We Do Not Forget Johannes Kepler

B. Wszołek

(invited lecture)

Jan Długosz Academy, Institute of Physics, Al. Armii Krajowej 13/15, 42-200 Częstochowa, Poland
Jagiellonian University Astronomical Observatory, ul. Orla 171, 30-244 Kraków, Poland
bogdan@ajd.czest.pl

Year 2009 was announced as the International Year of Astronomy. This was to mark 400th anniversary of the first astronomical observation through a telescope by Galileo. From the other hand, this year marks 400th anniversary of Astronomia Nova, the famous work of Kepler published in Prague in 1609. Two laws of planetary motions opened human efforts to understand gravitational force; so the overall cosmic space conquest, with its great importance not only for astronomy, was developed thankful to Kepler's work.

This contribution is thought to show the most inspiring ideas of Johannes Kepler, published in Astronomia Nova and in other his books.

Introduction

Four hundred years ago, in spring of 1609, Johannes Kepler published his Astronomia Nova and opened new era in human exploration and understanding the nature. In Astronomia Nova Kepler described the first two of his laws of planetary motion, which were discovered few years earlier, during his careful calculation of the orbit of Mars. He became therefore the founder of celestial mechanics and author of the first "natural laws" in the modern sense; being universal, verifiable and precise [5].

In 1600 Johannes Kepler became Tycho Brahe's assistant in Prague where he had to complete the tables of planetary motions Tycho had begun. He spent much time trying to reconcile Tycho's accurate observations of the planet with a circular orbit, but found (in 1605) that Mars moved instead in an elliptical orbit. Four years earlier (in 1601) Kepler discovered his second law of planetary motion which states that the radius vector joining planet to Sun sweeps out equal areas in equal periods of time. Kepler's idea that the Sun caused planetary motions by a magnetic force led him to the third of his laws, which gives the relationship between the planets average distances from the Sun and their periods of revolution. The third law Kepler discovered on May 15, 1618 and published it in Harmonice mundi in 1619 [6].

Kepler had discovered three laws of planetary motion which are still taught to students in the twenty-first century and it was Kepler's third law, not an apple, which led Isaac Newton to discover the law of gravitation and to give founds for nowadays cosmic space exploration. Three laws of planetary motion are not at all the only Kepler's achievements. He is famous for many fundamental works enabling the development of modern science. Kepler was the first to:

a) investigate the formation of pictures with a pin hole camera,

b) explain the process of vision by refraction within the eye,

c) formulate eyeglass designing for nearsightedness and farsightedness,

d) explain the use of both eyes for depth perception,

e) describe: real, virtual, upright and inverted images and magnification,

f) explain the principles of how a telescope works,

g) discover and describe the properties of total internal reflection,

h) form the basis of integral calculus,

i) explain that the tides are caused by the Moon,

j) try to use stellar parallax caused by the Earth's orbit to measure distance to the stars; the same principle as depth perception,

k) suggest that the Sun rotates about its axis,

l) derive the birth year of Christ, that is now universally accepted,

m) derive logarithms purely based on mathematics, independent of Napier's tables published in 1614.

Moreover, Kepler coined the words "orbit" and "satellite". He discovered two new regular polyhedrals, gave the first mathematical treatment of close packing of equal spheres (leading to an explanation of the shape of the cells of a honeycomb) and calculated the most exact astronomical tables hitherto known, whose continued accuracy did much to establish the truth of heliocentric astronomy (Rudolphine Tables, 1627). The most famous Kepler's works are the following:

