping of accurate records of what weather actually occurred on each day in some particular place. There are places for which "tomorrow will be a lot like today" and "next year will be a lot like this year" are quite good predictors. Southern California happens to be one of them, modified by things like the El Nino, La Nina roughly two-year cycle that they could not have known about (and there are other somewhat longer cycles now known belonging, for instance, North Atlantic).

The next step in better forecasts comes from watching for what is coming over the horizon, for which Earth-observing satellites are now of fundamental importance. But one can do something in the direction if you know about prevailing wind directions and what has been happening "upwind" of you. The trade winds were indeed known in 1600 (though their cause was still under debate – Hadley cells, we now say). For instance, through nearly 30 half-years at the University of Maryland, I learned to keep an eye on weather reports from Chicago, because significant temperature changes and precipitation there were likely to show up around Washington DC about two days later. Amsterdam is about the same distance north-west of Prague as Chicago is from Washington DC, and I have just started to track whether there is a similar correlation. Of use to Kepler? Well, no; because he would have had no way of finding out what yesterday had been like in Amsterdam before the same conditions hit him.

So, what can we say about astrometeorology? The word, according to the Oxford English Dictionary, goes back at least to 1669, again post-Kepler (though in any case he wrote mostly in Latin). The underlying principles were simply false, though could possibly have coupled into some cycles not known at the time. Record keeping would eventually prove to be useful, particularly once thermometers (which should NOT be kept indoors as they were in the 1700s) became common. And the echos linger longer.

The Old Farmer's Almanac (2021 J.S.) provides its forecasts mostly in the form of temperature and precipitation deviations from average (over 30 years) conditions in various places. They are also fairly secretive about their methods (which are claimed to be 80% accurate), but some astrology enters into it, and they attributed causative power to the sunspot cycle. This also Kepler could not have known about, since western astronomers were just discovering sunspots and learning to attribute them to actual solar phenomena (vs. transits of inner planets) in his lifetime. He actually changed his mind from transits to "attached" and useful for measuring solar rotation.

But let us end on a cheerful note! Back in the 1930s, when McDonald had left $1,000,000 to the state of Texas to build an observatory, many of farmers, whose land might be taken, naturally objected. What use is an astronomical observatory, one of them asked? Well, responded Joel Stebbins (a pioneer of photoelectric photometry), maybe if we know more about astronomy, we can provide better weather forecasts! In the dust-bowl Texas of the mid 1930s, this was regarded as something much to be desired, and in due course most of the bequest and observatory went forward (Abt 2020).

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"Shaking hands with Shakespeare" is a traditional passtime in which a person (or several in competition) try to figure out a minimum path, back through the generations, of the form "I knew person A, who knew B, who knew C ... who knew Shakespeare." For scientists, we can do this with advisors and mentors. Thus van der Kruit (2021) reveals that his own scientific genealogy can be traced back to Phillip Müller (1585-1659), a frequent correspondent of Kepler's.

Are there any remote descendents of Kepler among us today? Well, sort of. If you go to the Mathematics Genealogy Project and ask for Kepler, you will find him there, with a few supposed students, some of whom have 10^5 or more descendents. Follow a trail, step by step forward, at each step choosing the student said to have the most descendents of his own until you reach a name you recognize in the 20^{th} century.

In this fashion, I came upon John von Naumann, whom I never got to meet but have always been greatly in awe of. I backed up a few steps and followed someone with the second most descendents back forward and came upon Irving Segal, whom I really did know, near the end of his career. He was a mathematician, as are most of the individuals (well, men) you will encounter in this exercise, a very distinguished one, but who, late in life, took up the idea that the correct form of Hubble's law is velocity proportional to distance squared, not just to distance linearly. This in turn was and is inconsistent with a General Relativistic universe, but perfectly fit by his own chronometric cosmology.

Try it for yourself! It is possible that, following some other path through the maze of the Mathematics Genealogy Project, you may find that you are yourself a descendent of Kepler! There are other paths that lead backwards to medical doctors in Italy, sometimes to Galileo, and even al-Tusi of the Tusi couple!

Kepler References & Suggestions for Further Reading, With Comments

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[11] Hallyn F., Lammens C., 2014, Cornelis Gemma in Thomas Hockey et al. Eds. The Biographical Encyclopedia of Astronomers, 2nd Ed., p79-794, Springer. Mentions his view that patterns in the sky need not cause terrestrial events, but 'flow with them' and so have predictive power.

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[14] Hufbauer K., 1991, Exploration of the Sun: Solar Science since Galileo, Johns Hopkins Press. Discusses who and when recognized sunspots as intrinsic to the Sun and the 11-year cycle.

[15] J.S. The Old Farmer's Almanac, 2022 edition (Almanac.com). Partial explanations of their weather and other forecasts, by methods at least somewhat akin to Kepler's.

[16] Lawrence-Matthews A., 2021, "Medieval Weather Forecasting", Physics Today 74, No. 4 (April), p. 38. My introduction to astrometeorology. The oddity is that the author never quite says I can't be true.

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a frequent correspondent of Kepler. One of his pupils, Jacob Bartsch c. 1600-1633 became Kepler's assistant and son-in-low.

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[25] Voelkel J. R., 1999, Johannes Kepler and the New Astronomy, Oxford University Press.

[26] Voelkel J. R., 2001, The Composition of Kepler's Astronomia Nova, Princeton University Press. My web-search for astrometeorology and Kepler led me first to Prof. Sachiko Kusukawa of Cambridge University, who referred me to James Voelkel. He e-said that neither of these books would tell me much about the subject (TRUE), but that the Oxford one was a "good read" (also true), and referred me on to Dr. Bowden, who has been thinking about the subject for many years. Gratitude all around!

[27] Woltjer L., 1972, Supernova Remnants, Annual Review of Astronomy and Astrophysics 10, 129-159. Has very little to say about Kepler's; more about Tycho's; and quite a lot about the Crab Nebula.

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Virginia Trimble (*Photo: Bill Ray*)

When I was hired by the University of California, Irvine, three years after receiving a 1968 PhD from the California Institute of Technology, I was the youngest member of the physics department, as well as its only astronomer and only woman professor. I am now the oldest member of the Department of Physics and Astronomy, and there are also now quite a few women professors. In between, many wonderful things have happened – 28.5 years of marriage to the remarkable physicist Joseph Weber, making lots of friends in the astronomical community, many of the Polish, the opportunity to be President of two different divisions of the International Astronomical Union (Galaxies and Cosmology; Union-Wide Activities), and the receipt of some wonderful awards, most recently the first Keplerus Ellipsis from the Societas Astronomia Nova and membership in the American Academy of Arts and Sciences. To be continued!

Kepler and the Popular Imagination: Personal Reflections on the Value of a Multi-faceted Nothing

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The History of Science, in general, and the History of Astronomy, in particular, may be among the least naturally "popular" of academic disciplines.[1] While astronomy itself has always been one of the most directly accessible of the natural sciences (easily evoking the gee-whiz effect at public observing nights), our collective efforts to explain the historical development of its technical ideas do not typically rate similar responses. Relatively few folks have even heard of our specialty, let alone understand what it is we do. Over the years, I have discovered that my domains of interest afford me an unfortunate superpower. When asked at social events to describe what I teach and research, however succinctly I fashion my reply, it rarely fails to make the recipient's eyes glaze over! I have even had potential students exclaim: "What!? You combine everyone's *least favorite* high school subjects and teach them *all together*? Why would you *do* that?"

The answer to that question is complicated and has proven even less likely to win friends and influence people, but it is mostly because I find myself fascinated by human beings who were themselves so fascinated with the very fact of being alive in the universe that they devoted their whole hearts, minds and souls to trying to make meaning and beauty out of the experience. Plus, it helps if they love astronomy, math and poetry! Some of my best friends are polymathic "post-mortals," kindred spirits from the distant past who drew upon and synthesized in their

[1] For our purposes here, the term "popular" refers to "accessible, readable and understandable" (by a generally educated audience) and/or "widely appealing and sells well."

lives, thought and writing all the ways of knowing that we now divide into the Humanities and Sciences.

In college, I had already met one such friend in John Donne when I began to learn more about Johannes Kepler. Given the geographical distance and the treacherous terrain of religious and political turmoil between them, it was rather improbable that their lives should ever have crossed. Somehow, though, it never really surprised me to discover that they had met and instantly appreciated each other's "metaphysical" personalities, philosophies and writings. Why, *of course* a poet who loved astronomy *would* hit it off with in an astronomer who loved poetry! Plus, they both were infinitely curious and intellectually convivial types: they loved demanding debates and discursive brain games, paradoxes, puzzles, anagrams, codes and ciphers, multi-linguistic puns and word-play, complex analogies and metaphor, irony and satire. Indeed, they both appear to have seen their own inner-Renaissance man – Donne as a metaphysical poet and Kepler as a poetical metaphysician – mirrored in the other.[2]

Donne and Kepler were close cultural contemporaries in other ways as well. Their life dates (1571/72-1631 and 1571-1630, respectively) were nearly coincidental (which might make some wonder what Kepler's astrology would have had to say about that!). They led similarly complicated lives. Both were ardent, life-long learners who experienced periods of deep spiritual doubt and engaged profound cosmic questions from multiple angles and various analytical approaches. Both felt intense inter-personal passion and joy, suffered immense personal loss and grief and battled cycles of serious illness and depression. Both, from young ages, experienced the precarity of poverty and pandemics, social discrimination and persecution and were inextricably caught-up in seemingly endless – and dangerous – familial conflict, religious warfare (both rhetorical and actual), legal wrangling and political intrigue. Both found themselves on unintended, nonlinear paths professionally with uneasy relationships to persons of power. Donne, born into a recusant Catholic

[2]For additional discussion of some of their mutual interests and cross-influences in matters of metaphysics, theology, natural philosophy, politics etc., from a "*literary* history of astronomy" perspective (and, per force now, a distantly youthful one!), see: Pamela Gossin, *Poetic Resolutions of Scientific Revolutions: Astronomy and the Literary Imaginations of Donne, Swift and Hardy*, 1989, University of Wisconsin, PhD Dissertation, UMI Dissertation Abstracts International, #9010301; pp. 1-203.

family, first studied law, emerged as a gifted secular (if not profane) poet, converted to a divine Protestant one, took Holy Orders (reluctantly) and then served James I on foreign diplomatic missions as a chaplain (if not spy) as well as the Dean of St. Paul's. Kepler, raised Lutheran, trained for a divine post, but accepted a call (reluctantly) to teach math, worked with Tycho (and his data), served as Imperial Mathematician for Rudolph II and other well-positioned patrons, but self-identified more as a devoted celebrant and exegetical lay-reader of God's book of astronomy. Attempts to form a composite picture of such multi-faceted personalities have proven a distinct challenge for even a multi-generational village of biographers, literary scholars and historians of science, religion and politics.

Johannes Kepler (1610) and John Donne (by Isaac Oliver).

Recent discussions on the History of Astronomy listserv (HASTRO-L) concerning well-known visual representations of Kepler in extant portrait paintings may provide an instructive analogue for discussing the challenges of biographical, historical and literary "portraiture" as well. In "How a Fake Kepler Portrait Became Iconic," Steven N. Shore and Vaclav Pavlik propose that one of the best-known "viral" images of Kepler (held in the Kremsmünster Benedictine monastery) may not be picturing him at all, but instead, may be a nineteenth-century forgery based on a "corrupt" copy of an earlier portrait of Michael Mästlin.

Through further sleuthing, however, Franz Krojer finds that "the authenticity or at least authentic representation of Kepler portraits has almost always been doubted by someone" and he makes an intriguing case that this "fake" may not be so fake after all.[3]

Indeed, early modern art historians have long known that visual representations of individual figures of the era are fraught products and processes. During Kepler's lifetime, the near-photographic realism of Albrecht Dürer or the naturalistic precision of the anatomical drawings in *De Fabrica* were rarely evident even in the most official portraits of those at the highest-ranks. The representational accuracy and "true to life" detail of such works greatly depended on a multitude of factors such as an artist's individual skill-sets, then-current painting trends as well as the use of emblematic imagery and references, stock backgrounds, fashionable costumes, props and instruments. Such images often seem to have served as a general "keepsake" impression of a person or a public "business card" to signal someone's social standing and profession rather than a precise visual record of their physical appearance and facial features. Interpreting such depictions across time can be plenty complicated, even when later viewers agree that the subject represented had only one face (and not the two so often ascribed to Kepler).[4]

The representative realism of verbal portraits also varies greatly with the subject, writer and historical circumstances. Unlike the national and international accolades produced posthumously for later eminent natural philosophers (Isaac Newton being the main case in point), after Kepler's well-attended funeral procession, public eulogies, memorial odes and hagiographical memoirs seem not to have appeared or were lost over time.[5]

[3]See Appendix 4, p. 27 and the rest of Krojer's useful postings regarding "Ernst Zinner's 'Die Kepler-Bildnisse' (1930), short summary" which provides a comparative analysis of Zinner's account in light of Steven N. Shore and Vaclav Pavlik's "How a fake Kepler portrait became iconic" (August 2021, https://arxiv.org/abs/2108.02213). See also the History of Astronomy listserv: HASTRO-L@listserv.wvu.edu. An additional fun-fact: one of John Donne's best-known extant portraits (a later copy, based on a 1616 miniature) bears remarkable similarities in overall composition to this one of Kepler, including the dark background, deep-set thoughtful eyes and stylish Spanish collar.

[4]The "Janus-faced" label was specially applied to Kepler by influential early 20th -century scholars such as Ernst Cassirer and Alexandre Koyré whose own historical and philosophical arguments often "turned" upon whether a particular figure best fit "before or after" a key revolutionary moment in the development of science, for example: Ernst Cassirer, "Mathematical Mysticism and Mathematical Science" pp.348-49 in Ernst McMullin, *Galileo: Man of Science* (NY: Basic Books, 1968).

[5] The youthful prodigy, Jeremiah Horrocks, composed a poetic eulogy in Latin for Kepler, but it appears not to have been widely circulated. If others have knowledge of such works, the author would appreciate having the references. In Newton's case, the posthumous "PR campaign" was remarkably extensive, including the famous death mask (which inspired multiple memorial sculptures and statues), James Thomson's "A Poem Sacred to the Memory of Sir Isaac Newton," Alexander Pope's

Such documents can usefully provide a literary "death mask" of sorts that "saves the appearances" of an individual's life and achievements and work together to establish a baseline image of them in the public mind. Had a fair number of such commemorations of Kepler survived, we might well have seated him more readily and respectfully at the table with other "Great Men" or "Great Saints" of Science.[6]

As things have evolved, popular understanding and impressions of Kepler are still somewhat sketchy works-in-progress. While a wealth of primary writings is extant, their content is not easily accessible. Over time, readers with a mastery of Latin, at least some Greek, as well as a rare deftness with late-medieval / early modern German have had the most direct "read" of Kepler's voice, personality and ideas. Yet even those most proficient in his preferred languages, struggle with elements of Kepler's eclectic discursive style – a literary medley of personal narrative, classical allusion, allegory, poetry, fantastical fiction and religious reflection. The rhetorical and organizational frameworks of his works also considerably challenge even well-read readers' powers of comprehension as he draws from an intermix of models that range from ancient philosophical dialogues and literary classics to early modern natural philosophy and educational texts (perhaps even, I think, the style and tone of Luther's *Small and Large Catechisms*).[7] Additionally, Kepler fluently communicates his most important ideas and findings through the highly descriptive, but even less popularly accessible, "languages" of mathematics and geometry. Understanding of the depth and breadth of his achievements in astronomy, astrophysics, optics, mathematics and natural philosophy (by the general reading public, for sure, but also among his near-peers, then and now) has long been hampered by "the thicket of calculations and the rest of the astronomical apparatus," as

immortal couplet, a well-designed and well-placed tomb in Westminster and numerous early memoirs and biographical accounts; see: *Early Biographies of Isaac Newton*, 1660-1885, vols 1 and 2, eds. Rob Iliffe, Milo Keynes, Rebekah Higgitt (London; Brookfield, Vt.: Pickering & Chatto, 2006).

[6] Within a few years after his death, Kepler's gravesite as well as the churchyard where he was buried in Regensburg were effaced by the ravages of war. His self-written epitaph, however, survives, and it could be read as a prophetic "foreshadowing" of how his "body" of work would also be later obscured: *Mensus eram coelos, nunc terrae metior umbras; Mens coelestis erat, corporis umbra jacet* ("I used to measure the skies, now I measure the shadows of Earth. Although my mind was sky-bound, the shadow of my body lies here").

[7] For insight into some of the complexity of Kepler's rhetoric, see James R. Voelkel, *The Composition of Kepler's Astronomia Nova* (Princeton: Princeton UP, 2001).

he himself referred to such exhaustively extensive sections of his texts.[8] Kepler's math and geometry themselves have also required considerable "translation" into more modern expressions in order to be followed by subsequent readers (almost everyone who was not born Newton).

As Owen Gingerich once pithily put it, unlike Galileo's major works which were "eminently readable and have long been accessible in English translation" ... "Not so for [Kepler]."[9] But the fault was not in his stars, or in his writing about them. Kepler realized that he could not really market his technical masterworks to general readers (although he would have welcomed them buying more copies!). While some historians of science have blamed Kepler directly for his "failure" to communicate, in my view his complex mix of literary and mathematical expression is a distinct feature, not a bug. Through the complicated texts he has left us, Kepler has contributed to the history of science a unique and significant, almost in real-time, record of his trial-and-error experiments in improvising and inventing new ways of doing *and writing* natural philosophy. Kepler's major texts document verbally, visually and historically his own cognitive processes of theoretical investigation, geometrical visualization, mathematical demonstration and theological-cosmological synthesis (keeping in mind that "historia" can mean both an "account of research" and "storytelling"). Within those narratives, he simultaneously devises pedagogical explanations for students, provides key insights into his technical methods and lines of inquiry for their professors, plants delightful "Easter eggs" for fellow-practitioners and issues direct puzzle-solving challenges to future mathematically and astronomically adept readers.

Kepler's virtually stream-of-consciousness accounts also poignantly reflect how alone he was in his vision of the universe. While he personally took great comfort – and joy – in unhiding and tracing God's footprints within His geometrical design for creation (even regarding such elements as definitive proof of God's existence and demonstrative reassurance that nature was not the result of chance), Kepler realized that few of his friends or colleagues could directly grasp his comprehension of the cosmic order of things, no matter how clearly he managed

[8] *Epitome of Copernican Astronomy and Harmonies of the World, Epitome*, Book Four, trans. Charles Glenn Wallis, Great Minds Series (Amherst, NY: Prometheus Books, 1995) 5.

[9] See "Foreword" to Johannes Kepler, *Astronomia Nova*, New Revised edition, trans. William H. Donahue (Santa Fe, NM: Green Lion Press, 2020), xii.

to express it. Along with other visionaries who have struggled to put divine insights into mortal words and symbols, his explications seem caught in a complicated cognitive, cultural and compositional web of "betwixts and betweens": betwixt "learned" language and popular rhetorical style; between his own authorial inner thoughts and potential conversations with imagined audience members. This word-problem required crafting words that would communicate across social strata and bridge time: betwixt ever-present patron-pleasing and the peer-pressure of future posterity; between ancient forms and methods of nature philosophy and original-to-him, newly emergent ones. In his writing, Kepler also meaningfully records his hard-fought, deeply personal, natural philosophical-theological-literary resolution of the ultimate "betwixt and between" dilemma of all human experience: life and death. Over the course of his life, he develops and shares with unseen, but hoped-for readers his own grand unified theory of his understanding of nature and God's creation of harmonious unity between "things below and things above," the micro / macrocosmic correspondences between observable, material, earthly phenomena and their occult, immaterial, heavenly causes. This is the same epic syncretic quest undertaken a generation later by John Milton who also sought to "justify the ways of God to men" through the cosmological vision and extended poetic argument of *Paradise Lost* (a technically complex text that became a "best-seller").[10]

Kepler accurately predicted that his works might wait a hundred years for readers, but for more than four times that long now, the vast majority of those who have aspired to read and understand his ideas have necessarily depended upon others' translations and scholarly interpretations.[11] While some popular writers use selected primary materials in their research, such as Kepler's autobiographical "Self-Analysis," his correspondence, and references to him and his ideas in contemporaries' letters, most rely upon (and repeat) the information and characterizations available in a small subset of standard resources (early on, Carola Baumgardt and Max Caspar; more recently, *Wikipedia*).

[10] And it may be an example of another work of "poetic cosmology" that Kepler's ideas may have influenced, see: Catherine Gimelli Martin, *Milton and the New Scientific Age: Poetry, Science, Fiction* (London/NY: Routledge, 2019).

[11] *Epitome of Copernican Astronomy* and *Harmonies of the World, Harmonies*, Book Five, trans. Charles Glenn Wallis, Great Minds Series (Amherst, NY: Prometheus Books, 1995) 170.

During his life, Kepler seems to have been pre-destined to gain popular recognition in ways he did not want and to fall short when he actually aspired to such attention. He was made uncomfortably famous for his astrological ephemerides by far less-exacting (and less respectable) astrologers and was hailed in the streets for his accurate meteorological predictions by local farmers; yet he remained under-credited (and chronically under-paid) for what he considered his most significant achievement: worshipfully revealing to God's people the hidden beauty of their geometer-Creator's handiwork. The earliest reception of his major publications was frustratingly hit-and-miss, even among his own former Lutheran teachers and close colleagues, not to mention Jesuit astronomers and Galileo. Although he cultivated an extensive network of correspondents, the wide-ranging and meticulously detailed missives that he sent out to other "men of letters" sometimes read like notes-in-a-bottle, flung to far-off ports in search of a like-minded friend that he could bounce ideas off, collaborate with and count on to check his math.

Kepler's attempt to purposely write a more popular work, the *Somnium*, also missed the mark as the allegorical and satirical elements of this narrative were misread, literally, then used as incriminating evidence against his mother in court. Literary readers have long recognized that Kepler's proto-science fictional "moon voyage" draws upon many of the same classical originals (Lucian, Plutarch, Cicero) and takes satiric aim at many of the same religious and political targets as Donne's "lunar dream," *Ignatius His Conclave* (in which Kepler is mentioned by name). Kepler knew about this "shout out" and appreciated the joke (suspecting – probably correctly – that Donne had read a privately circulated early version of his story). This exchange may also indicate the extent to which his works and ideas had achieved recognition and appreciation among the elite, learned coterie of early English Keplerians. Donne had such a deep understanding of the technical and spiritual aspects of Kepler's astronomy that he creatively applied them within his own philosophico-cosmological poetry.[12] In addition to Donne, this tight ellipse of early adopters included Thomas Harriot, William Lower, Henry Wotton (perhaps also Henry Percy, Walter Raleigh, John Eriksen) and they collectively encouraged Kepler to join the court of James I as royal mathematician. Although concerns about living away

[12] Gossin, *Poetic Resolutions of Scientific Revolutions*, pp. 145-203.

from his native homeland, language and extended family led Kepler to decline, he might truly have thrived as a scholar, living and working in a more stable and peaceful setting, surrounded by genuine admirers and consistent collegial support.

While not confirmation of his reception within a "popular," generally educated crowd, the diverse intellectual interests of the members of this group do suggest that Kepler's technical works appealed to readers beyond mathematicians and astronomers. As a Protestant natural philosopher, his "evidence-based" approach to both astronomy and theology offered a powerful rhetorical reconciliation of the apparent – and still highly contentious – contradictions between scripture and heliocentrism. Among his English contemporaries, it appears that at least some of Kepler's readers were "getting" his theological and metaphysical message out of his complicated texts, even if his mathematical demonstrations flew over their heads.

After his death, the Kepler family formally published the *Somnium*, with over two hundred newly added explanatory footnotes in which he clarified the intended meanings behind his allegorical references. Kepler's legacy over the next eighty years or so, however, was more effectively represented by the wide adoption and extensive use of his *Epitome of Copernican Astronomy* textbook and the Rudolphine tables. Although Kepler had intended the *Epitome* as a popularly accessible work that would sell for a low price and provide easy-to-understand explanations, suitable for "school benches of the lower classes," it served more practically as "a handbook for [their] professors."[13] Despite its overly modest and misleading title, serious practitioner-readers discovered the full range of its subject matter and its utility: Kepler's new astronomy worked and that word got around.[14] Knowledge of his achievements and awareness of his genius were kept alive by every individual who read and used his texts, including Hevelius, Gassendi, Leibniz and Newton.

