A Companion to „From Copernicus to Newton"

Slides 2-3.

The invention of printing from movable cast by Gutenberg started a revolution in the dissemination of science and learning. Massive production of printed books made them available to large part of society and not only to the very richest citizens.

Slides 4-25.

Nicolaus Copernicus received education in liberal arts from the Cracow Academy which was regarded to be one of the best universities in Europe at that time (Slide 5). Later he traveled to Italy and studied canon law and medicine. After return to Poland he made his living as a civil administrator of the Catholic Church property in Ermland (Polish: Warmia). He was interested in astronomy since his youth but could pursue astronomical studies only in the time free from other duties.

The earliest version of his revolutionary hypothesis appeared in a short treatise *Commentariolus* which has circulated in handwritten copies since 1514. Copernicus was proud to announce there that by adopting seven postulates (Slide 7) he was able to reduce to 34 the number of circles needed to explain the movements of planets (Slide 8).

Copernicus' great work *De revolutionibus* (*On the revolutions*) was published in 1543 in Nuremberg under the title *De revolutionibus orbium coelestium* (*On the revolution of celestial spheres*). The change in the title was introduced without Copernicus' knowledge by the editor Osiander who thought that it would make the readers believe that it was just another book on celestial spheres, a notion well known since Antiquity.

Slide 12.

It is very important to remember that **Copernicus' system was not heliocentric** (as often wrongly presented) but **heliostatic - with the Sun at rest,** whereas the centres of planetary orbits were located in various points close to the Sun but not at its centre.

Copernicus firmly believed in the Plato's principle that the celestial bodies must move uniformly and follow simple circles or combination of cirles. His arguments are presented in Slides 13-18. The fragments given there have been taken from Book 1 of *De revolutionibus* written in a popular form. The remaining five books of Copernicus' great work are highly mathematical (geometrical) and could be understood only by people well trained in geometry (Slide 21).

By rejecting geocentric system Copernicus was able, nevertheless, to provide better measurements of distances within the solar system (Slide 20), and explain the origin of planetary loops (Slide 22). The very important fragment of *De revolutionibus* is the hypothesis of multiple centres of gravity (Slides 23 and 24). It contradicted directly Aristotle's explanation of gravity.

Slides 26-30.

Danish scholar Tycho Brahe, the last important astronomer in the pre-telescopic era possessed the two largest observatories in the world (Slide 27), as well as the largest and most precise instruments (Slide 28) to determine positions of the planets to a small fraction of a degree (probably ca. 4 minutes of arc). In 1572 he observed a nova star in the constellation of Cassiopeia (Slide 30, lower left picture) and by measuring its parallax gave the proof that its distance from the Earth was at least six times larger than that of the moon, that it thus appeared in the supralunar sphere which according to Aristotle could never change.

In 1577 Tycho observed a great comet and determined (Slide 29) that it also was moving beyond the sphere of the Moon. This contradicted Aristotle's statement that comets are just vapours in our atmosphere.

Tycho highly valued Copernicus' reformatory concepts but decided that „the Earth is too heavy to be a planet". Thus he adopted a mixed system (Slide 30, lower right picture) in which the five planets (Mercury, Venus, Mars, Jupiter, and Saturn) were spinning around the Sun, while the Sun and Moon revolved around the Earth. His system included comets as celestial bodies.

Slides 31-51.

Johannes Kepler studied at the university of Tübingen and excelled in mathematics. He was first employed as a teacher in a high school in Graz. In 1596 he published a small booklet *Mysterium cosmographicum* (Slide 32) in which he tried to explain the structure of the solar system by making use of the five regular Platonic solids (Slide 33) to reproduce the order and relative distances of six planets, including the Earth (Slides 34 and 35). The booklet was noticed by astronomers. Tycho Brahe asked Kepler to join him in Prague at the court of emperor Rudolf II and become his assistant. Kepler agreed but soon after his arrival to Prague Tycho died. Kepler was left with a rich collection of astronomical measurements. He spent 12 years in Prague as the Imperial Mathematician and tried to construct a better system of the world (Slides 36 and 37). After many unsuccessful attempts to fit Tycho's measurements to the system of circular orbits he finally abandoned Plato's principle, and introduced elliptical orbits (Slide 38).