1. Mysterium Cosmographicum – 1596,

2. Bericht von einen ungewohnlichen neuen Stern – 1604,

3. Ad Vitellionenen Paralipomena, quibus Astronomiae pars Optica traditur – 1604,

4. De Stella Nova in Pade Serpentarii – 1606,

5. Ausfuhlicher bericht von dem newlich im Monat Septembri und Octobri diss – 1607,

6. Jahrs erschienenen Haarstern oder Cometen, und seinen Bedeutungen – 1608,

7. Astronomia Nova – 1609,

8. Dissertatio cum nuncio sidereo nuper ad mortale misso a Galileo Galilae – 1610,

9. Strena seu de Niva sexangula – 1611,

10. Narratio de observatis quator Jouis satellitubus – 1611,

11. Dioptrice – 1611,

12. Nova stereometria doliorum vinariorum – 1615,

13. Ausszug aus der Uralten messekunat Archimedis – 1616,

14. Efemerides novae Motuum coelestium ab anno vulgaris aerae – 1617,

15. Epitome Astronomiae Copernicanae (Books I, II, III) – 1618,

16. Harmonices Mundi libri V – 1619,

17. Epitome Astronomiae Copernicanae (Book IV) – 1620,

18. Epitome Astronomiae Copernicanae (Books V, VI, VII) – 1621,

19. Pro suo Opere Harmonices Mundi Apologia – 1622,

20. Chulias Logarithmorum – 1624,

21. Tychonis Brahei Dani hyperaspistes adversus Scipionis Clarmontii – 1625,

22. Suplementum Chiliadis Logarithmorum – 1625,

23. Tabulae Rudolphine – 1627,

24. Ephemeridam (Vol. III) – 1630,

25. Somnium seu Opus posthumium de Astronomia Lunari – 1634.

Kepler adopted enthusiastically the Copernican heliocentric theory. In fact, Kepler gave Copernican theory a new, mathematical precision by specifying two fundamental tenets that were consistent with his conviction that the Sun was metaphorically the place of God and the Sun is responsible for all celestial motion.

Like Copernicus, whose work inspired him, Kepler was a deeply religious man. He viewed his continual study of universal properties as a fulfilment of his Christian duty to understand the very universe that God created. But unlike Copernicus, Kepler's life was anything but quiet and lacking in contrast. Always short of money, Kepler often resorted to publishing astrological calendars and horoscopes, which, ironically, gained him some local notoriety when their predictions turned out to be quite accurate. Kepler also suffered the early deaths of several of his children, as well as the indignity of having to defend in court his eccentric mother, who had a reputation for practising witchcraft and was nearly burned at the stake.

The Young Kepler

Kepler was born in 1571 (December 27) in the small town of Weil der Stadt and moved to nearby Leonberg with his parents in 1576. His father was a mercenary soldier and his mother was a daughter of an innkeeper. Johannes was their first child. His father left home for the last time when Johannes was five, and he probably died in the war. Kepler's early education was in a local school and then at a nearby seminary, from which, intending to be ordained, he went on to enroll at University of Tübingen, a bastion of Lutheran orthodoxy. It was usual for all students at the university to attend courses on "mathematics". In principle, this included the four mathematical sciences: arithmetic, geometry, astronomy and music. At Tübingen Kepler was taught astronomy by one of the leading astronomers of the day, Michael Mästlin (1550 − 1631). The astronomy of the curriculum was, of course, geocentric astronomy, that is the current version of the Ptolemaic system. At Tübingen, Kepler studied not only mathematics but also Greek and Hebrew. Teaching was in Latin. Kepler was one of the selected pupils to whom Mästlin chose to teach more advanced astronomy by introducing them to heliocentric cosmological system of Copernicus. Kepler established himself in Tübingen as a serious student of mathematics and astronomy, and became an advocate of the controversial Copernican heliocentric theory. He seems to have accepted almost instantly that the Copernican system was physically true.

Kepler's religious beliefs were not entirely in accord with the orthodox Lutheranism current in Tübingen. His problems with this Protestant orthodoxy concerned the supposed relation between matter and "spirit" in the doctrine of the Eucharist. This is probably a reason why Mästlin persuaded Kepler to abandon plans for ordination and instead take up a post teaching mathematics in Graz.

The Great Discovery

One day, while lecturing on geometry in Graz, Kepler experienced a sudden revelation that changed the course of his life. It was, he felt, the secret key to understanding the Universe. On the blackboard, in front of the class, he drew an equilateral triangle within a circle, and another circle drawn within the triangle. It occurred to him that the ratio of the circles was indicative of the ratio of the orbits of Saturn and Jupiter. Inspired by this revelation, he assumed that all six planets known at the time were arranged around the Sun in such a way that the geometric figures would fit perfectly between them. Initially he tested this hypothesis without success, using two-dimensional plane figures such as the pentagon, the square, and the triangle. Then he returned to the Pythagorean solids, used by the ancient Greeks, who discovered that only five solids could be constructed from regular geometric figures. To Kepler, this explained why there could only be six planets (Mercury, Venus, Earth, Mars, Jupiter, and Saturn) with five spaces between them, and why these spaces were not uniform. This geometric theory regarding planetary orbits and distances inspired Kepler to write Mystery of the Cosmos (Mysterium Cosmographicum), published in 1596. Kepler wrote:

"And how intense was my pleasure from this discovery can never be expressed in words. I no longer regretted the time wasted. Day and night I was consumed by the computing, to see whether this idea would agree with the Copernican orbits, or if joy would be carried away by the wind. Within a few days everything worked, and I watched as one body after another fit precisely into place among the planets".