Newton's understated acknowledgement of Kepler in the *Principia* seems to have sparked renewed curiosity about his contributions as a "giant" of pre-Newtonian natural philosophy. As general histories of astronomy began to appear, along with individual biographies, these

[13] Max Caspar, *Kepler*, trans. and ed., C Doris Hellman (NY: Dover, 1993) 239; 297.

[14] Additional studies of the professional and public reception of Kepler's ideas and texts across many cultures are still much needed; see Wilbur Applebaum's still highly useful "Keplerian Astronomy After Kepler: Researches and Problems," History of Science 34 (1996): 451-504.

more readable texts brought Kepler's achievements to a wider public. Although I cannot speak to his popular treatment or reception among German readers, his major contributions earned mention in important early histories such as LaLande's *L'Astronomie* (1792).[15] A few years later, Robert Small produced a similar overview in English that situates Kepler within the long history of astronomy, from ancient times (*An Account of the Astronomical Discoveries of Kepler*, 1804). He opens this volume with the ultimate (and surprising!) post-Newtonian compliment which will set a pattern followed by many future historians: "As the discoveries of Kepler have contributed more than all other causes to raise the science of astronomy to its present state of improvement, they not only deserve full and particular explication, but also all the circumstances which led to them, and even the mistakes committed in their prosecution become interesting objects of curiosity."[16] A decade after his influential biography of Newton appeared, David Brewster's *The Martyrs Of Science Or The Lives Of Galileo, Tycho Brahe And Kepler* (1841) helped establish Kepler as a significant case-study within in the history of religion and science. In 1905 (Einstein's *annus mirabilis*), J.L.E. Dreyer's *a History of Astronomy from Thales to Kepler* reinforced Kepler's foundational importance to modern astronomy while also underscoring the depth of Newton's indebtedness to his work. Gradually, from the end of the nineteenth century to the present, such popular works and the diversity of disciplinary perspectives they presented have brought greater detail to our collective historical portrait of Kepler.

In the first half of the twentieth century, much-needed scholarly editions of Kepler's collected works along with English translations of his correspondence and biographies became increasingly available. The general outlines of his profile were boldly highlighted by newly professional historians of science who focused on key aspects of Kepler's work viewed against the background of then-current scholarly debates: Should he be regarded as a "Great Man of Science" or was he one of many invisible "giants" upon whose shoulders another great scientist stood? Were

[15]For earlier historical references see: Daniel Špelda, "Kepler in the Early Historiography of Astronomy (1615-1800)" *Journal for the History of Astronomy* (2017) https://doi.org/10.1177/0021828617740948

[16]Robert Small, *An Account of the Astronomical Discoveries of Kepler: Including An Historical Review of the Systems Which Had Successfully Prevailed Before His Time* (London: J. Mawman, 1804) 1.

his methods and ideas more "ancient / medieval" or "modern / revolutionary"? Was Kepler "Janus-faced" (looking both forward and back)? Was he a "Sleepwalker" who stood with one foot on either side of the "watershed" of the medieval and modern, mystical and mathematical?

Scholars working within the then-new interdisciplinary field of "literature and science" offered unexpected new angles on Kepler. Marjorie Nicolson studied Kepler's influence within literary circles and produced rich historically and scientifically informed analyses of the *Somnium.* As she remarked in her ground-breaking *Science and the Imagination* (1956): "The wide-spread literary response of poets, dramatists, satirists and essayists to every aspect of the 'new astronomy' is the best evidence of lay interest in science during the early years of the seventeenth century."[17] Indeed, Kepler's astronomy directly inspired a long line of highly popular literature, from early modern moon voyages in prose and verse (by John Wilkins and Samuel Butler) to the nineteenth-century science fiction of Jules Verne and H.G. Wells.

Since the turn of the previous century, public engagement with Kepler's life and works has increased through the variety of literary and creative works that they have inspired, including fictionalized biographies and historical novels (e.g., Max Brod, 1915; Arthur Koestler, 1959; John Banville, 1981); drama, radio-plays and planetarium shows ("Reading the Mind of God," 2000; "Kepler's Mum's a Witch," 2007; "The Kepler Story," 2013); as well as operas (Paul Hindemith's "Die Harmonie der Welt," 1957; Philip Glass's, "Kepler," 2009; "Kepler's Trial," 2016). Popular biopics have been produced ("Johannes Kepler," 1974; "Johannes Kepler: Storming the Heavens," 2021) along with a multitude of popular educational and YouTube videos that now serve like last-generation science textbook sidebars to introduce high school and college students to Kepler's life and his three "laws" (see for example, "The New Astronomy" Crash Course: History of Science, episode 13). For younger "tween" readers, there is even a recent novel, *Kepler's Dream* (2012), that crafts a lightly astronomy-inspired, "Nancy Drew-style" mystery around a stolen rare edition of Kepler's book!

While the vast majority of articles and books on Kepler produced by historians of science have not reached (or even tried to reach) general

[17] Marjorie Hope Nicolson, *Science and the Imagination* (Ithaca, NY: Great Seal Books, 1960), 37.

audiences, a rare few have adroitly and valuably bridged the gap between technical explication and engaging readability. Notable in this group are the very different, but highly effective popular accounts of James R. Voelkel *Johannes Kepler and the New Astronomy* (2001) and Kitty Ferguson's *Tycho & Kepler: The Unlikely Partnership That Forever Changed Our Understanding of the Heavens* (2002). Both offer instructive models for how the history of astronomy can be written in popular prose that effective educates and delights (and suggest that we should try to do so more often).

As things stand, historical, biographical and literary characterizations of Kepler vary wildly in their views of the man and his work, unavoidably reflecting the strengths and limitations as well as projecting the philosophies and psychologies of each scholar or writer. Max Caspar's empathetic and multi-faceted biographical portrait concludes with this effusive appraisal:

> So his *Harmonice* appears as a great cosmic vision, woven out of science, poetry, philosophy, theology, mysticism, a vision risen from the abyss of the human mind, seen as a radiation from the countenance of God, nourished from the supply of the senses, molded in the belief in ratio, inflamed by the inspiration of the prophet. It belongs to the most sublime, which has been thought and devised by human intellect, locked in the material world, and desiring to lift itself out of it. It is a grandiose fugue on the theme "world, soul, God" with a maestoso finale. By the thoughts on which it is fed, by the shapes according to which it is molded, it is the *summa* of the Renaissance. (290)

While this assessment may well warrant deeper consideration among Kepler specialists, it is hard to imagine that the general public will ever grasp the genius within the complex sentence structure of the *Harmonice*, the way they instantly see it in Leonardo's sketches of a helicopter. Lately, popular interpretative "histories" of Kepler have taken a turn for the worse, presenting him as the prime suspect in Tycho's "murder" or exploiting the trauma of his mother's trial(s) to boost sales with sensationalized book titles that include the word "witch."[18] Perhaps the

[18] To mention a few: Joshua Gilder and Anne-Lee Gilder, *Heavenly Intrigue: Johannes Kepler, Tycho Brahe, and the Murder Behind One of History's Greatest Scientific Discoveries* (2005); James

phenomenal popularity of J.K. Rowling's *Harry Potter* series and Deborah Harkness's history of science-inspired *All Souls* triology (*A Discovery of Witches*, etc) are partially to blame, but if Oscar Wilde got it right that "There is only one thing in life worse than being talked about, and that is not being talked about," then such books and their media adaptations may prove wonderful vehicles for popularizing Kepler!

While most webpages and posts about Kepler rarely rise above wikipedia-level summaries, there are many points of online light that illuminate fascinating aspects of his complex life and mind. There are kindred spirits inspired by Johannes out there everywhere: on webpages created by universities' physics, history, philosophy, music and art departments; on the sites of science museums, planetariums and libraries; in feature stories posted on online astronomy 'zines and amateur astronomer sites; on creationist and intelligent design discussion boards; and myriad stories on space.com and nasa.gov. There are also exquisite Kepler spin-offs, such as the bedazzling http://snowcrystals.com/ and many dozens of delightful attempts to play and record his Harmonies' music of the spheres.

2009 marked the 400th anniversary of *Astronomia Nova*, Galileo's telescopic discoveries and the International Year of Astronomy, and it was a good year for Kepler in popular media. NASA's Kepler space telescope launched and operated successfully for over nine years, detecting (at last count), 2,662 confirmed exoplanets. The mission captured the imagination of countless observers and inspired hundreds of related webpages that included biographical and historical content on Kepler himself. Many of the mission's stated goals reflect Kepler's own values and aspirations: to improve scientific understanding, promote peace and unity within the human family on Earth, preserve and protect the cultural and natural heritage of the heavens, and establish a global network of understanding. When NASA announced the retirement of the Kepler instrument, its "obituary" appeared on "his" Twitter account.

In the Spring of 2020, along with myriad educators around the world who were moving classes online, I used the challenge as an opportunity to update my teaching of Kepler within my History of Science courses.

A. Connor, *Kepler's Witch: An Astronomer's Discovery of Cosmic Order Amid Religious War, Political Intrigue, and the Heresy Trial of His Mother* (2005); Ulinka Rublack, *The Astronomer and the Witch* (2015); Rivka Galchen, *Everyone Knows Your Mother Is a Witch* (2021).

Rather than use the traditional history of astronomical ideas or "Sci Rev" approaches, I assigned the first chapter of Maria Popova's *Figuring* (2019), an atypical "history of science" which presents Kepler as a "hidden figure" who has been hiding in plain sight. As he lived his life on the margins between poverty and privilege, visual impairment and insight, divine inspiration and dead-end iterations, playfulness and persistence, grief and giftedness, his story stands as a strong exemplum for STEM students training to be future researchers and STEM educators in the chaotic conditions of our current pandemic. Hopefully, as our world recovers and we regroup and rejoice, Kepler's model of true grit and glory can also help us remember to bring more complex, multi-layered perspectives to our readings of and relationships with each other.

For over four centuries now, each generation's categories of natural philosophy and frameworks of biographical and historical narrative have depicted Kepler in their own image. Perhaps now it may possible to collaboratively paint a more richly pixelated picture of Kepler's inherent complexity by following his own lead and metaphorically appreciating his "multi-faceted" mind and self as the exquisite fractal and crystalline structures they were. Wrought almost *ex nihilo*, traversing the cold realities of earthly adversity to fall into uniquely diverse and harmonious beauty, Kepler himself could be regarded as the embodiment of a six-sided snowflake, simultaneously simple and complex and not at all "nothing." To echo his own words one long ago New Year's Day: although he may often have considered himself "nothing" (and the world around him may have frequently sent him the same message) through his very existence, full humanity and creativity, he emblematically expressed, symbolically represented and "very nearly recreat[ed] the entire universe, which contains everything."[19]

In my own mind's eye, I see him forever standing transfixed in wondrous poise, on a bridge between two worlds, wearing his heart* on his sleeve: one of a kind.
Nihil sequitur.

[19]The full passage reads: "But I am getting carried away foolishly, and in attempting to give a gift of almost Nothing, I almost make Nothing of it all. For from this almost Nothing I have very nearly recreated the entire universe, which contains everything!" Johannes Kepler, *The Six-Cornered Snowflake: a New Year's Gift*, trans. Jacques Bromberg (Philadelphia: Paul Dry Books, 2010) 99.

Charles Bridge in Prague and snowflake.

* Let us also collectively hope that he would wryly appreciate (and hopefully, forgive us) for the fact that in our own contentious time and place, even the innocently lovely concept of a "snowflake" has been politically polarized!

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Science Education, she is planning two brand-new interdisciplinary classes in “Astronomy, Cosmology and Culture” in honor of the upcoming April 8, 2024 solar eclipse when Dallas will experience 3 minutes, 47 seconds of totality. Although not a witch by trade, at end-of-the-semester celebrations she has been known to cosplay Molly Weasley and Urania, the Goddess of Astronomy.

Pamela Gossin as a witch.

Kepler in Rome: Polemic with Francesco Ingoli

Jerzy Kierul

Łódź, Poland

[Polish version of the text was published as a part of the extensive biography of Galileo in 2012.]

I imagine that the Earth is spinning, not for the reasons presented by Copernicus, but for these reasons: the fire of hell, as the Scriptures teach, is locked inside the Earth, and the damned, wishing to escape the heat of the flame, climb as far as the ceiling, while turning the Earth; likewise a dog locked in a circle turns itself around, trotting.

Cyrano de Bergerac

Tommaso Campanella in his *Defense of Galileo* ("Apologia pro Galileo") presents a somewhat too extended list of supporters of the idea of the moving Earth. It features Cardinal Nicholas of Cusa, who lived in the 15$^{\text{th}}$ century and who was not scandalized by such a possibility, although he could hardly be considered a precursor of Copernicus in a strictly scientific sense. "There is also Nolanus and others, whose names we cannot name because of their heresy. However, they were not condemned for this reason" [1]. And Nolanus is, of course, Giordano Bruno; remembering him being an advocate of the movement of the Earth was not diplomatic. However, it may be assumed that not only Campanella, but also Cardinal Roberto Bellarmine, and other Roman prelates, hearing about Copernicus, thought of Bruno, and it did not matter much what kind of Copernicanism Bruno believed, or that he was not an astronomer in a technical sense. Most of the names on Campanella's list were Protestant scholars. Some, such as Erasmus Reinhold, used only the Copernican computational technique, others, such as Michael Mästlin and his former student Johannes Kepler, were genuine supporters of new astronomy.

It might seem that Copernicanism would arouse a particularly heated debate among the Protestants, accustomed to reading the Scriptures for themselves, while among the Catholics, knowledge of the Bible was limited to the clergy and a very small handful of educated people. However, this did not happen. The condemnations of Copernicanism by Protestant theologians were incidents without major consequences. Luther was not interested in this problem at all. John Calvin decided that since the Scriptures were not in agreement with Ptolemy, they therefore did not contradict Copernicus, and the reference to the sacred text in astronomical discussions was illegitimate. The Scriptures were adapted to readers and were not intended to teach astronomy or any other science [2]. Calvin's doctrine had a great influence on the Protestant world and also facilitated the adoption of Copernicanism.

The most eminent astronomer of the epoch was undoubtedly Johannes Kepler, the Imperial Mathematician (meaning astronomer and astrologer) and discoverer of the laws governing the motion of the planets. Kepler was an ardent Lutheran, so the problem of the contradiction of Copernicanism with the Scriptures came to him naturally. He presented his position in a long preface to *Astronomia nova*, probably known to Galileo. In the words of Psalm 19, "[He] is as a bridegroom coming out of his chamber, rejoiceth as a strong man to run a race" (King James Version) Kepler saw only a poetic expression, adapted to the way in which phenomena were presented to our eyes. We can see that the Sun is moving, but this does not mean that the Sun is really moving and the Earth is not. Kepler also discusses Joshua's miracle. The words of the leader of the Israelites: "Sun, stand thou still upon Gibeon; and thou, Moon, in the valley of Ajalon" (Josh 10:12) clearly indicates the reference frame of the prophet. The purpose of the miracle was to illuminate the battle scene: for Joshua, the luminaries stood in the centre of heaven all day, and for the people on the other side of the globe, they were underground for just as long. Thus, even a supporter of traditional cosmology must admit that Joshua's formulation is not entirely obvious, there are certain assumptions hidden in it: the same position of the Sun in relation to the Earth means day for some, night for others. "Joshua was simply praying that the mountains not remove the sunlight from him which prayer he expressed in words conforming to the sense of sight, as it would be quite inappropriate to think, at that moment, of astronomy and of visual errors. For if someone had admonished him that the Sun doesn't really move against the valley of Ajalon, but only appears to do so, wouldn't Joshua have exclaimed that he only asked for the day to be lengthened, however that might be done? (...) Now God easily understood from Joshua's words what he meant, and responded by stopping of the Earth, so that the Sun might appear to him to stop" [3].

Kepler, although he himself had no doubts about Copernicanism, considered it a difficult doctrine, appropriate for scholars: "I, too, implore my reader, when he departs from the temple and enters astronomical studies, not to forget the divine goodness conferred on men (...) I hope that, with me, he will praise and celebrate the Creator's wisdom and greatness, which I unfold for him in the more perspicacious explanation of the world's form, the investigation of causes, and the detection of errors of vision (...). But whoever is too stupid to understand astronomical science, or too weak to believe Copernicus without affecting his faith, I would advise him that, having dismissed astronomical studies, and having damned whatever philosophical opinions he pleases, he mind his own business and betake himself home to scratch in his own dirt patch, abandoning this wandering about the world" [4]. For the rest Kepler proposed the Tychonic system, which was just beginning to gain popularity among the Jesuits, because it did not break with tradition so abruptly and was closer to the Neo-Aristotelian Thomistic philosophy, which was the official doctrine of the Society of Jesus.

In 1617, Kepler received, through one of his correspondents, the essay *De situ et quiete Terrae contra Copernici systema disputatio* by Francesco Ingoli, a Theatine father from Rome. He reacted to it in May of the following year with the text *Responsio ad Ingoli Disputationem*, which in turn received an answer from Ingoli in October. The whole polemic was not published, but it was circulated in copies among those interested. After a long delay, in 1624, Galileo joined the discussion with the *Letter to Francesco Ingoli*.

Soon after promulgating the Copernican decree by the Congregation of the Index Francesco Ingoli was appointed consultor of the Congregation. This may have been due to the fact that his patron, Cardinal Bonifacio Caetani, was entrusted with the task of preparing corrections to the work of Copernicus, but undoubtedly such appointment was an important proof of confidence in Ingoli. He, too, was finally to deal with the amendments to Copernicus. Thus, in those years, he was one of the most visible figures on the side of the Church, a person who privately expressed views in accordance with the decisions of the hierarchical Church. In all these cases, Jesuit astronomers remained silent, obedient, indeed *perinde ac cadaver* – "like a corpse" – and even when asked for their opinion, did not try to influence the position of the Church.

Were it not for the author's special position, Ingoli's essay would not be interesting, as it contains only what one might expect from an intelligent dilettante: anti-Copernican arguments known from scientific literature and a number of misunderstandings. The work considers three types of arguments: mathematical, physical, and theological. The very first argument lowers the reader's expectations as to the rest: "If the Sun were in the centre of the world, it would have a greater parallax than the Moon, but since the conclusion is false, the premise must also be false" [5]. Ingoli did not understand that the parallax is related only to the distance of the body from the Earth, and did not admit the error, despite criticisms of the two greatest living scientists in turn. The theological arguments were more interesting. We learn from the Book of Genesis that the Creator created heavenly bodies in the firmament. And the word "firmament" and its Hebrew counterpart mean an extension or some space, a circumference, not a centre. So, the greatest celestial body – the Sun – cannot be in the center of the world. Another argument is that hell – the place of demons and the damned – must be as far away from heaven as possible, and therefore in the center of the Earth. Hence, we have a descent to hell and an ascent to heaven. And that's it for the problem of positions of the Sun and Earth. As for the movement, it's sufficient to quote the miracle of Joshua (of course! – we can see why Galileo gave a possible explanation for this particular miracle in the famous letter to Benedetto Castelli), and in addition, we have the words: "Thou made the Earth stationary" [6] in the church hymn *Telluris ingens Conditor*. Two of the four arguments referred not to the Scriptures, but to a faith derived from tradition: the location of hell and the church hymn. However peculiar such folklore arguments may seem to us, Ingoli and his principals were deadly serious. It was probably meant to emphasize the difference between the Roman Church and "heretics" breaking with tradition (who repaid the "papists" in kind with accusations of cultivating superstitions). From the quotation of Joshua's miracle, it seems that Father Caccini did not shoot blindly when accusing Galileo in his sermon and might have had some support in Rome. Ingoli also responded in advance to the argument that the language describing Joshua's miracle in the Scriptures is suited to human comprehension: all the Church Fathers explain this passage in such a way that the Earth is stationary, and the Sun is moving. The Council of Trent ruled that the Catholics must adhere to the Fathers in interpreting the Scriptures; admittedly, the decision of the Council concerned matters of faith and morals, but it cannot be denied that a change of interpretation would probably not have appealed to the Fathers of the Church. In the end, it was decided in Rome what was in line with catholic tradition and Ingoli knew very well current opinions there. The reference to the Church Fathers pointed to a Catholic provenance of this interpretation – the view of the Fathers of the Church was not binding for Protestants.

There is no room for nuances here: not only the interpretation of the Scriptures, but all human knowledge cannot go beyond what was intellectually available to the Church Fathers in the first centuries CE. The Biblical worldview was to be the alpha and omega of all knowledge. It is difficult to find a more anti-scientific position.

Johannes Kepler had not heard of the anti-Copernican decree of the Congregation of the Index, only inconclusive information was coming to him. He also did not know who Ingoli was and what role he played in Rome. As a committed supporter of Copernicus, he was ready to discuss the topic with anyone. He served as an astronomer for the Catholic emperor, but for a quarter of a century he was free to admit his Copernican views, and he was not subjected to any harassment, except for the reluctance of Lutheran theologians in Tübingen. In 1618, Kepler published the first three books of *Epitome astronomiae copernicanae*, which summarized his mature view of astronomy. In these early books he discussed the basics of astronomy: the celestial sphere, the seasons, and risings and settings of celestial bodies. However, from the beginning he did so from the Copernican point of view. He presented the daily rotation of the Earth and its physical consequences. There was also a drawing showing the Copernican explanation of the seasons of the year on Earth. Kepler's most important scientific achievements were contained in the subsequent books of *Epitome*, to be published later, but also this introductory part was decidedly Copernican.

In arguing with Ingoli, Kepler responded to accusations he had heard many times before, for example from Tycho Brahe himself, his predecessor at the post of Imperial Mathematician. Therefore, in many cases he referred Ingoli to the text of *Epitome*. On a purely scientific level, there was no question of their equal discussion. As an accomplished astronomer, Kepler tried to understand how the cosmos worked, starting from observations and fully understanding what it took to describe these observations. Ingoli, a doctor of both laws, remained on the philosophical or rather popular science level and was free to criticize various assumptions and concepts because it cost him nothing: everything remained an abstract rhetorical exercise in the style of disputes at medieval universities.

Copernicanism naturally led to the unification of the description of various parts of the universe, enabling Kepler and Galileo to apply terrestrial mechanics to cosmic phenomena. In *Epitome*, Kepler writes about the Earth's spinning around its axis as follows: "If boys can set the spinning top in motion in either direction, moving it steadily and uniformly according to the power of movement that was impressed to it, so that the spinning top, once set in motion, makes many turns with the power of its momentum, until, restrained by unevenness in the floor and air resistance, and also defeated by its own weight, it gradually slows down and falls, why could God not give the Earth such a movement at the beginning, as if from the outside, that even today, after many consecutive turns, it spins with the same vigour, although there were already two hundred thousand of them, because this spinning is not hindered by any protruding unevenness, nor the density of the ether, nor its weight, that is, its internal heaviness; for the more inertia it has, the more likely it is to take momentum and continue to rotate" [6]. And Kepler, like Galileo, pointed out that the Earth maintains a constant orientation of the axis of rotation in space – and that this corresponds to the situation of the mechanical spinning top. In reply, Ingoli writes that "it is impossible to know a priori whether God gave the Earth movement, if not from the Scriptures or by revelation, but neither of these ways leads to the conclusion that God gave the Earth movement, for from the Scriptures we learn about the immobility of the Earth" [7]. In this way, the Scriptures (as interpreted by Ingoli and his likes) once again became the limit of conceivable science.

Kepler did not have to submit to the Roman authorities, so, unlike Galileo, he could present his answer to the theological argumentation of Ingoli. On the argument about the greatest distance between the saved and the damned, he notes with amusement that "if we were to seek for the saved and damned places endowed with such geometrical properties, we would easily give a middle place to the saved, because the centre is under the protection of Jupiter, while the damned would be thrown out of the world into outer darkness, where they grind their teeth." In more serious vein he stated that theologians should not interfere with astronomy, just as astronomers should not enter the realms of faith and custom reserved for theology. As for the literal understanding of the Scriptures, he stated: "Whenever we deviate from the visual sense in explaining it, great differences immediately arise between the interpreters (...). Whenever possible, keep the meaning literal, a beautiful rule. But tell me – I ask – what judge determines whether it can be kept? Isn't it a common human experience? Therefore, one should also listen to the more secret experience of astronomers, and where they say it is impossible for given statements to be consistent with an eye sense and at the same time true, and in agreement with astronomy, the interpreter of scripture should cease to care about the astronomical sense" [8].