Kepler saw his cosmological model as providing evidence for the Copernican theory. However, the agreement of Kepler's model with values deduced from observation was not exact, and he hoped that better observations would improve the agreement. He sent a copy of the Mysterium cosmographicum to one of the foremost observational astronomers of the time, Tycho Brahe. Few years later Kepler was working in Prague as an assistant of Tycho.

Kepler in Prague

Tycho's priorities were not the same as Kepler's, and Kepler soon found himself working on the intractable problem of the orbit of Mars. He continued to work on this after Tycho died (in 1601) and Kepler succeeded him as Imperial Mathematician. Conventionally, orbits were compounded of circles, and rather few observational values were required to fix the relative radii and positions of the circles. Tycho had made a huge number of observations and Kepler was determined to make the best possible use of them. Essentially, he had so many observations available that once he had constructed a possible orbit he was able to check it against further observations until satisfactory agreement was reached. Kepler concluded that a line joining the planet to the Sun swept out equal areas in equal periods of time as the planet described its orbit and that the orbit of Mars was an ellipse with the Sun in one of its foci. After this work was published in Astronomia Nova Kepler found orbits for the other planets, thus establishing that the two laws held for them too. Both laws relate the motion of the planet to the Sun; Kepler's Copernicanism was crucial to his reasoning and to his deductions.

The actual process of calculation for Mars was immensely laborious. There are nearly a thousand surviving folio sheets of arithmetic, and Kepler himself refers to this work as *"my war with Mars"* [1]. However, the result was an orbit, which agrees with modern results so exactly that the comparison has to make allowance for secular changes in the orbit since Kepler's time.

The work on Mars was essentially completed by 1605, but there were delays in getting the book published. Meanwhile, in response to concerns about the different apparent diameter of the Moon when observed directly and when observed using a camera obscura, Kepler did some work on optics, and came up with the first correct mathematical theory of the camera obscura and the first correct explanation of working of the human eye, with an upside-down picture formed on the retina. These results were published in Ad Vitellionem paralipomena, quibus astronomiae pars optica traditur, on the optical part of astronomy (Frankfurt, 1604).

He also wrote about the New Star of 1604, now usually called "Kepler's supernova", rejecting numerous explanations, and remarking at one point that of course this star could just be a special creation *"but before we come to that I think we should try everything else* (De stella nova, Prague, 1606). Following Galileo's use of the telescope in discovering the moons of Jupiter, published in his Sidereal Messenger (Venice, 1610), to which Kepler had written an enthusiastic reply (1610), Kepler wrote a study of the properties of lenses (the first such work on optics) in which he presented a new design of telescope, using two convex lenses (Dioptrice, Prague, 1611). This design, in which the final image is inverted, was so successful that it is now usually known not as a Keplerian telescope but simply as the astronomical telescope.

Kepler's years in Prague were relatively peaceful, and scientifically extremely productive. In fact, even when things went badly, he seems never to have allowed external circumstances to prevent him from getting on with his work. Things began to go very badly in late 1611. First, his seven year old son died. Then Kepler's wife died. Then the Emperor Rudolf was forced to abdicate in favour of his brother Matthias, who did not believe in tolerance of Protestants. Kepler had to leave Prague. He and his remaining children moved to Linz.

In Linz

Kepler noticed that the volumes of wine barrels were estimated by means of a rod slipped in diagonally through the bung-hole, and he began to wonder how that could work and he studied the volumes of solids of revolution (Nova stereometria doliorum ..., Linz, 1615) in which Kepler, basing himself on the work of Archimedes, used a resolution into "indivisibles". This method was later developed by Bonaventura Cavalieri (c. 1598 - 1647) and is part of the ancestry of the infinitesimal calculus.