The German astronomer was not only an ardent supporter of Copernicanism, but also a supporter of calm, matter-of-fact argumentation. He believed that scientific discussions should be left to scientists. He was even more afraid of the interference of clergy and theologians because he saw around him how devastating a turn the denominational conflict can be: it was in 1618 that the religious war, known in history as the Thirty Years' War, began. Realizing that the Copernican cosmology was not readily accepted by the general public, he did not insist on teaching it to everyone. However, in a scientific discussion, religious arguments are irrelevant, if the topic itself is not related to questions of faith and morals.

Perhaps we should not underestimate the difficulties encountered by adherents of traditional cosmology when confronted with Copernicanism. However, the medieval philosophy of the nominalists or Thomas Aquinas also never found their way to uneducated people. The shepherds of the Church, catholic by its name, could be expected not to engage so vigorously in the construction or deconstruction of the astronomical cosmos. Still, Ingoli's arguments about hell pointed to a real difficulty. Aristotle's traditional cosmology, Christianized in the Middle Ages, allocated specific places to heaven and hell. The most suggestive description of that universe was left by Dante Alighieri in *The Divine Comedy*. The medieval cosmos was not only geocentric, but also diablocentric, as Arthur O. Lovejoy once remarked – for it was Lucifer himself that was placed in the centre of the Earth. Young Galileo dealt with the topography of Dante's Hell in a small treatise read out before the Florentine Academy. What for him was perhaps only a kind of poetical and mathematical exercise, for many others was an element of religious faith.

From a philosophical point of view, there is no need to ascribe any spatial location to the souls of the dead, hell and heaven, but the human imagination looks for a spatial conceptual framework. The entire culture of the Counter-Reformation, the Baroque with its exaggerated gestures and overloaded decorations, the splendour of the ceremonies in

Rome, imitated in all Catholic dioceses of Europe, appealed to the visual imagination. The epoch loved theatrical performances re-enacting various events from sacred history. Catholic art went in a different direction than the art of the Protestant part of Europe, where the iconoclasts won. Wonderful scenes from sacred history painted and sculpted by Catholic artists attempted to turn the dynamics of the miracle into a snapshot: the ascent to heaven looked almost like a live television broadcast. This whole culture of visualization of holiness was threatened by Copernicanism. And this probably gave rise to a deep and perhaps not always clearly realized reluctance of the Roman prelates to violate the cosmic status quo. This problem, so to speak, of religious spatial imagination turned out to be serious in the long run. This is where many Christians saw the source of the religious decline that permeated European civilization in the last few centuries [9].

Ingoli's answer to Kepler says much about the intellectual climate in Rome at that time. Work on the amendments to the Copernican book *On the Revolutions of the Heavenly Spheres* was almost finished and Ingoli decided that he should act as a defender of the correct version of Christianity and the only true philosophy. He was not the only one who thought so, he was persuaded to write this essay by Ludovico Ridolfi, the main chamberlain (maestro di camera) of Pope Paul V and at the same time the Imperial Councilor. "First, you said," writes Ingoli, "it is in no way fitting that the truth about the Earth's place in the center of the world and its immobility should remain unprotected, especially today, when it is – and this is the second point – beyond any doubt Catholic. You added, moreover, that I knew how pleasing my study would be to the Cardinals of the Sacred Congregation of the Index, for I know better than anyone what they think of Kepler's views on this subject. When I noticed that the books of Copernicus, about which I reported there, had barely escaped eternal disapproval, you replied that if they had not been recognized as useful to the public in correcting and emendating of the celestial movements, and if it had not been possible for them to be saved by hypotheses so that they would not contradict God's Scripture, they would have to be completely eliminated from God's Church" [10].

Ingoli's work was also supposed to be a piece of propaganda, showing the rest of Europe that Roman censorship acts according to the principles and not in an arbitrary manner, but after mature consideration and weighing various arguments. The author also hoped that "by means of repetition, this persecuted truth would reveal itself better and be able to enter human minds, so that the false dogmas of Copernicus, which, thanks to the efforts of amateurs of novelties, began for last few years to occupy the souls of mortals, gradually fell into oblivion and returned to the darkness of their peculiar uncertainty" [11]. That beautiful plan gave Ingoli all the courage needed to engage in polemic with the famous Kepler, as he himself modestly admits. As we see the defence of immobility of the Earth and rejecting of Copernicanism was not the result of an administrative error or a rash individual decision, but apparently was in line with Church policy. That policy was not based on refined philosophical or methodological arguments: according to the literal meaning of the Scriptures, the Earth is immobile and such a "truth" was to be defended against all scientific arguments, notwithstanding their merit. And this position was not limited in time to any one pontificate or any specific member of the Congregation of the Holy Office or the Congregation of the Index.

Francesco Ingoli, in addition to writing a reply to Kepler's text, dealt more closely with his new work, *Epitome of the Copernican Astronomy*, which they both mentioned in their polemic. "The book is very interesting and beautiful," stated the Theatine father in the censorship presented to the Congregation of the Index. It does, however, contain two misconceptions: Copernicanism and the claim that the Sun is alive, a mistake Origen of Alexandria once committed. As a result, at a meeting of the Congregation on February 28, 1619, held in the palace of Cardinal Roberto Bellarmine in the presence of Cardinal Maffeo Barberini (the future Pope Urban VIII) and five other cardinals, it was decided to ban *Epitome of the Copernican Astronomy* completely, without any possibility of amendment.

Kepler probably did not know what role his opponent played in Rome and that arguing with him he was hastening the ban of his own book. In the first half of 1619, the printing of his other great work *The Harmony of the world* was coming to an end. According to the Imperial

Mathematician, the planetary system of Copernicus can be explained on the one hand with the help of the physics of motion, and this was served by the laws he discovered earlier, today called Kepler's first and second laws. On the other hand, it was also necessary to explain why the Creator constructed this and not another planetary system: why the orbits were of the size we observe, and why, for example, the orbit of Mars is significantly eccentric, and the orbit of Venus is practically circular etc. He sought explanations of the divine plan in geometry and the old Pythagorean idea of the harmony of sounds. The orbits of the planets were to be intricately harmonized with each other, and the Imperial Mathematician believed he had discovered this harmony. In this Pythagorean-Platonic line of scientific research, the future astronomers would not agree with Kepler, but looking for harmonies, he discovered another law about planets: the cube of the size of an orbit is proportional to the square of the orbital period. This law, hidden among the material of the fifth book of *The Harmony of the World*, as the ninth proposition, today is called Kepler's third law. It was discovered by him in the same month he wrote his answer to Ingoli. The law is another strong argument in favour of the Copernican universe, a hint of hidden heliocentric symmetry of the planetary system.

The harmony of the world was Kepler's favourite subject and he wanted the book on harmonies to be sold also in Italy, where it was previously difficult to buy his publications. Now that the teaching of the Copernican cosmology had been banned, Kepler (yet unaware of the ban of the *Epitome*) decided to write a kind of announcement of the *The Harmony of the World*, addressed to booksellers in Italy. "I wrote this work as a German and according to German custom and freedom. The greater this freedom, the more it breeds faith in the sincerity of those who practice science. I am a Christian and a son of the Church, and I recognize Catholic teaching not only with my heart but also with my head, to the extent that in my present age I have been able to comprehend it; I present evidence of this in more than one place in the book. So its content does not carry any danger, it can withstand the censorship adopted in your country, and you do not need to be afraid of it. It is only in the science of the movement of the Earth that a difficulty arises, because due to the carelessness of those who taught astronomy not in the right place and with the wrong method, reading of Copernicus, allowed for less than eighty years (since the work was dedicated to Pope Paul III), has been forbidden until the time of the amendments" [12].

Kepler, who, as he himself writes, had been a supporter of Copernicus for twenty-six years, believed that a book on harmony must also convince those who have so far doubted the truth of heliocentrism. He proposed that booksellers distribute his work only to scholars: "You, booksellers, will act in accordance with the law and order if you do not put up the copies [of the book] for sale to the public because of the verdict. For you must know that you are for philosophy and for good authors like notaries who provide defence letters to judges. Therefore, sell the book only to the most eminent theologians, the most enlightened philosophers, the most experienced mathematicians, the most profound metaphysicians, whom I, as Copernicus's advocate, cannot reach. Let them consider whether they are dealing only with an exuberant fantasy, or with something that stems from nature itself and can be confirmed by clear evidence. Let them consider whether this mighty glory of God's works should be shown to everyone, or rather locked, and its fame persecuted by censorship. Whatever happens, whether Copernicus has been or is yet to be corrected by them, let them see whether Copernicus' astronomy outlined in my comments on the movements of Mars [i.e. *New astronomy*], developed in the second part of *Epitome astronomiae*, which is now in print, or also this harmonic structure of celestial movements, presented in this book may exist at all if the Earth's motion is eliminated and replaced with the Sun's motion. And which of the two hypotheses should we follow: that of Copernicus or that of Tycho Brahe (...) (since the ancient [hypothesis] of Ptolemy is certainly false). Whatever is established by all the evidence needed by the nature of things, it will most certainly be recognized as valid and sacred by all Catholic mathematicians" [13].

Kepler's works that were just published were indeed one prolonged and strong argument for Copernicanism. Of course, contemporaries did not immediately recognize what wealth of discoveries was offered to them. Even Galileo – an ally in the Copernican cause – did not understand it. But the discoveries had already been made, it was only a matter of time before they would be fully understood.

But while Kepler could be calm about the fate of his discoveries in the long run, he received the news that *Epitome of Copernican Astronomy* had been banned by the Catholic Church. He found out about it in the summer of 1619 when one of his correspondents, the Imperial Physician Johannes Remus Quietanus, reported that because of the ban, Galileo could not get a copy of the *Epitome of the Copernican Astronomy.* The news looked threatening, and Kepler began to fear for the fate of his works, both already printed and those he intended to publish. If his books were to be forbidden in Austria, he would not find a printer and the printed copies would be lost. For twenty-six years, he safely conducted his research on the basis of Copernicus's theory, and now he faced a decision either to give up astronomy or leave the empire. Fortunately, the Roman decrees had little power outside Italy and Kepler was able to complete his life's work. It is not clear whether the entire *Epitome* was banned, as further books were released after the decree of the Congregation of the Index. Apparently, the zeal for censoring Kepler's output was lost in later years, and none of his other books made it to the Index.

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Jerzy Kierul lost in Nature.

Jerzy Kierul taught physics and history of science at the University of Łódź, authored several biographies of great scientists, including Kepler, Galileo, Newton and Einstein.

The Origins and Legacy of Kepler's Gap

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Introduction

While it was not written to describe the search by Johannes Kepler for a new world order of the cosmos, these lines from John Milton's *Paradise Lost* (Book 2: 402-410) are descriptive of the only man who could traverse the palpable obscure and land safely.

> But first whom shall we send
> In search of this new world, whom shall we find
> Sufficient? Who shall tempt, with wand'ring feet
> The dark unbottomed infinite abyss
> And through the palpable obscure find out
> His uncouth way, or spread his aery flight
> Upborne with indefatigable wings
> Over the vast abrupt, ere he arrive
> The happy isle?

Kepler certainly believed that he had been selected by God to plumb the abyss and thus reveal the workings of the cosmos to his fellow mortals. Standing astride the divine and the physical, he grasped for immortality and achieved it. But one discerns a certain degree of *weltschmerz* in his glorious evocation upon reaching the happy isle. In the words of Kepler paraphrased by another immortal, Edgar Allan Poe (Stroe, 2019), "I care not whether my work be read now or by posterity. I can afford to wait a century for readers when God himself has waited 6000 years for an observer. I triumph. I have stolen the golden secret of the Egyptians." (Kepler, 1619: Book V). Thus, Kepler was reconciled to being misunderstood during his lifetime. Indeed, the full importance of his three laws of planetary motion only became accepted after his death (Humboldt: 1868, 2: 711).

In this respect he resembles many artists, whose fame is only fully expressed with the hindsight of decades or centuries. In his attempt to sketch the plan of the cosmos, Kepler can be thought of in artistic terms, and that is how he was viewed by the art historian Erwin Panofsky. In his 1924 study of how perspective influences perception, he shows how Kepler initially denied that the objectively straight tail of a comet could be a curve because of his training in linear perspective. Grootenboer (2006: 119) explains that Kepler "... unwittingly used linear perspective as a paradigm for his vision. In Kepler's case, linear perspective *produced* his view of the comet's tail, and thus his perception of the world (and of the universe), instead of being an expression of a worldview." Likewise, his adherence to the so-called Platonic solids (each of the five identified by Plato in *Timaeus* c. 360 BCE as a regular, convex polyhedron) produced his view of the universe; furthermore this was grounded in theology, as Kepler believed "that the Timaeus is nothing but a Pythagorean commentary on Moses." (Mehl, 2016: 202). While Platonic philosophy agreed with Aristotle that mathematics was perfect, Platonists believed a better guide to truth and reality "could only be found in the abstract perfection of forms, rather than their material manifestation." (Johnson, 2013: 140). An exploration of orbital gaps, and his fitting of these forms (solids and other basic geometrical shapes) to both orbits and gaps, is the subject of the first part of this study. Why he looked to geometry for answers is best encapsulated in his own words: "... I sometimes wonder whether the whole of Nature and all the beauty of the Heavens is not symbolized in Geometry. (Kepler, 1610; quoted in Walker, 1978: 55). The legacy of his vision that posited a planet in the gap between Mars and Jupiter is explored as a matter of inspiration for those astronomers who followed him up to the discovery of Ceres in 1801; however, Kepler's influence transcended astronomy in the late eighteenth and early nineteenth centuries. How this was expressed by England's great poets William Wordsworth and Samuel Taylor Coleridge will be examined. While this study will contend that Kepler's Lutheran beliefs were important in his intellectual pursuits, one must be wary of overreach. For example, the work of Barker and Goldstein (2001), who claimed theological factors were crucial for the derivation of the ellipse, has been soundly refuted by Blåsjö (2009). And Kepler was not averse to setting his own agenda. As Albert Einstein (1951) notes, "Kepler was a pious Protestant, who made no secret of the fact that he did not approve all decisions of the Church."

Mysterium Cosmographicum

"In the introduction to the edition of Rheticus' *Narratio prima* that accompanies the first edition of *Mysterium cosmographicum* (1596), Michael Mästlin (professor at the University of Tübingen) uses the biblical metaphor suggesting that the new astronomy (the Copernican one) is to the old one as the New Testament Law is to the Old Testament Law." (Mehl, 2016: 197). This metaphor can best be understood in terms of an old penal code (Graham, 2021). Luther's close associate Philip Melanchthon, in referring to the Mosaic Law of the Old Testament with a view consonant with that of Luther, wrote that "the entire Law has been abolished." (Melanchthon, 1521: 158). Thus the metaphor informs the reader the old Ptolemaic system, with the Earth at the centre of all, has likewise been abolished. The metaphor also established at the outset that the *Mysterium* book was, to a significant degree, a theological text – not an astronomical or mathematical one. Indeed, it was Kepler's original intent "to show in the *Mysterium* that Copernicus could not be refuted by Scripture," although he was compelled to eliminate that section under theological pressure. (Voelkel, 2001: 63; Rosen, 1975). And at the time he was working on *Mysterium*, he confessed to his astronomy teacher Mästlin in a letter of 3 October 1595 that "I had the intention of becoming a theologian. For a long time I was restless: but now see how God is, by my endeavours, also glorified in astronomy." (Baumgardt, 1951: 31). As Barker (2000: 86) has noted regarding the sixteenth century, "The earliest Lutheran humanist astronomers were Lutherans first, humanists second, and astronomers after that."

Kepler had the weight of historical precedence on his shoulders, stretching back some 1800 years to the cosmological artifice erected by Aristotle and Ptolemy. As the German poet Friedrich Hölderlin wrote in *Reif Sind* about bearing a burden,

And as
A load of logs upon
The shoulders, there is much
To bear in mind. (Berkowitz, 2017)

To throw those logs off his shoulders so that he could "... let go of the past and taste the ripeness of the present" was Kepler's driven goal, one he approached with a harmonic theory outlined in 1599 in a letter to his patron the Bavarian chancellor Johann Georg Herwart von Hohenburg. In this letter Kepler grounded "harmonic proportions in geometrical figures rather than in the status of certain numbers, which means bucking a tradition that had lasted since the Pythagoreans." Regier (2016: 219).

While Kepler clearly applied reason to his formulation of the Platonic solids in a planetary context, his underlying faith-based understanding of reason has not been given its due in this regard. Luther made a strong case for reason in his 1536 disputation, *De homine* (*Concerning the Human*). In his fourth thesis, Luther links reason with the divine; in this he was perhaps influenced by Aristotle, who wrote "thought is, no doubt, something more divine and impassible." (Smith, 1984: 651). Luther writes "And it is certainly true that reason is the most important and the highest in rank among all things and, in comparison with other things in this life, the best and something divine." Luther goes on to praise reason as the inventor and mentor of wisdom. Grosshans (2009:181) identifies science as being under reason's jurisdiction, with reason being "capable of making sound decisions about economy, politics, and the sciences."

Kepler was keenly aware of the need to discern and reveal the divine plan of the planetary distances; his Lutheran background gave him the intellectual grounding to reason not a problem of celestial mechanics that could be revealed by mathematics, but to reason a divine mechanism that revealed itself as a series of nested Platonic solids. Thus, he was 'skating on thin ice' as Luther specifically warned against extending reason into the heavenly sphere. It highlights the difference between how Galileo and Kepler got to grips with reality (Todorov, 2017). "Galileo's mathematization of movement on earth and in the heavens leads to the development of mechanics, to which the new world picture owed its identity. Kepler's mathematics, on the other hand, rests fully in the

Renaissance tradition, as does his search into the *causa formalis* of the universe." (Van der Schoot, 2001: 59).

Proportion held a central position in Kepler's planetary work. Its importance is best defined by the Swedish philosopher Thomas Thorild in 1799. The essence of his message is "that all science is reducible to measurement. Philosophy, the science of sciences, is therefore 'Archimetrie', as it were, the 'doctrine of archmeasurement'. The essence of reason is accuracy; the essence of accuracy is proportion" (Adickes, 1895). This Archimetrie is what Kepler applied in his study, where he employs measurement – defined by his reason – to adduce proportions in the solar system (Cunningham, 2017b: 335). Measurement was at the heart of a complaint the Austrian astronomer Georg Joachim Rheticus had about gaps. In his presentation of the Copernican theory, Rheticus (1540: 146) wrote "there has not yet been established the common measure (*mensura communis*) whereby each sphere may be geometrically confined to its place" and where "they are all so arranged that no immense interval is left between one and the other." Westman (1975: 184) writes that in these claims, one important assumption is that "there are no gaps between the spheres." Kepler begins his analysis in *Mysterium* "with a recognition of the gaps in the Copernican system that seems to have been an embarrassment for Rheticus and of no concern to Copernicus. To emphasize these gaps, at the end of chapter 1 of the *Mysterium*, Kepler presented two plates, one illustrating the Copernican system and the other the Ptolemaic system, both drawn approximately to scale for the first time." (Owen and Manning, 2018) (Fig. 1 and 2). Kepler dismisses the approach of Rheticus as the inverse of what should be done, namely giving sanctity not to perceived numbers, but to the framework of creation:

> *The opinion advanced by Rheticus in his Narrative is improbable, where he reasons from the sanctity of the number six to the number of the six moveable heavens; for he who is inquiring of the frame of the world itself, must not derive reasons from these numbers, which have gained importance from things of later date.* (Kepler, 1596: 7)

Once he had discerned the divine plan, Kepler admitted reason could have no further power over the divine, despite his utmost efforts. He writes of it in this striking passage that delimits the reach of reason:

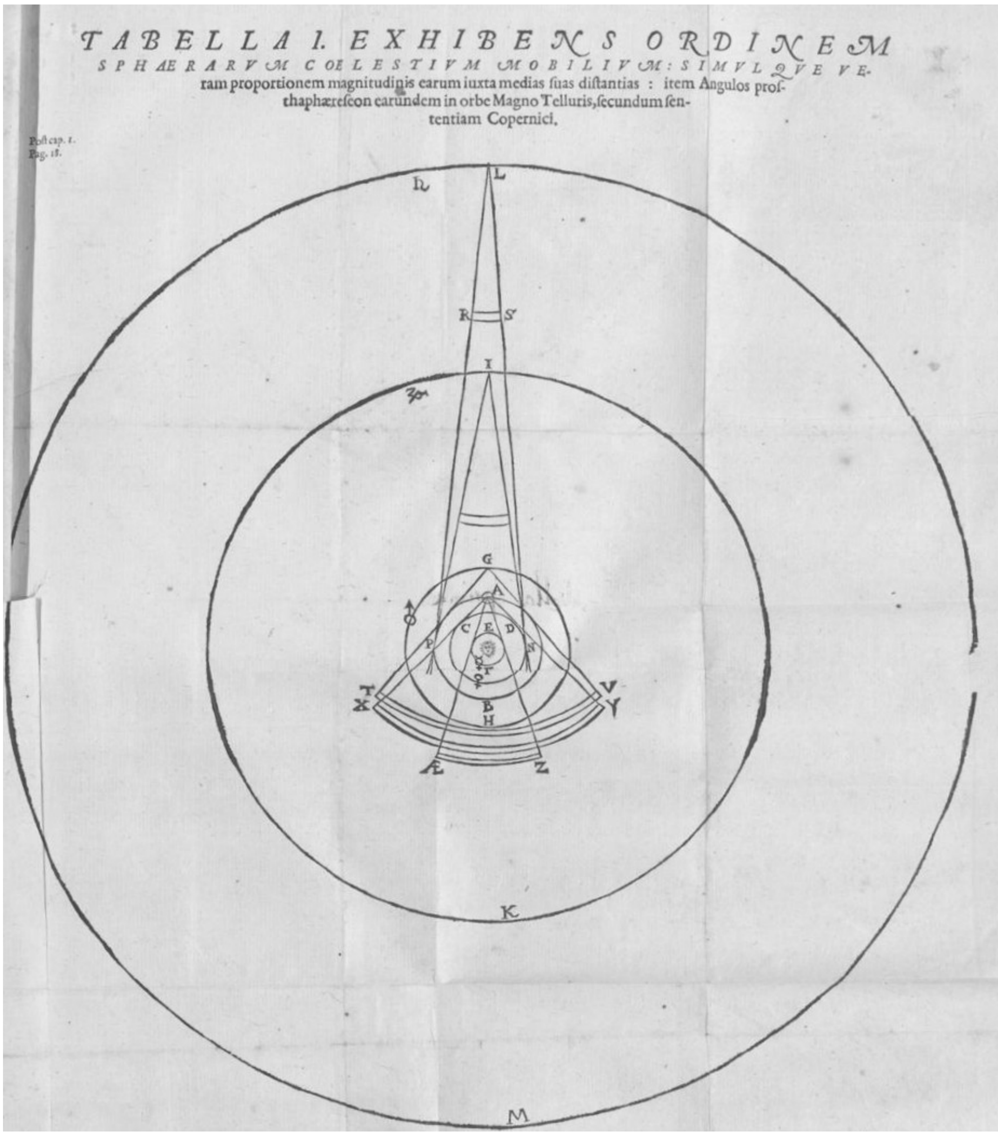


FIGURE 1. The Copernican solar system, Table I from Mysterium Cosmographicum (1596; Tubingen: Georg Gruppenbach), inserted between pages 18 and 19. (*Courtesy of ETH-Bibliothek Zürich*) (https://www.e-rara.ch/i3f/v20/123207/manifest)

> *What is worthy of admiration (since I had then no proof of any prerogatives of the bodies with regard to their order) is, that employing a conjecture which was far from being subtle, derived from the distances of the planets, I should at once attain my end so happily in arranging them, that I was not able to change anything afterwards with the utmost exercise of my reasoning powers.* (Kepler, 1596: 8)

According to nearly every major seventeenth century philosopher, there were 'truths above reason' and 'truths according to reason'. Kepler was accepting here that he had discerned 'truths according to reason' to its utmost degree. Beyond that, what Luther had declared, was the

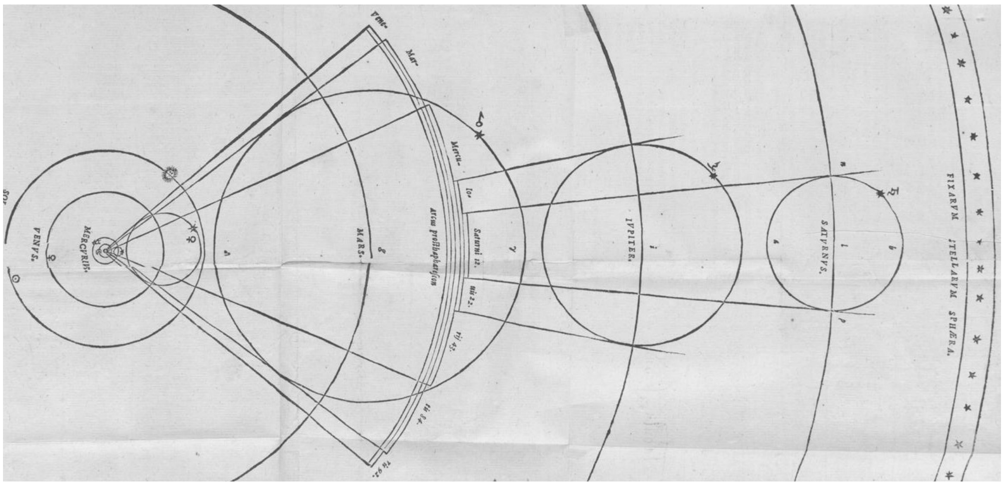


FIGURE 2. The Ptolemaic solar system, Table II from Mysterium Cosmographicum (1596; Tubingen: Georg Gruppenbach), inserted between pages 18 and 19. (*Courtesy of ETH-Bibliothek Zürich*) https://www.e-rara.ch/i3f/v20/123207/manifest

final standard of truth – "Scripture, which contains mysteries beyond the ken of our natural light." (Beiser, 2014: 4).

At the outset of the explanation of his study in *Mysterium*, Kepler couched his application of reason in terms that starkly displays the divide noted by van der Shoot. Here the 'adapted motions' he refers to means that orbital velocity declines with distance from the Sun.

> *I reasoned, that if God had adapted motions to the orbits in some relation to the distances [of the planets], it was probable that he had also arrayed the distances themselves in relation to something else.* (Kepler, 1596: 6)

This led him directly to the stunning supposition that gaps in the weave of the universe might be filled by unseen planets.

> *Finding no success by this method, I tried another, of singular audacity. I inserted a new planet between Mars and Jupiter, and another between Venus and Mercury, both of which I supposed invisible, perhaps on account on their smallness, and I attributed to each a certain period of revolution. I thought that I could thus contrive some equality of proportions, increasing between every two, from the sun to the fixed stars. For instance, the Earth is nearer Venus in parts of the terrestrial orbit, than Mars is to the Earth in parts of the orbit of Mars. But not even the interposition of a new planet sufficed for the enormous gap* [ingenti hiatui]

> *between Mars and Jupiter; for the proportion of Jupiter to the new planet was still greater than that of Saturn to Jupiter. And although, by this supposition, I got some sort of a proportion, yet there was no reasonable conclusion, no certain determination of the number of the planets either towards the fixed stars, till we should get as far as them, nor ever towards the Sun, because the division in this proportion of the residuary space within Mercury might be continued without end. Nor could I form any conjecture, from the mobility of particular numbers, why, among an infinite number, so few should be moveable.* (Kepler, 1596: 7)

Perhaps unknowingly, Kepler was applying the infamous 'saving the appearances' strategy of Plato by proposing the existence of new planets to rescue his proportionality argument. After explaining that a trigonometrical approach failed, Kepler next explains that something akin to the divine happened when he was giving a lecture in July of 1595.

> *... by a trifling accident, I lighted more nearly on the truth. I looked on it as an interposition of Providence, that I should obtain by chance, what I had failed to discover with my utmost exertions; and I believed this the more, because I prayed constantly that I might succeed, if Copernicus had really spoken the truth.* (Kepler, 1596: 8)

What did Kepler mean by an 'interposition of Providence?" Charles Mathewes of the University of Virginia has recently written on Luther's insistence "on the absolute governance of the world by a sovereign and providential deity... In his early work [of 1525], *On the Bondage of the Will*, Luther emphasizes that God's providential control is over all aspects of our lives." (Mathewes, 2021). It was the belief in a providential deity that "motivated the special Lutheran interest in astronomy... and provided Kepler with the resources to give the strongest and most lasting defense of Copernican cosmology." (Barker, 2000: 62). Kepler's text continues:

> *It happened on the 9th or 19th day of July [Julian or Gregorian date], in the year 1595, that, having occasion to show, in my lecture-room, the passages of the great conjunctions through eight signs, and how they pass gradually from one trine aspect*

to another, I inscribed in a circle a great number of triangles, or quasi-triangles, so that the end of one was made the beginning of another. In this manner a smaller circle was shadowed out by the points in which the lines crossed each other. The radius of a circle inscribed in a triangle is half the radius of that described about it, therefore the proportion between these two circles struck the eye as almost identical with that between Saturn and Jupiter, and the triangle is the first figure, just as Saturn and Jupiter are the first planets.

In the following sentence, one can literally hear Kepler's heart thumping in that lecture room as, before what must have been a dumbstruck audience, he desperately tries to fit the gap between Mars and Jupiter with geometrical figures.

On the spot I tried the second distance between Jupiter and Mars with a square, the third with a pentagon, the fourth with a hexagon. And as the eye again cried out against the second distance between Jupiter and Mars, I combined the square with a triangle and a pentagon. [ed: my emphasis] There would be no end of mentioning every trial. The failure of this fruitless attempt was the beginning of the last fortunate one; for I reflected, that in this way I should never reach the sun, if I wished to observe the same rule throughout; nor should I have any reason why there were six, rather than twenty or a hundred moveable orbits. And yet figures pleased me, as being quantities, and as having existed before the heavens; for quantity was created with matter, and the heavens afterwards.

Notice Kepler invokes "the eye," which means 'the eye of reason', a subject we will return to in a discussion of Coleridge. In his 1604 publication *Paralipomena*, Kepler made explicit how he regarded such excursions in geometry. "For geometrical terms ought to be at our service for analogy. I love analogies most of all: they are my most faithful teachers, aware of all the hidden secrets of nature." He revisited the topic in *Harmony*, writing "To successfully produce natural knowledge often required following the thread of analogy and passing through the labyrinths of the mysteries of nature." (Kepler, 1619: 495). According to

Heward (1912), Kepler first postulated the existence of an unseen planet while assisting Tycho Brahe in preparing the Rudolphine Tables:

> *Tycho's very exact observations of the places of the planets suggested to Kepler that Jupiter was very much farther away from Mars than accorded with his sense of just proportion of distances. All through his life Kepler had been dominated by a sense of analogy; he believed with unwavering faith that unity of design was an ordinance of the Creator's plan. Hence he concluded that, though invisible to the eyes now, a large planet existed in this region.*

What was Kepler trying to do when he tried first a square, then added a triangle and a pentagon, to deal with the recalcitrant distance between Jupiter and Mars? Klinger (2011) has identified seven dimensions to the act of judging; the third of these is measurement (German: Anmessung), in consonance with Thorild's application of measurement. In an English translation (Gumbrecht, 2021: 160), Klinger writes that

> *Acts of judging not only add new forms to reality; in doing so they also and of course presuppose that reality exists. Trying to make good (and not only random) judgments, we want to take into account the existing reality, with as much of its complexity as we can possibly perceive and process. We may also be concerned about how the forms we produce will 'fit' or will change reality in ways that we are hoping for.*

We can see Kepler adding new forms to reality – not randomly, but with care. His toolkit is comprised not of irregular shapes, but shapes (forms) basic to the real world: the square, triangle and pentagon. He is further grounded in the existing reality of the planetary orbits as revealed by observations, first and foremost those of his mentor Tycho Brahe. How the forms fit the data is what this is all about.

All of the above quotes are from the preface to his book. It is not until Chapter 21 (Kepler, 1596: 75) that he touches again on the sore point of the Mars-Jupiter distance.

		Coper.	Motoriæ	Diffræ	
♄	♃	572	574	+ 2	Cubus.
♃	♂	290	274	—16	Tetraedron.
♂	Terræ	658	694	+ 26	Dodecaedron.
Terræ	♀	719	762	+ 43	Icoſaedron.
♀	☿	500	563	+ 63	Octaedron.
		vel 559		+ 4	

> *Kepler's attempt to give an account of the errors in the period-distance relation was at the same time an argument for the polyhedral hypothesis and for the compatibility of the two. He did this by preparing a table of the absolute differences of the distances derived from the period-distance relation from those taken from Copernicus, and noting the similarities in the differences to the solids that determine the same spacing in the polyhedral hypothesis. Thus, for example, only in the case of the Jupiter-Mars distance was the difference negative, and that corresponded to the tetrahedron.* (Voelkel, 2001: 55)

In his discussion immediately following the table, Kepler mentions the cube, dodecahedron, icosahedron and octahedron, but sidesteps any mention of the tetrahedron. Kepler was also keenly aware that the separation of the planets from one another – the gaps between them – was a matter of great importance. "Since the Copernican theory allowed the actual proportions of the planetary orbs to be calculated from observations, the gaps between them were also determinate. In explaining these gaps Kepler removed another apparently arbitrary feature from the Copernican description of the Universe." (Field, 1988: 71). Yet it still remained a problem for the astronomer who wanted everything to fit perfectly. After all, how could God create an imperfect system? He was quite candid about the issue in a letter to Galileo in April 1610:

> *Recently, while recalculating the orbits and motions of Mars, the Earth and Venus from Brahe's observations, I noticed the spaces between the orbs are slightly too large, so that when the vertices of the dodecahedron are placed as far out as the perihelion of Mars the centres of the faces do not touch the Moon at its apogee when the Earth is at aphelion. Nor when the centres of the faces of*

the icosahedron are fitted to the aphelion of Venus do its vertices reach the Moon at its apogee when the Earth is at perihelion. This shows that there is extra space between the perihelion of Mars and the vertices of the dodecahedron, as between the centres of the faces of the icosahedron and the aphelion of Venus... I hope that I shall easily get moons of Mars and Venus into these spaces, Galileo, if you find such moons." (Caspar, 1938: 310)

Kepler evinces here the rather desperate circumstance he has fallen into. In the *Mysterium* book of 1596 he was willing to at least consider adding more primary planets, notably in Kepler's Gap between Mars and Jupiter. Here, fourteen years later, we see him hoping against hope that secondary planets will also be found to "improve the agreement between the observed planetary orbs and those calculated from theory." (Field, 1988: 80). There appeared to be no end to Kepler's gap-filling.

Cosmological Representation

Before leaving the subject of the Platonic solids, a study of Kepler's famous three-dimensional representation is in order. I will contrast it here with the approach adopted by the Swiss music theorist Heinrich Glarean whose most famous work was the *Dodecachordon* of 1547. This book, which Kepler was familiar with, embodies in its title a merging of the geometrical solid the dodecahedron with the musical term chord, thus promoting Glarean's idea that there are 12 modes of music instead of eight. What interests me here, however, is a comparison of Glarean's and Kepler's approach to cosmological representation.

In another major work, *De geographia*, Glarean (1527) included much of astronomical interest. But how to represent an Aristotelian universe populated by circles that moved in perpetual harmony? In his draft manuscript, Glarean tried "to create a sense of depth by using darker colours to shade the back halves of the major and minor circles in his most elaborate diagram of the universe, but in the end he abandoned the effort, including no three-dimensional illustrations in the final version of *De geographia*. All the visual refinement in the world could not produce on the printed page a perfect model of the perfect universe." (Johnson, 2013: 149).

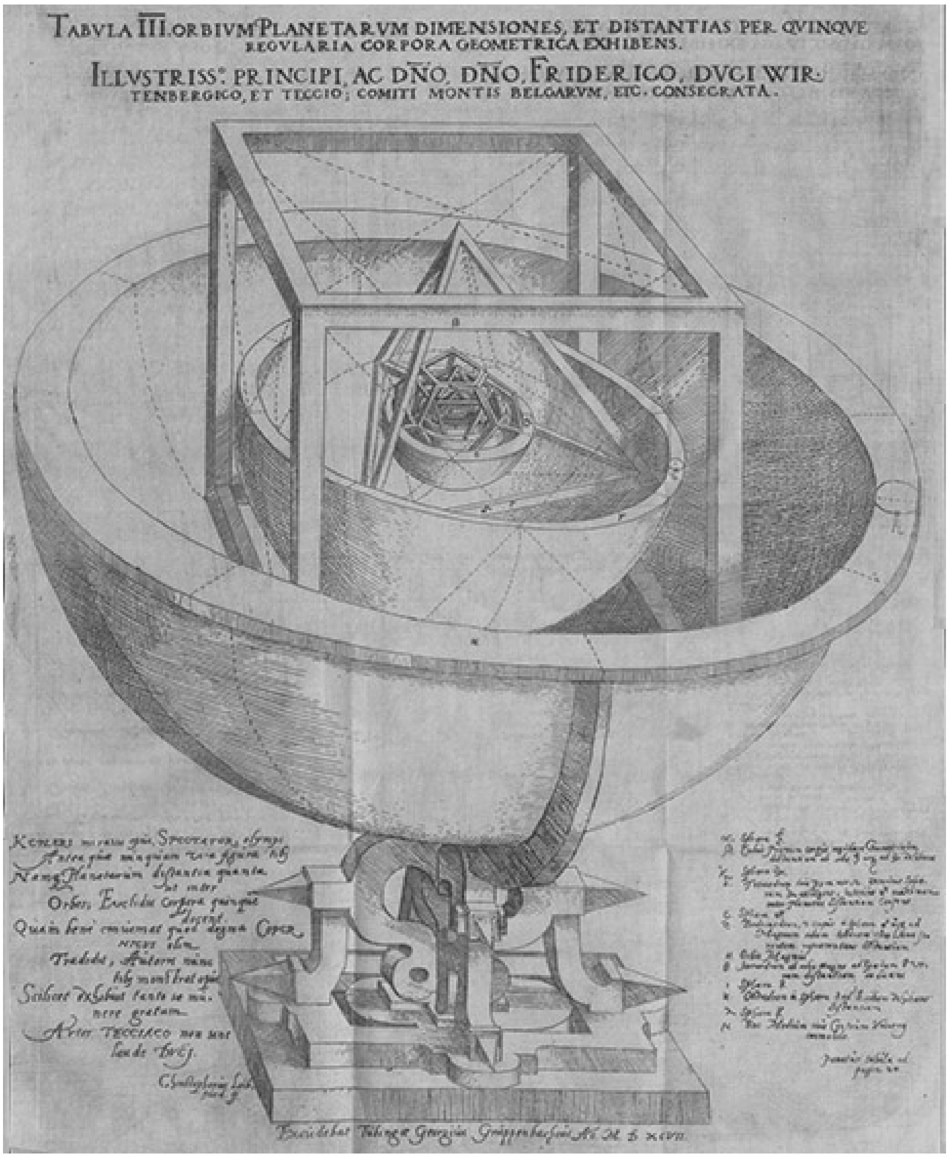


FIGURE 3. Table III from Mysterium Cosmographicum (1596; Tubingen: Georg Gruppenbach) inserted between pages 24 and 25. (*Courtesy of Wikimedia Commons*)

Kepler was not phased by this consideration, boldly using shading on the inner right portions of his nested spheres, and also on the outer left portions of those spheres, in what he identified as Tabula III (Fig. 3; the diagram between pages 24 and 25 in the 1596 ed). The light source casting these shadows, which appears to be coming from the upper right, is a matter left unsaid. J. V. Field (1988: 38-41), in engaging with this important diagram, wrote that "Some disembodied dotted lines have been drawn to indicate the positions of the centres of faces of the polyhedra and the points where their vertices touch the inner surfaces of spheres... It is possible Kepler's illustrator made use of the published versions of Leonardo's pictures" of the Platonic solids in a book for Luca

Pacioli (1509). "The weakness of the plate as an astronomical diagram is underlined by the brevity of the key, which contains only twelve entries. In any case, the uncooperative nature of the astronomical facts ensures that the inner part of the picture is exceedingly difficult to read." One wonders if this was deliberate, as zoomed-in detail of the inner solar system would reveal the gaps in the scheme (Fig. 4). Andrews (2017: 293) notes that whoever created the image "was well versed in the print genre of unbuilt, polyhedral models and used them as his primary source of inspiration." In an analysis commissioned for this chapter, Dr. Elvira Bojilova of the Harvard University Centre for Renaissance Studies offers some unique insights into Tabula III (Bojilova 2021a).

"The first thing that struck me is the fact that the image on page 24 is quite different from the other ones, not only in terms of style but also size, etc. It is much more detailed and highly 'finished' as art historians would sometimes describe it. Stylistically, it is hard to say what the artist might have known, but one can only assume he was familiar with some of the great engravers of his time, for instance Hendrick Goltzius. Keeping in mind that Kepler's book was not a work of art, the quality and the size of this etching are remarkable. The comparison to Leonardo/Pacioli is certainly interesting, and reminds me of Leonardo's machine drawings.

"The hatching in Kepler's image does not, however, produce a perfectly natural three-dimensional effect, especially in comparison to Leonardo's drawings and the way he used hatching. First, it is difficult to define what 'natural' hatching in an art work would look like since it doesn't have an equivalent in the natural world. Second, in Kepler's image the illusion of 'perfect naturalism' is somewhat disrupted by the way the artist applied the hatchings inside the big sphere for instance. It almost appears to be flat due to the dense cross hatching and the way the lines change direction and formation. By the same token, if you look closely, you'll see that the parallel hatching on the outer left side of the sphere is a bit too straight instead of curvilinear. It does *not quite* follow the 'underlying' round form of the thing it represents. Given the importance of this image, the slightly awkward layout of the page in general is odd, especially in the left corner where the writing almost overlaps the engraving. Maybe all these considerations played into the decision to rework the illustration for the 1621 edition (Fig. 5). In that later

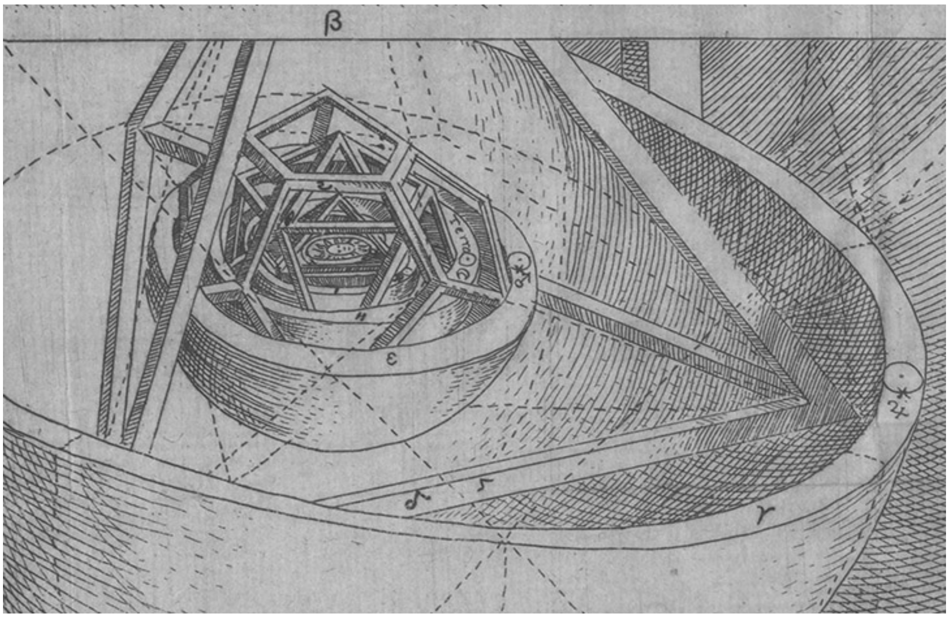


FIGURE 4. Detail of Table III from Mysterium Cosmographicum (1596; Tubingen: Georg Gruppenbach). (*Courtesy of Linda Hall Library*)

edition the hatching is much more 'organized' and less chaotic, if you will. In addition, the writing in the lower corners no longer clashes with the image. Note how the depth of the sphere is indicated by vertical parallel hatching that seem to be deliberately juxtapositioned against the quasi-horizontal parallel lines of the outside sphere in order to draw the beholder in. This is not to say that the artist attempted to apply hatching in a semiotic sense, meaning that there was a direct 'meaning' attached to a specific hatching style (which is an approach I am skeptical of). But there was clearly an effort to improve the illustration." See Bojilova (2021b) for further relevant analysis of contemporary engravings, and Field (1997) for a discussion of perspective and the representation of the geometrical solids in fifteenth century. Throughout his career, Kepler "... addressed the gap between knowable universals and concrete physical events. In order to surmount this gap and to disentangle his science from the multileveled interpretations of emblematic representations of the secrets of nature, Kepler had to redefine the epistemological status of pictures." (Chen-Morris, 2009: 152). This he did with the famous 'picture' of the solar system in *Mysterium Cosmographicum*; as the next section explores, addressing this 'gap' was just one of several that challenged Kepler.