Kepler's main task as Imperial Mathematician was to write astronomical tables, based on Tycho's observations, but what he really wanted to do was to write "The Harmony of the World", planned since 1599 as a development of his "Mystery of the Cosmos". This second work on cosmology (Harmonices mundi libri V, Linz, 1619) presents a more elaborate mathematical model than the earlier one. The mathematics in this work includes the first systematic treatment of tessellations, a proof that there are only thirteen convex uniform polyhedra (the Archimedean solids) and the first account of two non-convex regular polyhedra (all in Book 2). It also contains what is now known as "Kepler's Third Law". In fact, although the Third Law plays an important role in some of the final sections of the printed version of "The Harmony of the World", it was not actually discovered until the work was in press. Kepler made last-minute revisions. He himself tells the story of the eventual success: *"...and if you want the exact moment in time, it was conceived mentally on 8th March in this year one thousand six hundred and eighteen, but submitted to calculation in an unlucky way, and therefore rejected as false, and finally returning on the 15th of May and adopting a new line of*

attack, stormed the darkness of my mind. So strong was the support from the combination of my labour of seventeen years on the observations of Brahe and the present study, which conspired together, that at first I believed I was dreaming, and assuming my conclusion among my basic premises. But it is absolutely certain and exact that the ratio which exists between the periodic times of any two planets is precisely the ratio of the 3/2-th power of the mean distances from the Sun." (Harmonice mundi, Book 5, Chapter 3, point VIII) [2].

The Last Years

In 1628 Kepler eventually settled in the town of Sagan, in Silesia (Poland, not far from Zielona Góra). In Sagan he founded his own printing house and he wrote his famous Somnium (published after Kepler's death in 1634), generally treated as the first real science fiction novel. Somnium features an interview with a knowing "demon" who explains how the protagonist could travel to the moon. Kepler spent considerable energy defending the work as pure fiction and the demon as a mere literally device. The book was unique in that it was not only ahead of its time in terms of fantasy but also a treatise supporting Copernican theory [3].

In 1630, at the age of fifty-nine, Kepler once again found himself in financial straits. He set out for Regensburg, where he hoped to collect interest on some bonds in his possession as well as some money he was owed. However, a few days after his arrival he developed a fever and died on November 15. He was buried in the local church, but this was destroyed in the course of the Thirty Years' War and nothing remains of the tomb.

Though he never achieved the mass renown of Galileo, Kepler produced a body of work that was extraordinary useful to professional astronomers, like Newton, who immersed themselves in the details and accuracy of Kepler's science. Johannes Kepler was a man who preferred aesthetic harmony and order, and all that he discovered was inextricably linked with his vision of God. His epitaph, which he himself composed, reads: *"I used to measure the heavens; now I shall measure the shadows of the earth. Although my soul was from heaven, the shadow of my body lies here.*"

Kepler's Philosophy of Nature

Throughout his life, Kepler was a profoundly religious man. All his writings contain numerous references to God, and he saw his work as a fulfilment of his Christian duty to understand the works of God. Man being, as Kepler believed, made in the image of God, was clearly capable of understanding the Universe that He had created. Moreover, Kepler was convinced that God had made the Universe according to a mathematical plan. Since some authors have given Kepler a name for irrationality, it is worth noting that this rather hopeful epistemology is very far indeed from the mystic's conviction that things can only be understood in an imprecise way that relies upon insights that are not subject to reason. Kepler does indeed repeatedly thank God for granting him insights, but the insights are presented as rational. Kepler was a Christian Natural Philosopher, for whom understanding the nature of the Universe included understanding the nature of its Creator.

Kepler treated the nature as the second book of divine origin, in a metaphoric manner, beside the Holy Scripture. This second book is opened by the new science. According to Kepler's idea, its letters turn into stars, its words into cosmic structures, and its meaning becomes clearer by geometry. Nature is an image of God. Therefore, the Universe can only be seen as perfect. This perfection appears as qualities of light, warmth, motion and harmony, being effective by analogy with spiritual faculties, namely light with sensitivity, warmth with vitality, motion with the animal faculty and harmony with the rational faculty. For Kepler, the living nature is filled with mental qualities, as he does already explain in his Mysterium cosmographicum: *"Nature likes simplicity, it likes unity. Nothing of it is ever inactive or unnecessary*" [?]. Kepler conceived of nature as having an inherent gap; nature has some degree of freedom, some fuzziness, which no mathematics can determine. To be positioned in the solar system, a planet must be prescribed a solid figure, but this is not enough, for to move harmoniously it would require some freedom. Error, therefore, may occur not only because of miscalculation and instrumental limitations, but also because of the inherent Spiel in nature. In the Keplerian position there is another source of error to be taken into consideration, a source which may not be accounted for by mathematics and physics, but by the inherent degree of freedom which nature possesses that no mathematics can determine.