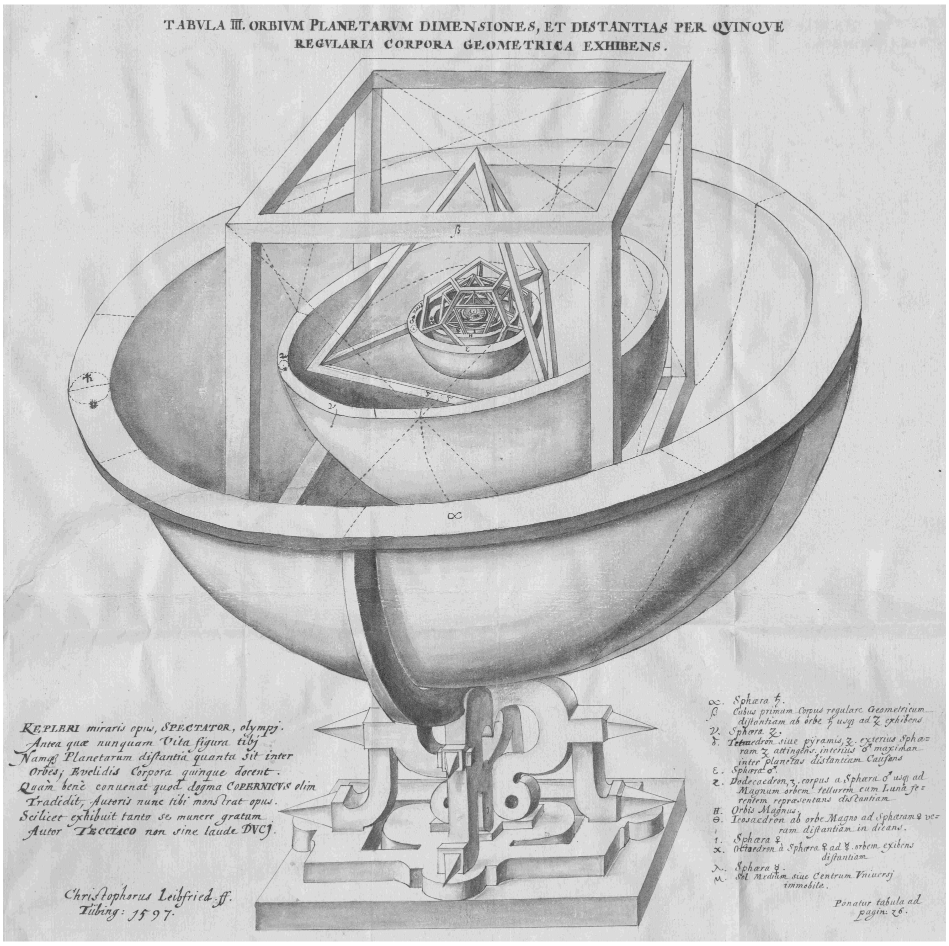
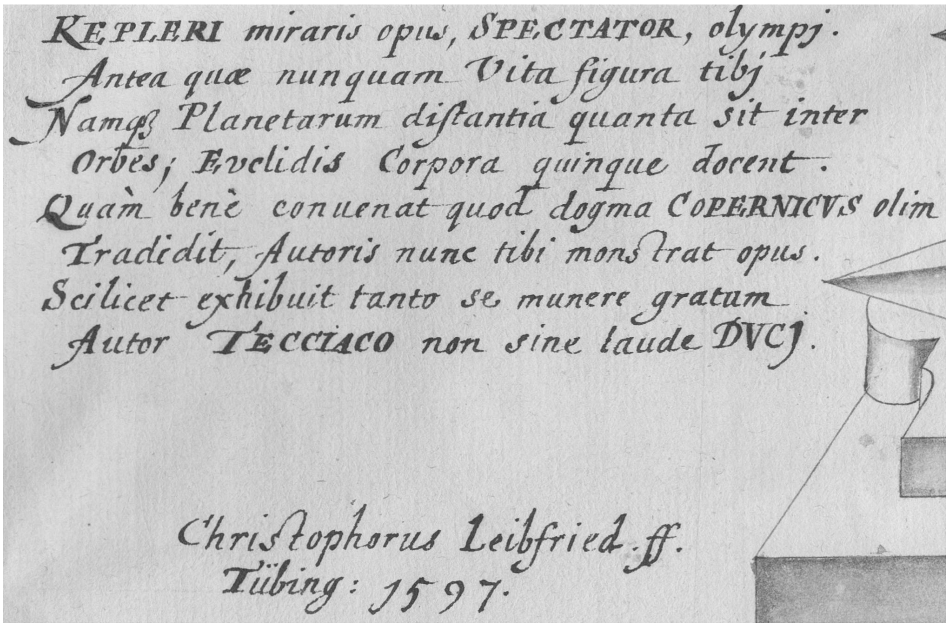
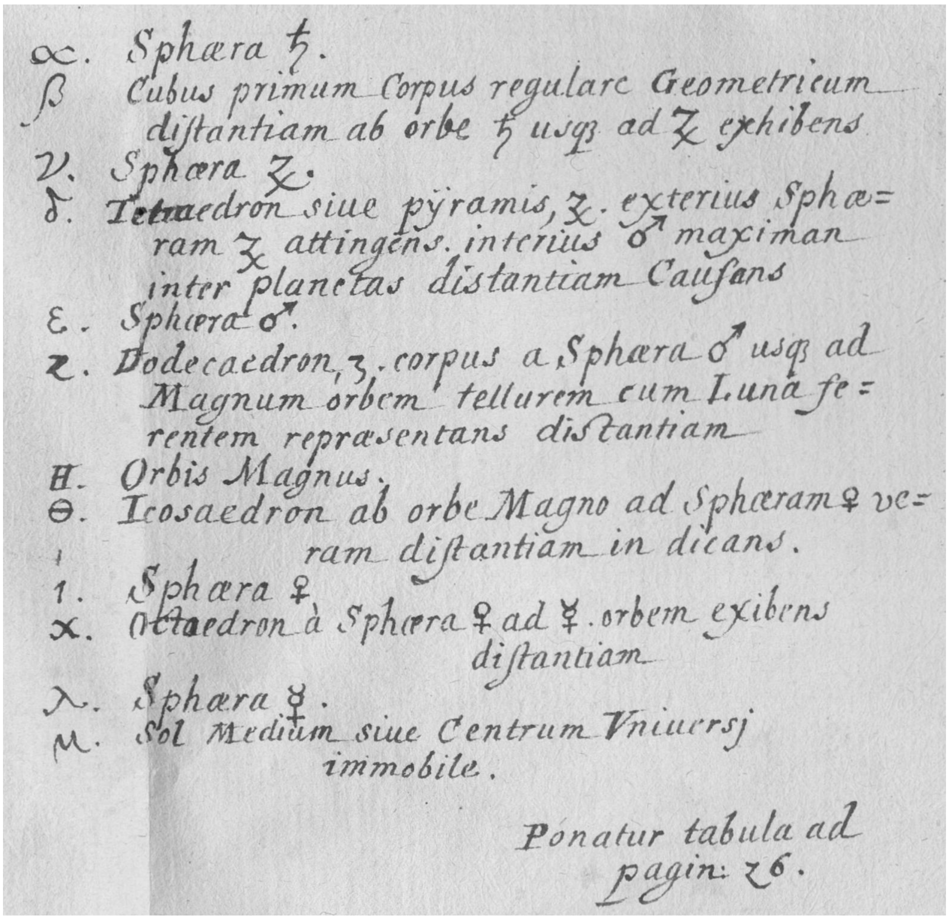


FIGURE 5. Table III from Mysterium Cosmographicum (1621; Frankfurt am Main: Godefridi Tampach). Enlarged texts in below. (*Courtesy of Linda Hall Library*)





α. Sphæra ♄.
β Cubus primum Corpus regulare Geometricum distantiam ab orbe ♄ usq; ad ♃ exhibens.
γ. Sphæra ♃.
δ. Tetraedron siue pyramis, ♃. exterius Sphæram ♃ attingens. interius ♂ maximam inter planetas distantiam Causans
ε. Sphæra ♂.
ζ. Dodecaedron, ζ. corpus a Sphæra ♂ usq; ad Magnum orbem tellurem cum Luna ferentem repræsentans distantiam
Η. Orbis Magnus.
θ. Icosaedron ab orbe Magno ad Sphæram ♀ veram distantiam in dicans.
ι. Sphæra ♀
κ. Octaedron à Sphæra ♀ ad ☿. orbem exibens distantiam
λ. Sphæra ☿.
μ. Sol Medium siue Centrum Vniuersi immobile.

Ponatur tabula ad pagin: 26.

Of Gaps, Nothing, and the Void

> Beyond the Universe NOTHING finds place,
> And NOTHING fills the mighty void of Space:
> On NOTHING turn the lucid orbs above,
> And all the Stars in mystic order move.

In this extract from a poem by Rev. Belsham (1857), an English Unitarian minister, the psychic void left by modern science in man's view of the cosmos verges on the nihilistic, saved only by some 'mystic order'. Anttila (2017: 73) writes of an early sermon by Luther, where he defined a threefold *nihil* (nothing). "The first is nothing in the literal sense, that is, related to being (ens), the second is nothing as an equivalent of being false, which is in opposition to truth (*verum*), and finally, nothing in the sense of evil, which is in opposition to good (*bonum*)."

One aspect of nothing in nature (the literal sense of *nihil*) is a vacuum, famously derived from the *fuga vacui.* This has variously been translated as 'nature's flight from the void' and 'nature abhors a vacuum.' Inventive strategies were employed "to avoid or justify or 'fill' the vacuum in natural philosophy." (Blum, 2017 :427). Robert Boyle, for example, "avoided the persistent philosophical problems surrounding the concept of void by referring to it as the absence of matter rather than the presence of a new entity." (Jenkins, 2000: 160) Kepler, by contrast, did invoke the presence of a new entity; when his most famous gap (Kepler's Gap) finally became filled, the asteroid/dwarf planet Ceres was revealed.

The first engagement with Kepler's "a priori derivation of the relative distances [of the planets] from the ratios given by the inscribed and circumscribed polyhedra" was made by the German physician, astrologer and anti-Copernican Helisäus Röslin. (Westman, 2011: 348). He too had correspondence with Hohenburg, and in May 1597 expressed doubts about Kepler's choice of Platonic solids. Although "... the cube gives the distance of the spheres of Saturn and Mars," he did not know if perhaps "another of the five regular solids could not also give such [a result]... And although there may be five such distances of five planets, with every body especially arranged for specific planets, still I will not be of Copernicus' opinion for that reason." (quoted in Westman, 2011: 347).

Two months later Röslin believed he had cracked the problem with what Ursus soon derisively termed a "gappy hypothesis." (Westman, 2011: 348). Röslin "asserted that the cube would give the size of Saturn's sphere, the tetrahedron would fit Jupiter, and the dodecahedron would fill the space between Mars and the Sun." He further posited the 20-sided icosahedron would subsume three gaps, giving the space between the Sun and the Moon, in which space his geoheliocentric view of the solar system placed both Mercury and Venus. Röslin also noted that Kepler had also overlooked a gap, namely "The almost infinite distance between the sphere of Saturn and the fixed stars." Röslin pondered the implications. "With which geometrical figure does he want to account for such an infinite empty space?" (Westman, 2011: 347). A year later, Tycho also criticized Kepler for ignoring that gap. In a letter to Kepler of 1 April 1598, Tycho "claims the heliocentric hypothesis is incompatible with the basic premise that the cosmos has to be well proportioned: the empty space between Saturn and the fixed stars violates the principle of continuity and produced 'assymmetria'." (Mehl, 2016: 206).

"If this gap filling was not decisive," states Westman, "Röslin believed that Herwart would agree his arrangement far better accommodated the polyhedra because of the last gap." Röslin wrote "I do not require a further geometrical demonstration, because I put the uppermost part of the sphere of Saturn to be contiguous to the eighth sphere. Thus Your Grace sees how his [Kepler's] invention confirms my system far better than his." (quoted in Westman, 2011: 348). What was left unsaid by either Ursus or Röslin was "the metaphysical relevance of the polyhedral as a new criterion for comparatively evaluating (and eliminating) multiple hypotheses of cosmic order." (Westman, 2011: 348).

Kepler was acutely aware of the fitting issue. Armed with the distances and excentricities given by Copernicus, how well did the dimensions of the spheres fit the Platonic solids computed from them in such a way that the inner surface of a sphere coincided with the sphere circumscribed to the next solid below it, and the outer surface with the inscribed sphere of the solid right above it? He identified two such gaps: "The orbit of the Earth does not even touch the sides of the proposed dodecahedron; neither does Venus with the corresponding icosahedron." In what must have been an act of some desperation that sacrificed the elegance of his system, he placed a star-shape between Mars and Venus "constructed from five equilateral triangles laid down outward and raised from the edges of each of the pentagons that constitute a dodecahedron." (Cardona, 2016). Somewhat like Ptolemy adding epicycles to make the observations fit the theory, the unreality of his geometric system was staring Kepler in the face, but he doggedly persisted in believing it, even after he discovered planetary orbits are elliptical. This may have been the inspiration for some lines in the famous 1679 poem *On Nothing* by the Earl of Rochester who writes "Nothing, who dwellest with fools in grave dispute/For whom they reverend shapes and forms devise."

The matter of a void arises in Kepler's work in two unexpected ways. As Barbour (2001) has described it, a void point is a point in space where no object, no matter, is located but plays an essential role in describing the motion of a planet. Such is the case with Ptolemaic epicycles and equants. "The dynamic void points in models of planetary orbits were exactly what drew Johannes Kepler's attention and objection." (Kosso, 2013: 385). The circular orbits that were thought to exist contained an empty point in space that directed the planet's circular orbit. Kepler rejected this notion, writing "A mathematical point, whether or not it is the centre of the world, can neither affect the motion of heavy bodies nor act as an object towards which they tend." (Kepler, [1609] 1992: 54). As part of the abolition of Ptolemaic concepts noted by Melanchthon, "the Keplerian model of planetary orbits has no void points whatsoever." (Kosso, 2013: 385).

Secondly, in his effort to "prove that a vast portion of the universe should be particularly different," Kepler makes a bold proposal about a spatial void that ultimately fails to persuade as it is based on a circular argument as "the same measurements used to propose the distance to the stars are employed to predict the cavity without any further proof." (Luna, 2021: 79). In his book on the supernova of 1604, Kepler (1606: 689) writes:

> *For let it be admitted that the fixed stars are extended outward to infinity. Nevertheless, it is a fact that in this inner bosom there shall be an immense cavity, distinct from the spaces among the fixed stars and vastly different in proportion. This, if it occurred to somebody to examine only this cavity,... from the sole comparison of this void with the surrounding spherical region filled with stars, he would utterly conclude that this is a certain particular place and, in fact, the main cavity of the world.*

One can see in this passage Kepler attempts to apply the concept of proportionality once more, in keeping with his unwavering stance "that the geometry of the universe amount to a complete and physically fused astronomical landscape." (Luna, 2021: 79). In proposing this cosmic void within the landscape, Kepler was attempting to prove his model which included the heliocentric Copernican view, but his application of proportionality was overshadowed by a gap Copernicus himself identified (in chapter 10 of his 1543 book *De revolutionibus orbium coelestium*): "From Saturn, the highest of the planets, to the sphere of the fixed stars there is an additional gap of the largest size." (Dobrzycki, 1978: 22). The proportion problem posed by the stars remained unresolved for Kepler, as it had for Copernicus.

Reflecting on the beguiling influence of Kepler's Gap between Mars and Jupiter as seen from the beginning of the nineteenth century, the man who co-discovered Ceres in 1801, Giuseppe Piazzi, wrote this about Kepler:

> *The first we can mention to have an idea about a planet between Mars and Jupiter was Kepler's thought as the father of modern astronomy. Living at the time of the Renaissance, he was overwhelmed by the fascination, common at that time, of the ancient philosophy made majestic by the names of Pythagoras and Ptolemy. He believed in the mysterious property of numbers: he thought that in the multiplicity of their relationship was the seed of human knowledge "so I looked in their order and structure in the sky." But being a great genius more worthy of the title of divine than Ptolemy, submersed by the most absurd extravagance of a dream of celestial harmony and by a myriad of combinations, he pointed out an emptiness between Mars and Jupiter that could only be explained through a dissonance and lack of harmony. This dissonance was not felt by him about the other planets, which combined in direct or inverse order to create a beautiful concert.* (Piazzi, 1802).

In the same year, the mathematician Carl Gauss accorded Kepler a very high accolade: he believed that as a man of science, Kepler was quite capable of discarding even his most cherished belief in the face of new observational evidence.

> *I do not want to disapprove of the fact that one seeks in nature such approximate correspondences. The greatest men subscribed to such lusus ingenii [games of nature]. But as proud as Kepler was of his regular bodies reconciled with the distances of planets (as he said he did not want to give his find to the Electorate of Saxony) he certainly would not have used it to challenge Uranus' planetism (if this discovery had been made in his times) simply because it did not match his ideas. Most likely he would have abandoned them immediately.* [letter of Gauss to Franz von Zach, 16 Oct 1802]

Gauss alludes in this missive to the 'game of nature' popularly known as Bode's Law, which noted the famous gap between Mars and Jupiter.

It was Jacob Bernoulli, in 1681, who first assigned numerical values to the orbital properties of the 'missing planet' in this gap. After a century of general speculation about the supposed planet (Beswick, 1851), Baron Franz von Zach followed with his own calculation of orbital properties in 1785. He became one of the first persons to see that long-sought planet, Ceres, in December 1801. The American astronomer Ormsby Mitchel (1860: 98) celebrated the discovery of Ceres in extravagant Victorian prose. "The vast interplanetary space between Mars and Jupiter was the real locality of a discovered world, whose existence had been conjectured by Kepler 200 years before, and whose discovery, by combined systematic and scientific examination, constituted the crowning glory of the age." For the astronomical and philosophical details of the grand venture begun by Kepler in 1595, see Cunningham (2017a).

The Poetic Legacy

It was Plato whose name was given to the solids Kepler employed, but Plato filled another role not as clearly appreciated in Kepler's work. In the following quote, Dr. Roberto Calasso refers to the eighth century BCE Greek poet Homer, and the Chaldeans. In the second century CE *Chaldean Oracles*, their god "can be considered to be Nous, whose function is to 'think' the world of platonic forms into being." (Dietz, 2014). One great fault of Homer," writes Calasso (1993: 274), "for which Plato never forgave the poet, was that he omitted any serious comment on the structure of the cosmos...But with the Orphics, followers of the Book, and later with Plato, Chaldean wisdom took its revenge on Homer. The roving islands of celestial bodies, the frayed progress of the Milky Way, the soft sounds of the spheres all regained their privileges." The "soft sounds of the spheres found a new maestro in the person of Europe's greatest astronomer," (Cunningham, 2017b: 336) and found poetic expression in the person of the English amateur astronomer Capel Lofft (1781: 38). After lines that enumerate the orbital periods of the planets, he wrote of when Kepler found the Third Law of planetary motion:

Nor Poetry these numbers will disdain,
Since Harmony, her sister, these approves;
In perfect scale most musically true:
So sweet a concert regulates the spheres.
Justly, O KEPLER! Are the Ides of May
Rever'd, which taught to thee this wondrous truth.

While a full exploration of musical harmony and the cosmos is beyond the remit of this study (see Haase, 1975), it must be noted that in Chapter 12 of *Mysterium*, Kepler "tested some arguments that established relations among planets and the lengths of strings that determine harmonious combinations." (Cardona, 2016). Kepler's 1619 book *Harmonice Mundi* (Harmony of the Spheres) opens with a presentation of the Platonic Solids he had employed in the *Mysterium* book, but goes further "in alluding to the relationship between the harmonic proportions and the five regular solids." (Haase 1989:117). For a study of Kepler's use of geometry and music in his astrological writings, see Linde and Greenbaum (2010).

Kepler's methodology "was heavily influenced by the spirit of Pythagoras." (Cardona, 2016). Kepler was imbued by this tradition through the work of the fifth century CE Greek philosopher Proclus: three books of *The Harmony of the World* begin with epigraphs from Proclus, one of which reads "Thus Plato teaches us many wonderful doctrines about the gods by means of mathematical forms, and the philosophy of Pythagoreans clothes its secret theological teaching in such draperies." (Proclus, 1970: 19). This directly links forms, such as the Platonic solids, with divinity – Kepler's animating principle. By invoking Proclus, Kepler himself relates how his ability to know the plan of the cosmos came to be. "For to know is to compare that which is externally perceived with inner ideas and to judge that it agrees with them, a process which Proclus expressed very beautifully by the word 'awakening' as from sleep." (Kepler, 1619). In Book V of *Harmony*, Kepler admits his polyhedral hypothesis (published 23 years earlier) does not perfectly account for planetary distances. Abandoning his effort to fill the gaps between the nested solids, he explains they are necessary for the harmonies of the cosmos to emerge. "The forces that cause the ellipse also bring about the harmonies." (Regier, 2016: 234). By explaining all this in anthropomorphic terms (the original bulk of the world, determined by polyhedral forms, was fine-tuned by harmonies so that the world's body could take on the "organs necessary to life"), Kepler (1619: 490) opened the door to connect cosmic harmony with humans.

Three brief examples will suffice to show the intertwined nature of humanity and musical harmony from the sixteenth to eighteenth centuries. In a sermon of 1538, "Luther comments that Pythagoras claims that the movement of the stars begets a sweet harmony, but people are unable to perceive it because they are accustomed to it." (Anttila, 2017: 86). An early version of Shakespeare's play *King Lear* "has Cordelia bring Lear back to sanity partly through the force of music which, operating alongside medicines, retunes him to the order of the cosmos." (Davis, 2011). According to Newton's nephew, John Conduitt, "Sir Isaac used to say he believed Pythagoras had some notion of gravity, and meant by that what is vulgarly called the Musick of the Spheres." (Conduitt, 1732).

In reality, what Pythagoras believed or did not believe is highly speculative, but for the purposes of this study the reality is irrelevant – the perception of what was believed about Pythagoras, the harmony of the spheres, and its relationship to actual planetary distances and musical tones, is expressed in the Keplerian legacy. Nowhere was this legacy more profoundly felt than in the poetry of William Wordsworth and Samuel Taylor Coleridge.

In a lecture delivered in 1819, Coleridge singled out Kepler as marking the beginning of "truly scientific astronomy" because "by laws demonstrably drawn out of his own mind he has, in that mind, not only, but as far as his own purposes require it, controlled the mighty orbs of nature." (quoted in Owens, 2019: 168). Coleridge "found it impossible not to admire the celestial harmony he found in Kepler which relied on a congruence between geometrical and physical phenomena." (Owens, 2019: 19).

Coleridge took the concept of forms – so central to the work of Kepler – and overlaid it on William Herschel's discoveries. "It was Herschelian 'forms & schemes of motion' of the stars and planets which excited Coleridge." (Owens, 2019: 168). To enable this rather dubious association, he appropriated the instrument Herschel used – the telescope – as the means by which to link reason and faith. "Now that the telescope is to the eye, faith, that is the energies of our moral feelings, are to the reason. Reason is the eye, and faith the telescope." (Coleridge, 1818-1819, 1:377).

The poet went much further than this however, adopting the very method of Kepler to design a unifying system that – in Coleridge's words – was "based upon the reconciliation of faith, and consistent with human nature and experience." This was manifested by Coleridge in an utterly bizarre fashion, even employing the analogical approach of Kepler. As Thomas Owens writes, "It took a mind like Coleridge's to galvanize physics with metaphysics and to see in Herschel 'actual analogies' for a blazing variety of Trinitarian and broader epistemological proofs." (Owens, 2019: 168). This Trinitarian approach is the very one adopted by Kepler! "Before the universe was created," Kepler wrote, "there were no numbers except the Trinity, which is God himself." This was grounded in Martin Luther's belief "in God's ubiquity, namely, the presence of the triune God in all of creation." (Raunio, 2009: 220). Kepler "explained the stationary aspects of the heavens – Sun, fixed stars, and space – archetypally by drawing an analogy with the Holy Trinity." (Martens, 2009: 40). Kepler expressed it thus in *Mysterium*: "The image of the Triune God is a spherical surface: the Father is in the centre, the Son in the outer surface, and the Holy Ghost in the equality of the relation between centre and circumference." Just as Kepler tried to reconcile reason and religion, Coleridge was driven to do the same, but he did so by regarding the telescope as 'the Organ of Theology' via faith in Trinitarian Christianity.

Like Kepler, Coleridge used analogies, writing that "they present a far more perfect, both a fuller and a more precise & accurate language than that of abstract or general words." (quoted in Owens 2019: 164). By using the telescope as an analogy, he found 'actual analogies' to bridge the gap between Man and God. (Jackson, 2016). He was then able to invoke the very 'eye of reason' used by Kepler who was keenly concerned, as we have seen, with the distance (aweful depth) of the stars:

> *Religion passes out of the ken of Reason only where the eye of Reason has reached its own Horizon; and that Faith is then but its continuation... the upraised Eye views only the starry Heaven which manifests itself alone: and the outward Beholding is fixed on the sparks twinkling in the aweful depth, though Suns of other Worlds.* (Coleridge, 1817: 309)

Wordsworth was equally in the thrall of the Keplerian legacy. While neither poet was entranced by the use of mathematics by Newton,

> *... geometric shapes gave the poets a unique capacity to perceive, interact, and respond to the world around them. They never relinquished this way of seeing and its was instrumental to Wordsworth's pronouncement in the Preface to Lyrical Ballads (1800) to gauge how 'the passions of men are incorporated with the beautiful and permanent forms of nature.* (Owens, 2019: 19)

In Wordsworth's Manuscript B of his poem *The Ruined Cottage* (1798), he introduces a character named The Pedlar. He must have been thinking of Kepler when he wrote such lines as "In all shapes | He found a secret and mysterious soul, | a fragrance and a spirit of strange meaning." (B.83-85) The Pedlar had "an eye which evermore | looked deep into the shades of difference | As they lie hid in all exterior forms" (B.94-96) and which "Could find no surface where its power might sleep, | Which spake perpetual logic to his soul." (B.100-101). The Pedlar's ability to understand the world derived from a set of geometrical principles which "lived to him | And to the God who looked into his mind." (B.88-89). To make matters even more clear, Book Six of *The Prelude* states that geometric science "is | And hath the name of God." (Owens, 2019: 20). In these lines the investigations of Kepler are writ large, a literal description of what he accomplished in *Mysterium*, with even the word 'mysterious' inserted as a calculated affect to direct the reader's attuned mind to Kepler's book. The alliterative assonance of 'forms,' 'surfaces,' and 'perpetual logic' (as a synonym for reason) are striking, as is the mention of 'shades of difference,' which evokes a form of measurement. The use of the word 'soul' is also strategic: "Kepler postulates for creation... and for the Sun and the planets in particular, not only an external dimension, but also a soul with a mind." (Gerdes, 1975: 345). That Kepler believed God had literally looked into his mind can hardly be doubted; in the 1621 second edition of *Mysterium* he wrote "It is as if the heavens had dictated to me an oracle." (Beer, 1975: 402). The identification of God as a geometer can be traced back to Plato (Burnyeat, 2000), originator of the forms that captivated him. "... the idea of the geometer God assumed special importance with the Lutheran emphasis on the providential plan, a geometer god would have a geometrical plan for his providentially ordered universe." (Barker, 2000: 82). Wordsworth achieved through his Pedlar character a form of apotheosis of Kepler, one that has not hitherto been fully realized, and only apparent when one performs the conformal mapping of *Mysterium* onto his poetry quoted here. Wordsworth's encounter with the void is described in *The Prelude* of 1799:

> And after I had seen
> That spectacle, for many days my brain
> Worked with a dim and undetermined sense
> Of unknown modes of being. In my thoughts
> There was a darkness—call it solitude,
> Or blank desertion—no familiar shapes
> Of hourly objects, images of trees,
> Of sea or sky, no colours of green fields,
> But huge and mighty forms that do not live
> Like living men moved slowly through my mind
> By day, and were the trouble of my dreams.
> (Wordsworth, 1799. Book 1: 119-129)

Was the spectacle the very cosmos itself, the cosmos Kepler perceived as being composed of 'mighty forms' in the guise of the Platonic solids? As Gibson (2006: 19) writes, "... the 'darkness' of which the poet tells us, the experience of 'solitude' or 'desertion,' of the falling away of the familiar: all these suggest an experience of a void, the *tabula rasa*, an event which is not to be interpreted, understood or reasoned away." As an evocation of the boundary between the physical and the unknowable Kepler encountered through his application of reason, these lines of Wordsworth are striking. "For Wordsworth, poetry and science differed only in degree and not in kind" (Owens, 2019: 61), a way of thinking that gave us some of the finest poetry in the English language.

Conclusion

Even though Kepler's use of Platonic solids, his belief that there are exactly six planets, and his insistence that the angular speeds of the planets must agree with musical intervals have all been relegated to the dustbin of history (Abramowicz, 2011: 287), his key belief in harmony is central to our modern understanding of solar system dynamics. This was noted recently by Peter Lynch, emeritus professor at University College Dublin, School of Mathematics & Statistics: "Harmony was at the core of Kepler's cosmic model. This idea was not warmly supported by his contemporaries and never gained widespread support. Yet, harmonic relations are known today to be crucial, through the mechanism of dynamic resonance, which is of central importance in our current view of the solar system." (Lynch, 2018). The orbital/harmonic gap he identified between Mars and Jupiter exercised the imagination of many astronomers and led to the search for a 'missing planet' there; the 1801 discovery of Ceres in the gap was a stunning vindication, followed in subsequent centuries by observations of a huge population of asteroids in what is now termed the 'main belt.' While written in another context, no words could better encapsulate the intellectual life of Kepler than this line in the 1803 poem *Mnemosyne* by Hölderlin: "Prophetically, dreaming on the hills of heaven." (Mitchell, 2007: 95).

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Clifford Cunningham

Clifford J. Cunningham earned his Ph.D. in the history of astronomy at the University of Southern Queensland in Australia, where he is now a Research Fellow in the Astrophysics Group. His undergraduate degrees in physics and classical studies were earned at the University of Waterloo in Canada. He has written or edited 15 books on the history of astronomy: *Introduction to Asteroids* (in 1988), a 5-volume series on nineteenth century asteroid research, 7 volumes to date in the *Collected Correspondence of Baron Franz von Zach*, and (as editor) *The Scientific Legacy of William Herschel*. His most recent book, published in 2021, is *Asteroids* by Reaktion Press. He is currently editing three books: a volume in Bloomsbury's *Cultural History of the Universe*; a book on the three comets of 1618 for Springer; and a book on the Solar System for Reaktion Books. He was appointed by Springer as Series Editor of their Historical & Cultural astronomy books in 2019. He is associate editor of the *Journal of Astronomical History and Heritage* (JAHH), a contributor to Encyclopedia Britannica, and since 2001 has been the history of astronomy columnist for Mercury magazine. His scientific research ranging from ancient astronomy to Milton's *Paradise Lost* has been published in many leading journals, including Journal for the History of Astronomy, Renaissance & Reformation, JAHH, and Annals of Science. Asteroid (4276) was named Clifford in his honor in 1990 by the International Astronomical Union based on the recommendation of its bureau, the Harvard-Smithsonian Center for Astrophysics. In 2020 he was elected to membership in the International Astronomical Union.

Order and Harmony: Kepler's Guiding Forces

Dan Broadbent

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As the subject librarian for physics and astronomy at Brigham Young University, the author has had the privilege of handling some of Johannes Kepler's original books preserved in the university's archives. One of the most impressive materials in the archive is a large page from *Mysterium Cosmographicum* that unfolds to reveal a print of the Platonic solids, as shown in Figure 1.

Kepler used the Platonic solids in his attempt to explain the orbits of the six then-known planets. While unsuccessful, the effort shows how the concepts of order and harmony shaped how Kepler saw the universe and influenced how he developed explanations for his observations.

Order describes a convenient or purposefully organized arrangement. Harmony describes the consistency, congruity, or pleasing nature of that arrangement.

As Kepler observed the order and harmony of the planets' orbits, he connected that pattern with another orderly and harmonious pattern found in arranging the Platonic solids in just the right way. This correlation filled Kepler with delight, as he explained:

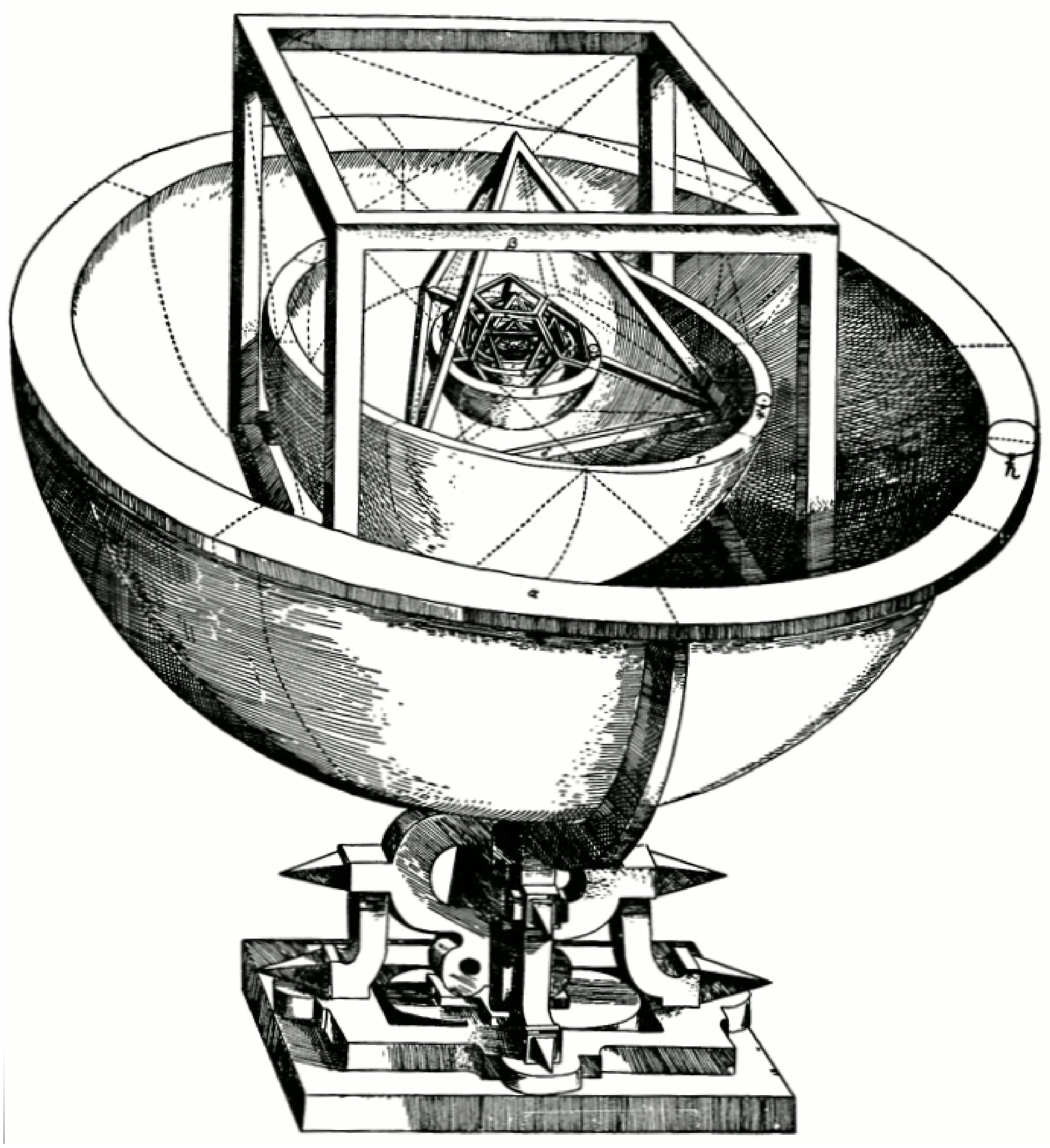

Figure 1. Image from *Mysterium Cosmographicum*, by Johannes Kepler.

> "It will never be possible to describe with words the enjoyment which I have drawn from my discovery. Now I no longer bemoaned the lost time; I no longer became weary at work; I shunned no calculation no matter how difficult." (Caspar, 1959, p. 63).

For Kepler, order and harmony were not just patterns to be seen and appreciated. They were the guiding forces that gave life and direction to his efforts to discover through observation and then craft an explanation. A compelling symmetry provided guidance: If what was observed had order and harmony built into it, then the explanation for what was observed would be made, naturally, from the building blocks of order and harmony.

Kepler described the invitation he felt from order to understand why it was there:

> "Whenever I consider in my thoughts the beautiful order, how one thing issues out of and is derived from another, then it is as though I had read a divine text, written into the world itself ... saying: Man, stretch thy reason hither, so that thou mayest comprehend these things." (Caspar, 1959, p. 152).

Osterhage (2020) added, "the one theme that drove [Kepler's] endeavors from his youth to his very end was the quest for order—or rather, the quest to discover the one singular order underlying all things" (p. 4). The process of figuring out this order thrilled Kepler. In his words, "the ways by which men arrive at knowledge of the celestial things are hardly less wonderful than the nature of these things themselves" ("Johannes Kepler: His life, his laws and times," 2017).

Kepler was not alone in using order and harmony. They are embedded in Copernicus's heliocentric theory. In Copernicus's own words, "in this ordering we find that the world has a wonderful commensurability and that there is a sure bond of harmony for the movement and magnitude of the orbital circles such as cannot be found in any other way" (Copernicus, 1543/1995, p. 26). Kepler based much of his work on Copernicus's theory, which ultimately led to his three laws of planetary motion.

According to Sambursky (1971), "in all his works and in his letters to friends, Kepler repeatedly expresses his belief in a universal harmony that subsists in the structure and occurrences of the physical world" (p. 95). Kepler believed that this universal harmony was a connection within each of us. In his words, "the souls of human beings were formed in such a way that man expects harmonies as well as observes and grasps them" (Kepler, 1858, p. 228).

This fundamental axiom guided his work: Nothing was created by God without a plan. In his efforts to discover that plan, Kepler differed notably from other scientists of his era. He brought everything he had to bear on the problem – not only his mathematical abilities but also his imagination and beliefs. Indeed, one of Kepler's outstanding attributes was "his ability for lateral thinking ... the ability to approach a given problem in multiple fashions, i.e., by using methods of analysis and synthesis of a number of different scientific disciplines, and by synthesizing these fragmented results into a coherent overall model" (Osterhage, 2020, p. 109). These abilities found productive expression through Kepler's utilization of order and harmony.

It is important to note that order does not mean lack of change. In Kepler's era, a supernova introduced what was thought to be a new star. A comet also emerged and moved across the European sky. These events created difficulties for those who clung to Aristotle's explanations that required the heavens to be perfect and unchanging. Being locked into one set of explanations prevented them from making progress as new observations were made.

In contrast, Kepler was willing to experiment with various explanations for what he observed. The difficulty was that those explanations were "so far outside the bounds of previous thought that there was no evidence in existence for him to work with. He had to use analogies" (Epstein, 2019, p. 100). To explain why planets that are farther away from the Sun move slower than those that are closer, he considered parallels with other natural orders. Smells and heat dissipate with distance. Light diminishes with distance as well. Could planetary motion be linked to the Sun's light or heat? Magnetism also provided interesting possibilities; maybe the planets were like magnets. To explain why the planets all move in the same direction, Kepler drew from the effect a whirlpool's swirling waters have on floating objects (Epstein, 2019). Wherever a similar pattern or order existed, Kepler was willing to consider it.

That is not to say Kepler's efforts went smoothly. He struggled to explain the orbit of Mars, with its strange retrograde motion, for five years before he finally aligned the data from Tycho Brahe's diligent observations with an explanatory theory. No wonder Kepler referred to this work as his "war" against Mars ("Kepler's Discovery," 2021). In the end, it was extremely disappointing to him to have to abandon the perfect order and harmony of circular orbits and replace them with ellipses. "Having cleared the stable of astronomy of circles and spirals, he was left, he said, with 'only a single cartful of dung,' a stretched-out circle something like an oval" (Carl Sagan, 1980).

Interestingly, that disappointment eventually gave way to a recognition of a different kind of harmony embedded in the discovery.

"The Earth was a planet, as Copernicus had said, and it was entirely obvious to Kepler that the Earth, wracked by wars, pestilence, famine and unhappiness, fell short of perfection. Kepler was one of the first people since antiquity to propose that the planets were material objects made of imperfect stuff like the Earth. And if planets were "imperfect," why not their orbits as well?" (Carl Sagan, 1980).

The order and harmony found in religious faith—or at least the potential for it—permeated Kepler's life and influenced his scientific approach. In his words, "there is nothing which I desired more to investigate thoroughly and to know than this: can I also find God within myself, God, whom I readily grasp when contemplating the universe?" (Caspar, 1959, p. 221).

This faith-based approach inoculated Kepler, to a degree, from the plagues of egocentric battles and offenses that have afflicted so many great minds through the ages. In response to an allegation that Galileo had used Kepler's ideas as though his own, Kepler responded, "that makes no difference to one who has set truth and the honor of God as the highest goal, not his own fame" (Caspar, 1959, p. 372). This humility is further manifested in Kepler's statement, "I much prefer the sharpest criticism of a single intelligent man to the thoughtless approval of the masses" ("Johannes Kepler: His life, his laws and times," 2017).

In his personal life, order and harmony were often denied Kepler. The state of the world into which he was born has been described as "a time fraught with disaster, a time in which one would gladly flee to the stars in order to find home and security there" (Caspar, 1959, p. 27). His home life as a child was very turbulent. According to Love (2015), Kepler's "lifelong search for harmony in the Universe was arguably, at least in part, a reaction against the total lack of harmony in his childhood years" (p. 36). His first wife died young, and eight of his twelve children died before adulthood (Love, 2015). Because of disagreements he had with teachings from the Lutheran church, Kepler was not permitted to take communion – a serious affront to him. He also endured years of distress while his mother was tried as a witch, with the possible outcome of her being burned at the stake. (Thanks to Kepler's efforts she was finally released, but she died half a year later.) Further, some of his publications were placed on the index of prohibited books.

As a remedy to his life's many difficulties, Kepler did indeed flee to the stars for security, and he enjoyed solving riddles – injecting harmony and order on his own terms. Additionally, he often wrote poetry, including this epitaph that he penned for himself (Koestler, 1959, p. 427):

> "I measured the skies, now the shadows I measure.
> Skybound was the mind, Earthbound the body
> rests."

Through his determination, natural brilliance, and reliance on order and harmony, Kepler made momentous discoveries. His three laws of planetary motion, still fully in use today, describe and predict exactly how planets move, not only in our solar system but anywhere in the universe. His work laid the foundation that Isaac Newton built on to develop the law of universal gravitation. Kepler improved the understanding of optics, including how vision occurs, and made advancements in geometry and mathematics. Order and harmony are at the root of science, and both are on generous display in the works and methods of Johannes Kepler.

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Dan Broadbent on time line.

As a boy Dan loved to learn about astronomy and wanted to be an astronaut. Frequent bouts with motion sickness made him realize, reluctantly, that being an astronaut was not a great idea. Instead, he studied physics and worked in businesses related to science, eventually becoming a physics teacher and science research librarian. He happily recounts the latest developments in astronomy and science to his wife and five children, and anyone else who is willing to listen.

Planetary Power Proportions: Plato to Kepler

George Latura

In *Harmonices Mundi* (1619), Johannes Kepler promulgates what would come to be known as his Third Law of Planetary Motion:

> 'But it is absolutely certain and exact that the proportion between the periodic times of any two planets is precisely the sesquialterate proportion of their mean distances...' (tr. Aiton et al., 1997: 411).

The sesquialterate proportion is the ratio of one to one-and-a-half, or, of two to three. Kepler links the sesquialterate power ratio, squares and cubes, to the speeds and distances of planets.

The proportions of squares and cubes, connected to planetary metrics, is found in antiquity. Plato's Timaeus (35b-c) has the Demiurge, or cosmic craftsman, fashioning the template of the universe – the cosmic Soul – from an elemental mixture of Same, Different (or Other), and Being. From this mixture, he takes various proportions.

> 'First He took one portion from the whole;
> 'then He took a portion double of this;
> 'then a third portion, half as much again as the second portion, that is, three times as much as the first;

> 'the fourth portion He took was twice as much as the second;
> 'the fifth three times as much as the third;
> 'the sixth eight times as much as the first; and
> 'the seventh twenty seven times as much as the first.' (tr. Bury, 1929: 67).

Plato's proportions give seven numbers: 1, 2, 3, 4, 9, 8, 27. According to Plutarch's On the Generation of the Soul in the Timaeus (c. 110 CE), the Academy scholarch Crantor arranged these numbers in a triangular form:

> '...in the figure of a lambda with the first placed at the apex and the double and the triple numbers ranged separately from each other in two rows underneath...' (tr. Cherniss, 1976: 265-267).

Crantor's Lambda (Fig. 1) highlights the power progression, in Plato's numerical proportions: squares (2×2, 3×3) and cubes (2×2×2, 3×3×3). Plato's power proportions remained important throughout subsequent periods, because Plato had linked his seven numbers, through the Circle of the Other, or Different, (Timaeus 36d), to the orbits of the seven Wanderers in the heavens (Timaeus 38c).

> 'He split the inner Revolution in six places into seven unequal circles, according to each of the intervals of the double and triple intervals, three double and three triple.' (tr. Bury, 1929: 73).
> 'And when God had made the bodies of each of them He placed them in the orbits along which the revolution of the Other was moving, seven orbits for the seven bodies.' (tr. Bury, 1929: 79).

According to Plutarch's commentary, scholars of his time debated the relationship between Plato's proportions and planetary structure.

> 'Yet certain people look for the prescribed proportions in the velocities of the planetary spheres, certain others rather in their distances...' (tr. Cherniss, 1976: 321).

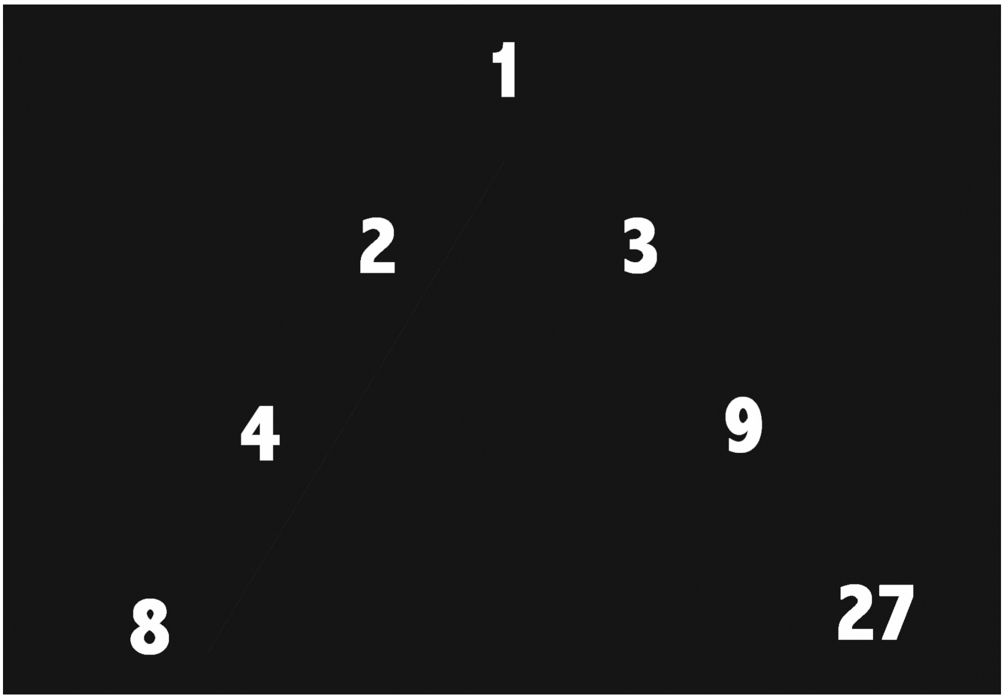

Figure 1. Plato's numbers in Timaeus were arranged in the shape of the letter Lambda by the scholarch Crantor, emphasizing the squares (2×2, 3×3) and cubes (2×2×2, 3×3×3) in the numbers that Plato had linked to the planets.

Shortly after Plutarch, Theon of Smyrna wrote Mathematics Useful for Understanding Plato. There Theon wrote about two numerical 'quaternaries' that make up the harmonic and mathematic proportions that comprise the universe: the Pythagorean Tetraktys, an equilateral triangle of ten tokens that sit atop one another (1, 2, 3, 4); and the Platonist Lambda, that progresses the numbers 2 and 3 through powers of squares and cubes.

> 'The importance of the quaternary obtained by addition (that is to say 1, + 2, + 3, + 4) is great in music because all the consonances are found in it... The first quaternary is... formed by addition of the first four numbers.' (tr. Lawlor, 1979: 62).
>
> 'The second [quaternary] is formed by multiplication, of even and odd numbers, starting from unity... Next comes three numbers from the odd as well as the even series.'

> ‘The second number in the even and double (series) is 2 and in the odd and triple is 3. The third of the order of even numbers is 4, and in the odd series, 9. The fourth among the even numbers is 8, and among the odd numbers, 27... It is with these numbers that Plato, in the Timaeus, constitutes the soul [of the cosmos]...’
>
> ‘There are then two quaternaries of numbers, one which is made by addition, the other by multiplication; and these quaternaries encompass the musical, geometric and arithmetic ratios of which the harmony of the universe is composed.’ (tr. Lawlor, 1979: 62-63).

In his commentary On Plato’s Timaeus (c. 300 CE), Calcidius reports on the connection between Plato’s proportions and the Wanderers in the heavens.

> ‘He [Plato] himself testifies to this when he says [36d] that god cut the circle derived from the nature of the other six ways and fashioned seven disparate spheres, which in contrary patterns of movement revolve according to the intervals of the double and the triple, and in those orbits he placed the Sun, Moon, and other wandering luminaries.’ (tr. Magee, 2016:179).

Around 400 CE, Macrobius wrote his Commentary on the Dream of Scipio, and in Book 2, we find Plato’s proportions connected to the planets.

> ‘Now we must ask ourselves whether these intervals, which in the incorporeal Soul are apprehended only in the mind and not by the senses, govern the distances between the planets poised in the corporeal universe.’ (tr. Stahl, 1952: 196).

Macrobius’ work would prove useful to Kepler when he sought to reconstruct missing portions of Ptolemy’s Harmonics, as Kepler relates in Harmonices Mundi.

> 'And because the text is missing for this chapter also, I have supplied it as far as I could, especially from Macrobius...' (tr. Aiton et al., 1997: 503).

In Book IV of Harmonices Mundi, Kepler translates a portion of Proclus' commentary on Euclid's Elements. Here, as in Timaeus, Plato's seven numbers are connected to the formation of the world.

> 'And here we must follow Timaeus, who integrates and completes the whole source and structure from the mathematical types, and locates in it the causes of all things. For those seven terms of all numbers pre-existed in it, as far as cause is concerned.' (tr. Aiton et al., 1997: 301).

After Kepler provides his formulation of the planetary power law in Book 5 of Harmonices Mundi, he gives an example, using Earth and Saturn, where the cube roots of the planetary periods, when squared, yield the proportion of the planetary distances.

> 'Thus if one takes one third of the proportion from the period, for example, of the Earth, which is one year, and the same from the period of Saturn, thirty years, that is, the cube roots, and one doubles that proportion, by squaring the roots, he has in the resulting numbers the exactly correct proportion of the mean distances of the Earth and Saturn from the Sun.' (tr. Aiton et al., 1997: 412).

In Epitome of Copernican Astronomy, Vol. IV (1620), using Saturn and Jupiter as examples, Kepler repeats that the proportions of cube roots of planetary periods, when squared, give the planetary distances.

> 'The ratio of the times is not equal to the ratio of the spheres, but greater than it... That is to say, if you take the cube roots of the 30 years of Saturn and the 12 years of Jupiter and square them, the true ratio of the spheres of Saturn and Jupiter will exist in these squares.' (tr. Wallis, 1995: 48).