In his scientific researches both empirically and speculatively, he looked into the universal principles of the structure and the design of nature. These investigations directed Kepler to his Harmonice Mundi with the comprehensive idea of the harmony of the Universe.

Corresponding with the religious idea of the essence of nature as image of God, Kepler developed a comprehensive spiritual principle. By causing the effects of things on each other and their coherence, this principle is interpreted as a reviving force which runs through the whole nature. The idea that all the parts of nature are animated was evident for Kepler. Therefore such a spiritual faculty is also effective in the whole Earth up to its innermost part. Therefore the Earth is to treated with care as all the creation and not be exploited to the point of ecological exhaustion.

Another element in Kepler's philosophy of nature, combined with the idea of the spiritual principle, is the conception of essence of light. For the fundamental explanations of essence and origin of light are based again in his doctrine of spirits. For Kepler, the soul is incorporeal and invisible; insofar its nature must be akin to light and warmth. If the soul breathes life into a being, it happens in connection with light and warmth. Therefore light is a scion of the soul. It is not an isolated physical phenomenon, but an organic component of the whole creation. Light has two essentials: substance and quantity. Substance is that moment by which it becomes light. It is arranged by origin according to the image of the creator by spreading spherically to all directions. The sphere as image of the Holy Trinity is presumed as archetype of light as well. Lighting originates from emanating light hitting a solid. By a longer distance, light reduces its intensity equal to the reversal of the surface of the corresponding sphere, but is not reduced by radius. So the density of light or its brightness decreases with square of the distance. This is the fundamental law of photometry which Kepler represents here.

The second essential is the quantity of light. In the local motion it is either reflected by an object or refracted or scattered by passing through a medium. Spreading out the light in a straight line corresponds with a principle of nature that light looks for the shortest way. Generally speaking nature realizes its possibilities by the smallest effort.

For Kepler, science is a part of the common heritage of the whole mankind, not only in its useful application for the common benefit but also in serving the human understanding and peace. Following Plato's idea that science and philosophy are also means for moral purging, Kepler is convinced about the ethical authority of science. The investigations of nature promote the peaceful conduct of the human beings. Corresponding to his world view Kepler was convinced that the recognition of the laws of nature should serve the whole mankind and *"astronomers are priests of the Highest God with respect to the Book of Nature"*. This attitude seems to be the quintessence of his ethics of science.

In Memory of Johannes Kepler

In March 2009 NASA lunched space telescope Kepler, the first mission capable of finding Earth-size and smaller planets. The challenge is to find terrestrial planets (i.e., those one half to twice the size of the Earth), especially those in the habitable zone of their stars where liquid water and possibly life might exist. The Kepler Mission is specifically designed to survey our region of the Milky Way galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone and determine how many of the billions of stars in our galaxy have such planets. Results from this mission will allow us to place our solar system within the continuum of planetary systems in the Galaxy.

References

[1] Kepler J., 'Neue Astronomie' (übersetzt und eingeleitet von Max Caspar), Verlag R. Oldenbourg, München-Berlin (1929)

[2] Kepler J., 'Harmonies of the World – Book Five' (Edited, with Commentary, by Stephen Hawking), Running Press, Philadelphia-London (2002)

[3] Kepler J., 'Sen (Somnium)', Wydawnictwo Naukowe Scholar, Warszawa (2004)

[4] Kepler J., 'Noworoczny Podarek', Wyd. Uniw. Warszawskiego, Warszawa (2006)

[5] Kierul J., 'Kepler', Panstwowy Instytut Wydawniczy, Warszawa (2007)

[6] Koestler A., 'Lunatycy', Zysk i S-ka, Poznań (2002)