After stating his planetary sesquialterate power law in Harmonices Mundi, Kepler uses Plato's seven proportional numbers – which Plato had connected to the planets – to illustrate his planetary power proportion discovery.

> 'Let the periodic times of two planets be 27 and 8.Then the proportion of the mean daily motion of the former to the latter is as 8 to 27. Hence the semidiameters of the orbits will be as 9 to 4. For the cube root of 27 is 3; that of 8 is 2; and the squares of these roots are 9 and 4.' (tr. Aiton et al., 1997: 413).

In Principia, Isaac Newton acknowledged Kepler's discovery.

> 'This proportion, which was found by Kepler, is accepted by everyone... There is universal agreement among astronomers concerning the measure of the periodic times. But of all astronomers, Kepler and Boulliau have determined the magnitudes of the orbits from observations with the most diligence; and the mean distances that correspond to the periodic times as computed from the above proportion do not differ sensibly from the distances that these two astronomers found...' (tr. Cohen, Whitman, 1999: 800).

Earlier in Principia – Book 1, Section 3, Proposition 15, Theorem 7 – Newton gives a mathematically equivalent formulation of Kepler's planetary proportions.

'... I say that the squares of the periodic times in ellipses are as the cubes of the major axes.' (tr. Cohen, Whitman, 1999: 468).

Kepler had the cube roots of periods, when squared, proportional to planetary distances.

(cube root of Period)^2 is as Distance

Newton has the squares of the periods proportional to the cubes of the major axes, or distances.

(Period)^2 is as (Distance)^3

If one takes Kepler's formulation, and cubes each side, one arrives at Newton's formula, which is neater and more elegant than Kepler's, but the connection to Plato's planetary power proportions is lost.

Plato's proportional power numbers had traveled to Crantor, to Plutarch, to Theon of Smyrna, to Calcidius, to Macrobius, to Proclus, and to Kepler, who illustrated his planetary power proportion discovery with Plato's planetary numbers from Timaeus.

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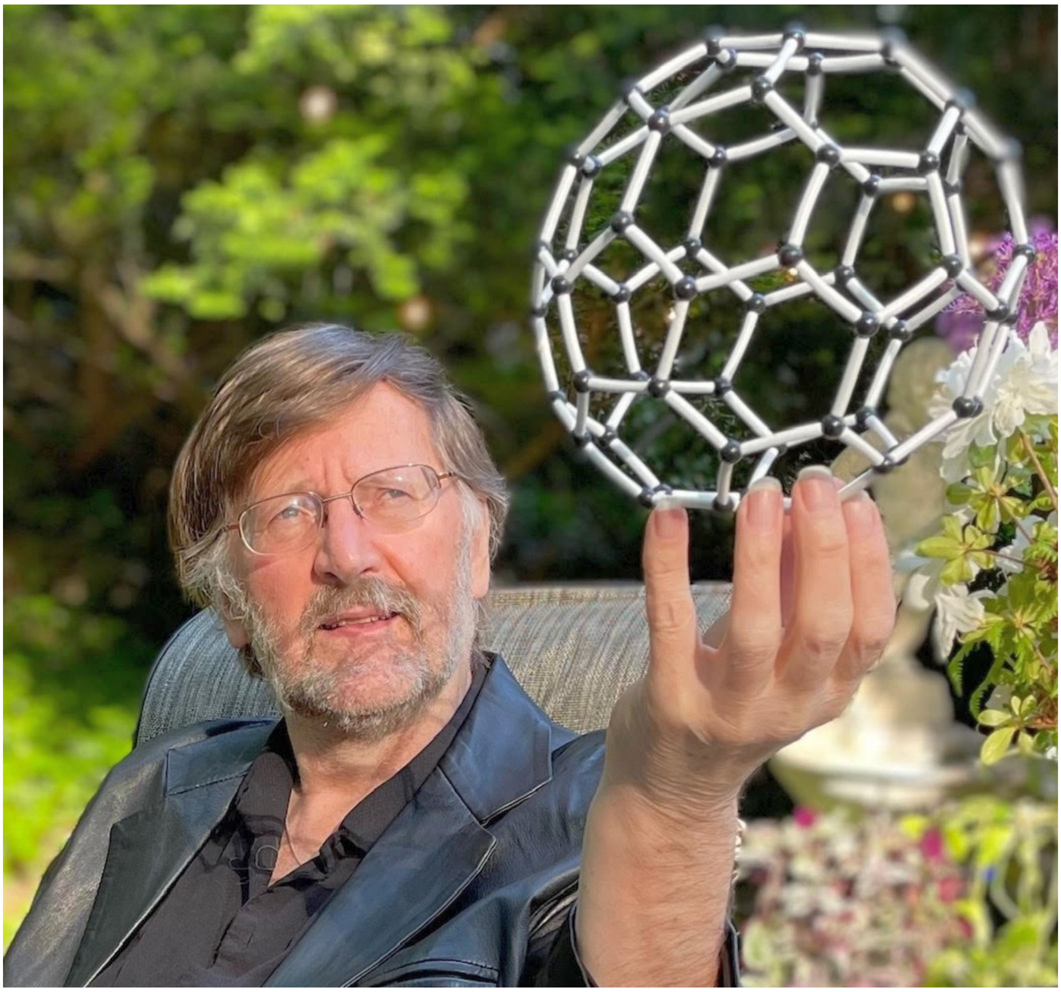

George Latura (*Photo: Katherine O'Shaughnessy*)

Born in Hungary, George Latura has lived in the USA for decades. An avid interest in historical and cultural astronomy led to oral presentations at conferences such as AAS/HAD (2022, 2021, 2020, 2019), SEAC (2021, 2018, 2016, 2013, 2012), INSAP (2015, 2013), and others.

Modern Incarnation of Kepler's Idea of Platonic Solids

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Johannes Kepler whose 450$^{\text{th}}$ anniversary of birth we celebrate this year 2021, is primarily known for his three laws of planetary motions. It had really been an ingenious and brave idea to abandon circles – the most perfect curves – for ellipses as trajectories of planets around the Sun. However, prior to discovery and formulation of his laws, which later found a solid explanation within Newton's law of gravity, Kepler had built an image of the solar system based on Platonic solids. His inspiration was from looking at figures like circles or squares inscribed in and circumscribed on an equilateral triangle. There is a fixed ratio of sizes of such figures. This ratio, while definite is different for triangles, squares or pentagons. According to young Kepler this could have been the key to the Solar System, explaining why six (known at that time) planets follow orbits of particular size.

Kepler's clue was that pure geometry and symmetry (i.e. mathematical beauty) could be the answer. However, regular figures should be generalized to solids and luckily there were five regular Platonic solids: tetrahedron (4 faces), cube (6 faces), octahedron (8 faces), dodecahedron (12 faces), icosahedron (20 faces). He observed that these solids nested in the order: octahedron, icosahedron, dodecahedron, tetrahedron, and cube would reproduce the relative sizes of orbits of Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Eventually, Kepler himself abandoned this concept and later formulated his famous laws. It is needless to say that discovery of planets beyond Saturn, and many other, smaller bodies in the solar system would invalidate this concept immediately (there is no room for other Platonic solids).

However, there is something in this idea which is worth mentioning as a prophetic view of future development of physics. First, the Kepler's view of the world (Solar System at his time) was based on fixed relative sizes of planetary orbits. Later on, when Newton announced the law of gravity, it turned out that all sizes of these orbits are permitted by the theory. There are the initial conditions like total energy and angular momentum, that determine the final size (and shape) of the orbit. But in quantum mechanics (XX$^{\text{th}}$ century achievement) we again have the well defined discrete energy levels and well defined radii of electron orbitals in an atom with no possibility of finding the electron in between. Second, the principle of symmetry is pervading contemporary physics. Noether's theorem relates basic principles of physics like energy, momentum or angular momentum conservation with specific symmetries: homogeneity of time and space and isotropy of space. Gauge symmetries underlie modern theory of elementary particles and quantum field theory. Evidently, the Nature respects the beauty of geometric concepts. Johannes Kepler would love it, even though the Nature chooses geometric ideas much more sophisticated than Platonic solids. Yet, in this contribution, I would like to point a sort of revival of the Platonic solids in modern physics, more precisely in modern cosmology.

The ambition of cosmology is to understand the world in the largest possible scale. It has also been an intellectual challenge for Kepler, but limited at that times to the Solar System. In the largest scale, the world is shaped by gravity – the long range universal attractive force. There is no "negative" mass, which could prevent or screen, this universal attraction between massive bodies. From the times of Newton, the idea of universe infinite both in time and space only created problems. If the distribution of stars was not perfectly homogeneous, small overdensities would collapse. Such world would be unstable. Moreover, the darkness of the night sky was not easy to understand in such world (the so called Olbers' paradox). All in all, cosmology was the domain of philosophy not empirical science until the birth of General Relativity (GR). According to the GR, the essence of gravity is that the spacetime can be curved by the presence of mass-energy, and their flows. This is captured (in geometrical terms) by the Einstein's equations. From now on, one can think about cosmology as the investigation of the spacetime geometry in the largest possible scale. By the way, Kepler would love this: geometry reentered the play but in more contemporary disguise of differential geometry. The so called Copernican principle, which states that no place or direction in the universe could be distinguished, led to the first models of the universe. Assuming that building blocks of cosmos – galaxies as we now know – could be in the largest scales described as a perfect fluid the famous Friedman-Lemaître-Robertson-Walker (FLRW) metric has been found as a solution to the Einstein's equations. The FLRW model has been supported by growing observational evidence and currently it is being assumed as the right model in any cosmological consideration.

Homogeneity and isotropy imply that one can distinguish a universal cosmic time and spacetime can be foliated i.e. expressed as a set of spatial slices evolving in time. Due to homogeneity and isotropy these slices, 3-spaces of constant cosmic time, are maximally symmetric i.e. have a constant curvature. This means that they could be either of three types: with positive, zero or negative curvature. This respectively corresponds to the hypersphere $\mathbb{S}^3$, Euclidean space $\mathbb{E}^3$ and hyperbolic space $\mathbb{H}^3$. The most recent and most precise cosmological results obtained by the *Planck* satellite very strongly suggest[1], if not definitively prove[2], that our Universe has zero curvature. Spaces of constant time, i.e. spaces of homogeneity are Euclidean. However, this is not the end of this story.

Einstein equations are in fact differential equations, which determine the metric of the spacetime. The metric describes the geometric structure of spacetime including the inertial motions (along the so called geodesics) of objects in the spacetime. They do not tell anything about the global structure of the spacetime i.e. about its topology. Usually the simplest topologies are tacitly assumed, as in the above mentioned cases

[1] N. Aghanim et al. "Planck 2018 results: I. Overview and the cosmological legacy of Planck" A&A 641, A1, 2020

[2] It is impossible to prove observationally the flatness. Measurements yield the value of the curvature – within certain confidence interval, which allows that the true curvature could be either positive or negative. Currently such probability is very small, yet not ruled out. Definite answer would be possible if the Universe was positively or negatively curved. In such case precise measurements could give confidence intervals disjointed from zero.

$\mathbb{S}^3$, $\mathbb{E}^3$ and $\mathbb{H}^3$. However, more complicated spaces are allowed. Let me start with two-dimensional case of $\mathbb{E}^2$ (the plane), which is easy to understand. Let us take a rectangle. If we identify (clue together) its opposite sides we get a torus $\mathbb{T}^2$. We say that the rectangle is the *fundamental domain* for the torus. This is the way to see that flat metric of $\mathbb{E}^2$ is also the metric on the torus $\mathbb{T}^2$. Similarly, you can imagine the infinite strip of width L with the sides glued together. This would give you a cylinder where also the flat metric is valid (locally). But unlike the $\mathbb{E}^2$ the torus $\mathbb{T}^2$ is multiply connected. It means that there exist closed curves (loops) that cannot be continuously deformed to a point. On the cylinder as well. Imagine the noose rope you throw to catch the horse. If you miss the lasso would contract to the point – the $\mathbb{E}^2$ case (or rather the $\mathbb{E}^3$ case). But if you make it the loop will not contract to the point. It will contract to the circumference of the horse's neck (topologically equivalent to the cylinder). Now, when we consider the fundamental domain – the rectangle for two-torus, it can be reproduced (by translations) to tile the full plane $\mathbb{E}^2$. We say that the plane $\mathbb{E}^2$ is the *covering manifold* for the torus. Consider the geodesics on the plane – the straight lines. They will leave the rectangle (the fundamental domain) at some points and reenter the copy. After gluing to the torus this would give geodesic on torus (not the straight lines now!) winding around the torus. All of this can be generalized to three (or more) dimensions.

Let us imagine the generalization to three dimensions. Instead a $\mathbb{T}^2$ torus we would have the $\mathbb{T}^3$. The procedure described above would suggest the fundamental domain being a cuboid with edges of length L_1, L_2, L_3, whose opposite faces are identified. Yet the covering manifold would be $\mathbb{E}^3$. The visualization of this is the cuboidal room whose walls, floor and ceiling are made of mirrors (hall of mirrors). The person standing in such a room will see apparently infinite copies of the room and that person filling the whole $\mathbb{E}^3$ space. To summarize what was said so far: the nontrivial topology of the manifold (space) allowing the given metric (flat in our case) would consist of: the covering manifold, the fundamental domain and the discrete group of tiling the covering manifold with fundamental domains (translations in our case). There exist excellent reviews on this topic[3] so we would not go any further into abstract mathematical details. Let us just comment that in the case of flat spaces with non-trivial topology there are 17 discrete groups generating tiling of $\mathbb{E}^3$ with fundamental polyhedra. They have been discovered long ago by Fedorov[4] and are known as cristallographic groups. It is interesting that in his treatise on the "Six-cornered Snowflake" (1611) Kepler himself formulated the ideas relevant to modern cristallography[5]. Indeed he discovered three of four Fedorov's parallelohedra. And miraculously the cristallographic group reappeared in modern cosmology!

We will skip discussion of the multiple-connected forms of negatively curved spaces, referring the interested reader to the above mentioned reviews. What is interesting, however, is that in the case of positively curved spaces fundamental domains include: tetrahedron, octahedron and icosahedron. This means that Platonic solids – the very first idea of Kepler, concerning geometry underlying the structure of cosmos – reappeared in XX$^{\text{th}}$ century cosmology![6]

It is important to stress that the issue of the topology of the Universe, also known as the issue of "the shape of the Universe" is not just a mathematical curiosity. Indeed when cosmology entered the precision era with dedicated satellite experiments: WMAP (2001 – 2010) and *Planck* (2009 – 2013), cosmic topology has been one of the key scientific projects of these experiments. Unfortunately, *Planck* has not discovered nontrivial topology of our Universe[7]. On the other hand, when WMAP provided its first precise measurements of temperature fluctuations of the cosmic microwave background (CMB) it turned out that the power spectrum of temperature anisotropy correlations revealed unexpectedly low (to large signifcance) power at lowest harmonics (quadrupole, octupole). This

[3] M. Lachieze-Rey, J. P. Luminet "Cosmic topology" Phys.Rept. 254 (1995) 135-214; J.P. Luminet, "The status of Cosmic Topology after Planck Data", Universe 2, 1, 2013

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[6] There are two more Platonic solids: the cube and the dodecahedron. However, their symmetries are the same as octahedron and icosahedron, respectively. So we may say that all Platonic solids reappeared in current cosmology.

[7] P.A.R. Ade, et al. "Planck 2013 results XXVI. Background geometry and topology of the Universe." Astron. Astrophys. 2014, 571, A26.

could be the signature of non-trivial topology, and a paper was published in Nature[8] suggesting that so called Poincaré dodecahedral space provides better fits at low harmonics than the standard FLRW model. *Planck* data confirmed this small power at the largest scales, but now the consensus is that one should not pay so much attention to this, since we have just one Universe and low signal in quadrupole and octupole could just happen by chance (as with any observation based on a very few data points). The things are different for larger harmonics (smaller scale correlations) where we have from tens of thousands to million data points. Modern approach to constrain cosmic topology from CMB is based on a different concept of so called circles on the sky[9], where one can take advantage of the rich statistical material provided by *Planck*.

Let me conclude that it is really amazing that the idea of symmetry and geometric structure as a guiding principle to understand the world is still valid and successful in modern physics (even though at a very different level of abstraction than in times of Kepler). It is also amazing that Platonic solids, whom Kepler himself (rightly) abandoned eventually reentered the scene of modern cosmology.

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Marek Biesiada works on broad aspects of theoretical and observational cosmology. Current research interests comprise testing of fundamental physics, dark energy and dark matter models using gravitational waves and strong gravitational lensing. He is also interested in application of Bayesian statistics, information-theoretical techniques of model selection and non-parametric statistical methods. In the past he worked on multi-dimensional Kaluza-Klein cosmological models as well as on application of dynamical systems, deterministic chaos and complex systems theory in astrophysics and theory of gravity. He studied Astronomy at the Jagiellonian University in Cracow and obtained his PhD in Physics under supervision of rev. prof. Michael Heller (2008 Templeton Prize Winner). He worked at Nicolaus Copernicus Astronomical Centre (10 years) and in the Institute of Physics, University of Silesia (20 years). He also studied medicine at the Silesian Medical Academy (currently Medical University of Silesia) and obtained his M. D. title. After completing the residency programme he suspended medical practice and left for Princeton invited by prof. Bohdan Paczyński and next visited Niels Bohr Institute in Copenhagen. Later on, working at the University of Silesia, he simultaneously practiced as M. D. dealing with the impact of environment on human health and health risk assessment of existing and planned enterprises. At that time he participated in working groups and expert panels of the World Health Organization (WHO), European Commission (EC), United Nations Economic Commission for Europe (UN ECE) and European Environment Agency (EEA). Around 2010 he definitely abandoned medicine devoting himself to cosmology exclusively.

Vivere est cogitare

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Let the title phrase of Marcus Tullius Cicero, "*to live means to think*", accompany the reader through this article focused on thinking, and the thinking man, that was Johannes Kepler. What is more wonderful in the Universe than thinking? In this phenomenal process something is born from nothing. Thinking also leads to the understanding of matters already existing and experienced. Among these matters, nature, and the cultural (or rather mental) heritage of humanity comes to the fore. As long as nature remains a pure form and is a reflection of the deepest truth, the cultural heritage is very much contaminated by all kinds of departures from the truth, born from the lack of hygiene of thinking or from a sick desire for some people to dominate others. As built overwhelmingly on false foundations, the cultural heritage of mankind is a dangerous and difficult area for a self-respecting thinker. The very phenomenon of thinking, along with the wide possibilities of its artificial strengthening, limiting and directing, have been the subject of professional theoretical research and practical verification, for years. This is not the place here to discuss them. It is enough to realize that there is a wide spectrum of quality and efficiency of thinking. A responsible thinker will present his own theorems only when he is able to prove them on a rational basis, governed by the rules of logic. There are also "philosophers" who are irresponsibly throwing their unproven ideas to the wind in the hope that they will go down in history at a low cost, if any of these ideas are justified in the future through the efforts of others.

The natural process of thought is like an unpolished diamond. It's superficial character does not captivate anyone and does not give the world anything extraordinary. Thinking skills need exercise like a diamond needs grinding. Because thinking should be efficient, logical, in-depth and verifiable. Practicing your thinking skills should start when you are young, when the innate curiosity of the world reaches its height. Frequent and prolonged interaction with nature means a lot. This is when a man, just from boredom and for pleasure, takes a closer look at this or that and tries to understand. Thinking is then a pure joy. Efficiency of deeper and more responsible thinking is effectively developed in mathematics. This is why she, mathematics, deserves to be called "the queen of science". Family homes and schools have a decisive influence on shaping the efficiency of thinking of individual people and consequently of entire societies. Anytime, anywhere praise be to good math teachers! There are also other exercises to support an efficient thinking, like translation of classic fiction, however only consistent mathematical formation, up to the time when a man loves mathematics so much that he cannot live without it, leads to a kind of permanent phasic transition in the brain that allows you to be sober and deeply thinking about all topics, including about natural phenomena.

It is said to be okay if a statistical scientist spends even five minutes on effective thinking during one day! The rest of his daily activity would just be routine operation. Thinking is therefore a process of sparse use and additionally is not free from the cultural climate of the environment in which it takes place. Fortunately, there are examples of people undertaking long, intense and healthy meditation on deep topics without coercion. Johannes Kepler was such a person without a doubt. If someone wants to undertake, for example, a mental path from blind religiosity towards understanding the essence of religion, or from delusions about supernatural things to tread hard in the real world, let him follow Kepler.

When in 1572, Tycho de Brahe observed a bright supernova star (another one appeared over 500 years earlier) Kepler was only 10 months old. In 1604, 33-year-old Kepler witnessed the appearance of another supernova. Both thinkers went to the trouble of proving that these new stars were not some strange phenomena in the atmosphere of the Earth, but they were born in the depths of heaven. This way, by observation of a natural phenomenon and its logical interpretation, they have refuted a dogma eternally reigning in culture about the perfect character of the heavens, treated as the work of the "perfect Creator". If something is perfect, it doesn't need further improvements. Could the Creator have neglected something earlier, and now He needs to make some improvements in the sky? We have here a beautiful example of a collision of the views well established in the culture (created irresponsibly but with great calculation) with factual arguments drawn from the selfless observation of nature. We are aware of the social tensions that are born with this kind of collision, and how dangerous their release can be. Kepler is a great example of a "towards truth" thinker who, with truths discovered in the sky, tried to eliminate from human culture the pseudo-truths impoverishing it. As a religious man, he knew, understood, and implemented the biblical record in which his namesake, the evangelical John the Baptist declared, "Prepare the way for the Lord, make straight paths for Him!" (Luke 3: 4-5). Straightening the paths of thinking, even if it was about the dogmas of his religious faith, became Kepler's life mission. Thanks to him and people like him, the darkness of the Middle Ages gave way to the splendors of cultural enlightenment.

In Kepler's heliocentric model, the Copernicus epicycles and orbits have disappeared, and the planet's orbits turned out to be elliptical and not circular. In addition, in Kepler's Universe, planets were circling the real material Sun, unlike in Copernicus's universe, some "empty" geometric point called the mean sun. The one who understands the genre gravity of Kepler's breakthrough achievements appreciates the effort and the courage of the author. He will also enjoy the "flourish" from heaven made by the supernova from 1604, whatever it may mean to someone.

It is hardly possible to know to what extent Kepler was "Kepler" himself, and to what extent a result of the didactic and educational influences of his environment. Where in a young man enamored with mathematics and hardly introduced to the question of the highest mathematics, (i.e. mathematics relating to matters in the sky), there was such a mature desire to look into the world's best observational data to verify his first cosmological views? And such an "insignificant" Kepler is writing a letter to “prominent” Tycho de Brahe and includes his *Mysterium Cosmographicum*. He also hopes, that with this little piece, he will soften Tycho enough that he would want to share his observations with some random teacher from Graz, unknown to him. Tycho de Brahe, a quarter of a century older than Kepler, will show a lot of understanding for the novice who does not see weaknesses in the Copernican system of the world. The authorities of astronomy at that time did not accept Copernicus’ heliocentric theory, because it did not withstand the confrontation with observations. Tycho de Brache himself had his own cosmological concept and to prove it, he undertook a great surveillance action. Brahe concluded that Kepler was like a raving lunatic, but he was a good mathematician and if managed properly he could prove the validity of Tycho’s cosmological conception. This concept he proclaimed was that the Earth is at the center of the Universe. The Moon and the Sun are orbiting around her. Mercury, Venus, Mars, Jupiter and Saturn orbit the Sun.

A few years later, Kepler was already employed by Brahe and had access to desired data. Here again, a strange thing happens. Kepler is officially working on the proof of the correctness of Tycho’s model, but he has no heart for this work. In conspiracy, he makes parallel calculations to prove the correctness of Copernicus’ model. He fell in love with this model when it was first mentioned to him by a lecturer in mathematics at the university in Tübingen. That lecturer, a quiet supporter of the Copernicus theory, was Michael Mästlin, with whom Kepler was friends and corresponded until the end of his life. This intellectual intimacy with his master meant a lot to Kepler. It is good when the mind, working extremely intensively, has someone to honestly exchange views with from time to time. A couple of thinkers can mean more than two separate ones. Such is the higher mathematics. How much more would the Brahe-Kepler pair signify than both of them operating in isolation from each other and what about the over-generational Copernicus-Kepler couple? The ability to match pairs properly means a lot. Even a stone upon a stone means more than two stones separately. The vocation of “couples” means more than two “singles”.

The hardest thing for a thinker is to shake off all sorts of well-established dogmas or stereotypes. Few people come (mentally) to such a degree of development, to have the courage and bravery to openly verify what is "holy", and by definition does not need any verification! There, where the boldness and courage of such people like Copernicus or Galileo, turned out to be powerless in the face of the seriousness of the problem, Kepler was needed. He, who in the name of truth, was able to knock down the highest authorities of human thought, and in a masterly style. How many false authorities are there in the world!

Kepler showed that under the pressure of sound logical thinking, even of a single person, if supported by sound empirical evidence, "Platoes, Aristotleses, Pythagorases, ..." can burst like soap bubbles.

The modern reader may not immediately and fully perceive the importance of Kepler's departure from ideal geometric figures toward the shape of an ellipse, or from ideal numerical proportions towards some not perfect ones. For such a "heretical" ellipse Kepler could have been quickly burned at the stake. If we recognize Gagarin as a hero because risking his life he dared to taste the elliptical orbit, what hero should Kepler be considered, who risked his life, even more, to announce to the world the ellipse as the typical shape of the orbit for heavenly wanderers? When Kepler's youthful idea for perfect Platonic figures explaining the proportions of the distance between the planets and the Sun did not withstand empirical verification, it was time to verify the usual views on the circle as the only correct shape of the road on which celestial bodies could travel. An unprecedented "coup" was being prepared that had no equal in thousands of years. The reason for this was the dogma that everything concerning heaven (the abode of God as the highest ideal) cannot deviate from excellence. Circles, rounds, spheres, and globes were treated as the only geometric figures, which thinkers were allowed to use in their mathematical considerations about what is happening in the sky. An attack on these shapes was in the opinion of the highest authorities of the world equivalent to an attack on God himself. For to admit imperfections in the work of Creation meant surrendering to a doubt about the perfection of the Creator himself. Despite being a deeply religious man, Kepler was able to reconcile his religion with the requirements of reason. He was able to separate what was valuable in the religion from superstitions and fallacies.

Another dogma that Kepler had to refute was the immutability of matters on heaven. This immutability was derived, in ancient times, from apparently unchanging systems of stars (constellations). From this, the idea of eternity was derived and was ascribed to God. The finding that celestial objects can succumb to changes, that, for example, a star may change its glow, arise or disappear, was regarded as heresy. If the wandering stars (planets) stood out from among the fixed stars, it was only because they were meant to be the King of Heaven's means of communication with people on Earth (hence astrology). Complicated movements of planets being watched on the celestial sphere were built on a series of circular motions (deferens, epicycles, second-order epicycles...). And it was also not allowed to violate another important dogma that only uniform (perfect) movements are permitted in the sky. Kepler proved that the movements of planets follow (imperfect) ellipses and with a changing speed along the orbits. You can imagine how much Kepler put himself in danger, wanting to replace the ideal mathematical description of the ideal universe with the mundane, defective, physical description. After all, it was obvious to many that Kepler simply imagined that everything in the Universe is essentially similar to what is happening on Earth and is governed by the same laws of physics. Only someone who was still protected by an umbrella of the Emperor himself could afford to proclaim such "heresies".

It's hard not to ask where Kepler's irresistible belief in the rightness of the Copernican picture of the world came from. Many think Kepler understood *De revolutionibus* in-depth and that was enough. However, understanding alone could have and should have had the opposite effect as it did for Tycho. Original Copernicus's concept was not defensible either at that time or at any time thereafter. [The most opposed to the heliocentric system was the crowning fact that for stars, the annual parallax effect cannot be observed. Discovered in 1728 by James Bradley, the phenomenon of light aberration was the first evidence of the Earth's orbital motion around the Sun. The first parallax of stars was measured only in 1839 (Wilhelm Struve, Friedrich Bessel, Thomas James Henderson). The whirling motion of the Earth as postulated by Copernicus has been proven only in the experiment with the Foucault pendulum in 1851]. The mathematical correctness of Copernicus' theory was therefore nothing like the results of the observations. In addition, there was too great an attachment to the widespread image of the world spinning around the "king of hell" inside the Earth. Why did Kepler succumb so easily and irresistibly (even obsessively) to the provocative and speculative work of Copernicus? Some will say that theological considerations were decisive. Yet Kepler, following Copernicus, wanted a Universe with God at the center. Whether only this? Perhaps some strong intuition took hold of Kepler? Let the psychologists break their heads figuring out what such intuition really is and where it comes from. Is it, for example, any higher form of consciousness achieved through intense, often up repeating, specific thinking on a specific topic? It would not be about "blank" thinking, but thinking in action, in a clash with reality, subject to ongoing empirical verification. When frequently repeating some thought process (deeply experienced) the brain probably undergoes some sort of reorganization and one enters a higher level of initiation, a state of hypersensitivity to falsehood and increased ability to recognize truth. It is very likely that Kepler developed such an intuition about the movements of the planets by having the *Almagest* and *De revolutionibus* studied in-depth. Confrontation of the empirical models took place in Kepler's collision with the first-class observations of Tycho. Anyone who has personally experienced even minor glimpses of such "superconsciousness" in their lives, knows what we are talking about. Most probably Kepler's intuition made him undertake the defense of heliocentrism. It wasn't about the usual rhetoric in the style of Galileo, but about factual research and about irrefutable evidence of the research.

It is amazing that Kepler's memorable and still useful findings were deduced without knowing of any distances between the Sun and the planets. Kepler lived in a universe with a radius of 20,000 Earth radii, which is approximately 0.85 astronomical units. In Kepler's day, the provisions of *Almagens* were still in use. Both Copernicus and Kepler were not in a very comfortable situation having no way to refine the knowledge of the Earth's actual distance from the Sun, and consequently also all other distances of interest to them. It was especially important to know how distant the fixed stars are. It would allow verifying the correct Kepler hypothesis (after Copernicus) that we don't observe the parallactic motions of the fixed stars because the stars are too distant to measure their parallax with instruments allowing us to measure angles in the sky with an accuracy of one arc minute (the pinnacle of astronomical spyhole instruments). Kepler was not idle on the subject of the refinement of the size of the Universe. On the one hand, he tried to use the phenomenon of the transit of Mercury and Venus in front of the Sun to determine the value of the Astronomical Unit. Kepler had promised himself a lot from the Venus transit he had predicted for December 1639. Unfortunately, Kepler did not live to see this phenomenon. On the other hand, Kepler developed a model of an astronomical telescope that was used for measuring the angles in the sky with stunning precision, even more than 100 times in excess of the precision obtained with the help of Tycho's spyholes. Based on the Venus transits, the descendants determined a precise value of astronomical units, and Kepler's telescopes were used to determine the first parallaxes (distances) of fixed stars. It turned out that the closest of these stars are 300,000 times farther than Kepler expected.

One can risk the statement that any sensible practice of the philosophy of nature should necessarily begin with an in-depth study of Kepler's works, who became an extremely important figure not only for the development of astronomy, but also for all of world science and civilization. The vision of the world which Kepler created and developed, is one of the most remarkable in history. It includes items that over time became the common intellectual property of mankind. For example, the laws of planetary motion discovered by Kepler bore fruit hundreds of years later to the advent of the cosmic age and the realization of Kepler's vision, unfolded in his work of *Somnium*, of a man landing on the Moon. All contemporaries, the people of Earth, have a bit of Kepler in them. Even if not in the way of seeing the world and getting involved in understanding it better, at least as consumers of the benefits

Kepler would give a lot for a photo like this! On the other hand, if not for Kepler, perhaps no one in the world today would yet have been able to get such a picture. Kepler predicted the phenomenon of Venus transit in front of the Sun, observing which would allow determining the distance from the Earth to the Sun, and thus to know the actual size of the Solar System (understood in those days as the entire universe). After Jeremiah Horrocks (1618-1641) observed the real Venus transit in 1639, it was necessary to drastically revise views on the subject of the distance of the planets from the Sun. At present, transits of extrasolar planets are observed in the background of their parent stars. The Kepler space telescope mission has resulted in the discovery of many extrasolar planets by the transit method. The photo shows the last transit of Venus (from 2012). [The closest transit of Venus will happen on December 11, 2117, and the one visible in Europe will be on June 11, 2247]. (*Photo by A. Leśniczek and B. Wszołek*)

of civilization obtained on the basis of Kepler's achievements. A true nature researcher is aware that the results of his work may not quickly find understanding or applications. Kepler wrote his works thinking of readers who will live even hundreds of years after him. Once penetrated and brought to the light of knowledge, facts about nature will sooner or later translate into the civilization progress of mankind.

Kepler's philosophical and natural perception of the world is expressed in his numerous scholarly works and correspondences. Nothing can replace studying at the roots, but allow me to give you a sample of the fruit of Kepler's thoughts on nature. I mention them below to arouse the contemplative activity of the reader, especially the one who is planning or already is leading advanced nature research. In addition, I allow myself to, using this occasion, to sneak my own thoughts under which, I hope, Kepler would have signed up.

For Kepler, all nature is an image of the Creator. Contemplating it, going hand in hand with the diligent investigation of its innermost secrets gives a man a chance for a closer acquaintance with the Creator of the Universe. Maybe it is even the only chance. The content of nature requires understanding. This requires the mental work of a man. If a man understands nature better thanks to this work, he will be closer to getting to know his Creator. A mindless life by no means brings a person closer to God. The terms "God" or "Creator" can be cloudy to many contemporaries. Kepler, as a religious and deeply enlightened religious man, most likely understood them at the first approximation as taught by the Church. Nevertheless, he was ready to let go of any dogma if it contradicted the facts of observation or rational arguments. The perfect philosopher of nature does not need to be religious. It even seems that it cannot. Once attending a cosmological conference in Princeton (USA) I was asked by one of its astronomers if I was a believer. Surprised, I had no hesitation in saying that I am. The astronomer was very surprised because he thought that religious faith and natural science excluded each other. Today I regret not pointing him to Kepler as a religious naturalist. After all, he showed emphatically that religiousness, if not blind, is not a critical barrier to cognition.

Kepler preached that nature liked simplicity and unity. Thus, it is easier to be researched. The researcher does not need to use any superhuman tricks to be successful in learning about nature. The fundamental laws of nature can often be summarized in very simple mathematical formulas. Basic laws of nature, discovered in the researcher's local environment also refer to the distant parts of the Universe, far away from the researcher. Conversely, laws discovered by observing distant parts of the Universe are also important locally. For example, the elements that first were discovered on Earth were also found later in the stars. Other elements such as helium were first spotted in the stars and then were found on Earth. The principle of conservation of angular momentum was born into the world by Kepler's Second Law. Gravity, commonly felt on Earth, was included in the mathematical equations only on the basis of observations of planetary movements. Likewise, the problem of the speed at which light travels was solved on the basis of observations of phenomena in the sky. Even the shape and size of the Earth were established based on astronomical observations. Geographical maps, surveying, calendars, time measurements, GPS, come from observing the stars. These are just some examples. The familiar phrase "whatever you bind on Earth will be bound in heaven" [Bible, Matt.18:15-25] should be, in the name of Kepler's "unity" expanded to "whatever you bind in heaven, will be bound on Earth".

Everything in nature is active and necessary. In nature, there are no unnecessary things. Nature is not dead. All nature is active and is subject to constant and harmonious transformations. Thus, the man himself, along with his activity and creativity, is supposed to be in harmony with nature. Humans need nature and nature needs them. I would add here, myself, that everything in nature is over abundandant. This excess secures a lot, including surely, life itself.

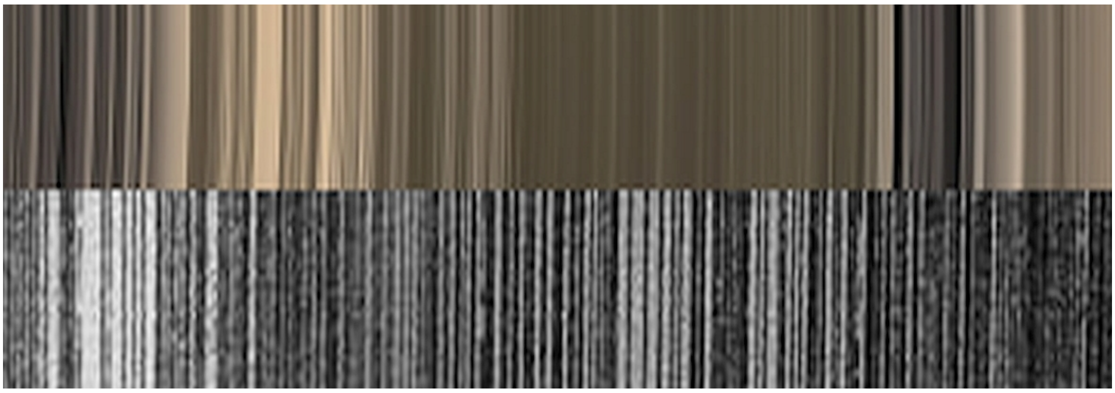
Kepler's Universe is not chaos, nor is it tending to chaos. On the contrary, it functions in a harmonious manner and proceeds towards the higher forms of its own organization. If somewhere in nature harmony is violated, then it recovers back. In this context, it is worth mentioning that modern astrophysicists officially take a different view. They argue that entropy (a measure of disorganization, disorder, chaos) is constantly growing in the Universe. Thus, the Universe is going toward self-annihilation. We would like to know who is right. Kepler allows nature to deviate from the ideal, from being in harmony constantly. Kepler's universe is alive, not petrified. It is, therefore, "more than perfect", because it has the capacity to "regenerate" the diminishing perfection. If Kepler, after Pythagoras, had compared it to a number, it would be not so much 8, but rather 9. According to Kepler, nature, although it adheres obediently to strict fundamental laws, it leaves itself a certain margin of discretion (freedom), which allows it to tune in on an ongoing basis and to correct deviations from the perfect harmony. Were it not for this property of nature, then according to Kepler, for example, the solar system would fall apart very quickly. This margin of discretion is real and does not result from imperfections in measurement methods. A strong illustration of such a margin of discretion is the handlebars of a bicycle. Riding a bicycle with the handlebars locked immediately ends in a fall. The possibility of making small adjustments to the steering wheel while driving allows you to maintain balance and achieve harmony between the rider's and bicycle's movements. N-body systems, according to Kepler, use the postulated margin of discretion for conservation stability. It seems very likely that further advances in physics will not be possible without mathematically framing the physical reality, which Kepler called the margin of discretion. Any mechanic, not only a quantum one, knows what the appropriate clearances in systems of many elements cooperating with each other serve. So, is it possible to have such a margin of discretion, some additional constraint on N bodies systems, use for the needs of mechanics of the sky and quantum mechanics? You can try to compare the movements of the planets around the Sun to a group dance. In a group dance (zorba, cancan, ...) there are more than just movements to the rhythm of the individual dancers. Something is on the attack, something else is on reverse. Collision or falling out of formation is out of the question. Free space made by one is used by the other.

Kepler also perceives that natural processes are realized with minimal effort. In the context of this claim, it is worth recalling an easy experience during modern ski jumping observations. If you sit in the stands so that you can clearly hear the whistling accompanying the flights of jumpers, it can sometimes happen that one of the jumpers is not accompanied by any noise. We can see a jumper in the air and we can hear nothing. It moves noiselessly. A jumper like these fits into the natural environment, so his jump is almost ideal. The process took place with minimal energy loss. Such jumps are on the measure of gold medals and hill records. Kepler looked for harmony in the movements of planets orbiting the Sun, and he sensed that these movements could only take place with minimal effort. And here you can think of an ordinary dance again. It can be wonderfully light if the dancers achieve a complete harmony of movement. Maybe it can also be terribly tiring if this harmony is disturbed.

Kepler spent his whole life wondering why the planets were at specific and not quite random distances from the Sun. *Mysterium Cosmographicum documents* the beginning of these investigations wonderfully. In the second half of the 18th century, Titius and Bode, acting in the spirit of Kepler, noticed an interesting law governing the distances of the planets. At the base of the observed system of distances of planets, according to them, lies the following sequence of numbers:

$$0 \qquad 3 \qquad 6 \qquad 12 \qquad 24 \qquad 48 \qquad 96 \qquad 192$$

After increasing each of these numbers by 4 (according to the algorithm found by Titius and Bode) and after dividing by 10 (transition to modern astronomical units of distance) we get contemporary determinations of the mean distances of planets, with great accuracy. Although the compatibility of the actual average distances of individual planets from the Sun with simple geometric formulas (with Kepler) and arithmetic (with Titius and Bode) is not perfectly exact, they can give much food for thought to contemporary nature researchers. Today we are richer, for example, in elementary knowledge of quantum mechanics, which orders light electrons in atoms to stay at strictly defined distances from the heavy nucleus that can be determined by simple arithmetic rules. Precise determination of the average distances of individual asteroids from the Sun shows that not all distances are equally preferred. Within the asteroid belt, there are zones of avoidance and zones of abundance of these tiny bodies. Quite the same things are presented with bodies within Saturn's ring. Certain distances from Saturn are unacceptable to tiny bodies, and others are in turn allowed and therefore occupied in large numbers. In fact, Saturn's ring is made up of a great number of very narrow concentric rings with virtually empty spaces between them. Is it just pure coincidence that radial slices of very accurate photographs of Saturn's ring, containing lots of black (empty) and white (filled with lumps of matter) lines, are deceptively similar to photos of star spectra? Or perhaps the natural tendency of nature to make processes take place with minimal effort and in harmony with the environment leads to "quantization" of some physical quantities, in this case, distance from the central body?



Saturn's rings (above) and example of stellar spectrum (below).

According to Kepler, scientific achievements are the common heritage of all mankind. The scientist searches for truths about nature not only for himself but most of all for general mankind. His intellectual abilities are shaped based on the existing cultural resources and are to influence the further development of culture. Justice demands that the scientist shares the results of his research with the public free of charge, and society provides him with the necessary conditions for growth. Investigational results of science are a common heritage of mankind, not only in terms of practical applications and profit but also for world peace and for a better understanding of nature. The development of science should be free from economic, political, philosophical, and religious pressure, and scientific achievements should not be traded. How correct are these statements, that we perceive in the present times, which are the most vulnerable precisely because of rejection of these Kepler's postulates!

Kepler noticed that shaping forces in nature act not only because of purpose, but also "for decoration". You can build a house that will perfectly fulfill your primary purpose. However, you can build it at the same time to be beautiful and with its beauty make an influence on the inhabitants and the environment. You can create a man who will not only be fit to fulfill his calling but will also be handsome. Plants could only fulfill their assigned goals, and yet they come in all sorts of beautiful forms, positively influencing the environment with their appearance and smell. A free man, if he lives in harmony with nature, also tries to create beautiful things, not only functional or profitable. Such action gives him the greatest joy. And a man who is busy with work (including mental work), as Yuri Alekseevich Gagarin put it right after his flight into space, is the most beautiful view on Earth.

Kepler said that finding truths about nature takes a lot of effort. The very development of potential research abilities requires from a human an enormous toil. Nature does not oppose knowledge but always requires enormous effort from a researcher before revealing its secrets to him. Voluntarily undertaken research was for Kepler a form of worshiping God – the Creator and King of the Universe.

The philosophy of nature cannot be based on descriptions of natural phenomena but on the causes of these phenomena. Nor can it be based on the Bible or other holy books, because these are not the authority in the field of natural science. Both a nature researcher and a nature philosopher (ideally, he should also be a researcher), if they want to accomplish something significant in their fields, must rely on specific information that comes from experience. Experience is the first and necessary stage on the way to cognition. Meditating on the course and result of the experiment is to provoke a question about the cause of observed phenomena. In search of an answer to such a question, you need to always do serious thought work and often plan new observations and experiments. A true naturalist, following Kepler's example, always asks about the cause of natural phenomena (e.g. what is happening between the Sun and the Earth, that these bodies attract each other?). The pseudo naturalist will stop at cognitive science inquiries at the stage of a simple description of the behavior of bodies (e.g. to Newton it was enough to say that the Moon orbits the Earth as if it was attracting it with a force proportional to the mass of the Earth and the mass of the Moon, and inversely proportional to squared distance between the centers of these bodies). To do physics the Newtonian way, we don't need to know what mass is, what gravity is, or what light is. It would be bad to ask about these things. That's why a naturalist has to act in Keplerian style if he wants to find out something essential about nature. The fact of strange movements of the planets, in comparison with the fixed stars, was known to scientists for thousands of years. Until the time of Kepler, many models were created describing these movements, including the geocentric model given by Ptolemy, the heliocentric model developed by Copernicus, and the geo-heliocentric model by Tycho de Brahe. Kepler asked nature the question: why do planets move just like that and not differently? He did not seek answers from philosophers and in the scriptures. Instead, he started analyzing the observational data and he properly inquired into the deeper essence of planetary movements. Such action resulted in groundbreaking discoveries.

A man, based on reasoning coupled with the experience of the real world is potentially capable of ever deeper and deeper conscious union with nature and creatively influencing its transformations. If somewhere there are already beings more developed than humans, it means that they have overtaken us in terms of quality and the intensity of reasoning. If nature was able to create from herself one Kepler, it is without a doubt capable of creating more. So, let's learn to follow the guides proven in combat.

Kepler firmly believed that one day man would fly to the Moon. Once this happened, some "new wise men" denied that it happened, among those "wise men", there are lots of university professors, politicians, generals, lawyers, doctors, and teachers. We remember, after Einstein, that you had to come up with a symbol of infinity in mathematics, to have something to measure human stupidity. If you don't think, you give full access to any false content which will destroy you from within. This is the world we live in. Therefore "to be or not to be" for the human species depends, as probably never before, on the sober thinking of individual people. Meanwhile, the world more often prefers to throw black balls at Socrates than to recognize that "it is not worth living a mindless life".

What about Kepler's mental heritage? Was it already fully used by posterity? Suppose that when that happens, another bright supernova will appear in the sky. Meanwhile, what remains is to carefully read Kepler's works and to continue, like in a relay, every unfinished run of his thoughts.

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Bogdan Wszołek and Kepler's *Ubi materia, ibi geometria.*

Bogdan Wszołek was born on Sunday, December 30, 1956, although the official registration was dated January 3, 1957. From early childhood, he was very keen about mathematics and biology, and these soon expanded to include physics. By age 18, he dreamed of becoming simultaneously an astronomer and an astronaut. In fact, only his first dream was fulfilled, and he has been a professional astronomer since 1982. His main field of astronomical interest is cosmic dust and its influence on the transparency of the Universe. In addition he has focused on the carriers of the Diffuse Interstellar Bands (DIBs). As an academic teacher at the Jagiellonian University in Kraków, he has supervised dozens of degree diplomas for young astronomers. In 2006 he established a modern digital planetarium in Częstochowa, the first of these in Poland. He has written "Introduction to Astronomy" and co-authored "Astronomy in Geography". Both are in Polish and are meant mainly for university students. He was a founder and editor (2005-2019) of the annual Polish journal, *Częstochowa Astronomical Calendar*, followed by a new astronomical journal, *Annales Astronomiae Novae.* From 2009 onward, Wszołek has been the founding president of the Astronomia Nova

Association {astronomianova.org}, and the organization of his private observatory, Queen Jadwiga Astronomical Observatory in Rzepiennik Biskupi {oajadwiga.pl} began in 1998. Nowadays he is officially retired and devotes his efforts and resources to the further development of his observatory and to the editing of new books. His wife Magdalena, as well as three adult children, support him in this.

Johannes Kepler was clearly one of the greatest astronomers. Anyone who had anything to do with astronomy has heard about Kepler's laws. In our time, knowing that it is gravity that drives planetary motions, it is easy to derive these laws. It is hard even to imagine how Kepler found them without knowing the nature of interactions within our planetary system.

Kepler made his discovery based strictly on observations, measurements, calculations, and independent thinking. Precise data, as far as it was possible, gathered by Tycho de Brahe and himself, followed by thorough analysis, led to the revolutionary notion of elliptical planetary orbits. This idea turned the "ideal" ancient world of the “only perfect circular motions” on its head.

This book consists of a set of articles devoted to Kepler's heritage. It describes Kepler's works in the post-medieval times when the rule was to block any reasoning that disagreed with official church dogmas. We can read here that Kepler set the truth of measurements in first place. Let this way of performing scientific deliberations remain a good lesson for us all.

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