His great book *Astronomia nova* (*New astronomy*) published in 1609 was not just another treatise on calculations of celestial orbits (Slide 39). For the first time in history Kepler asked for the causes of planetary motions and that's why he used the expression *physica coelestis* (celestial physics). At that time people often used the terms „planet" and „star" interchangeably, so you should not be surprised that Mars was called a star.

Kepler was very close to the idea of universal gravitation (Slides 40 and 41). He did not believe that a mathematical point could be a centre of a planetary orbit (as was the case in the Copernican system). He was convinced instead that the cause of motion must always be located in a material body.

After several years of trials Kepler finally found the two laws of planetary movements. The first law states that planets move in elliptical orbits which have the Sun in one of the focuses. The second law is illustrated in Slide 42.

Contemporary astronomers rejected Kepler's ideas as being absurd and not belonging to astronomy which should remain the science of calculating orbits and not searching for their causes (Slides 41-45).

The third law of planetary motion (Slide 49) was announced by Kepler in 1619 in the book *Harmonices mundi* (*The harmony of the world*). Kepler's style of writing was quite confusing as you may see in Slides 47 and 48. In his search for harmony in the world he tried to represent nonuniform speed of planets in their orbits as sequences of sounds in a musical scale (Slide 50).

Having read Gilbert's treatise on magnetism (Slides 57-61) Kepler became convinced that the Sun is a great magnet (having one pole at its centre and the other one everywhere on its surface) and emits its magnetic virtue in much the same way as it emits light. The Sun rotates around its axis and so these magnetic rays push the planets in their orbits. Kepler provided a diagram (Slide 51) showing how the orientation of the magnetic poles of a planet revolving around the Sun explained both the orbital path and orbital speed. As a planet revolves anti-clockwise about the Sun its two magnetic poles retain the same orientation with respect to the orbit. At points A and E the are equidistant from the Sun and the planet has no tendency to approach or recede from it. As the planet goes from A to C the attractive pole pole is nearer the Sun, and so the planet tends towards it; as it goes from E to G the repelling pole is nearer the Sun and hence the planet tends to recede. That, according to Kepler, explained the elliptical shape of the orbit.

Slides 52-61.

Modern studies of magnetism. The treatise by Petrus Peregrinus was printed in 1558. One of the earliest scholars to perform experiments with magnets was an Italian Giambattista della Porta who described his results in one of the chapters of his famous and highly popular book *Magia maturalis* (*Natural magic*) which was translated into several languages and went through many editions. Porta no longer simply repeated ancient fables concerning magnetism but tried to check them by experiments. Slides 55 and 56 show an amusing example taken from his book.

William Gilbert, an English physician and scholar wrote the first modern treatise on magnetism *De magnete* (*On the magnet*) published in London in 1600. One chapter in this book contained Gilbert's studies of electricity - we shall deal with it later. *De magnete* gives an account of numerous experiments. Gilbert experimented with the spherical magnet which he called *terrella* (small Earth). He introduced a novel notion of the sphere of magnetic influence (*Orbis virtutis*) - see Slides 59 and 60. Gilbert's experimental procedure was quite modern: he secured witnesses and repeated experiments several times to make sure that there was no mistake (Slide 61).

Slides 62-107.

Galileo Galilei is generally regarded to be the originator of modern physics. He also started a revolution in astronomy. He did not invent the telescope himself but constructed it in July 1609 after hearing about its use in Flanders (Slides 63 and 64). When he decided to use it to study celestial bodies he was overwhelmed by what he saw: the mountains on the Moon, the satellites of Jupiter, the star clusters, and the Milky Way composed of a multitude of stars.

Galileo swiftly wrote a small booklet *Sidereus nuncius* which was published in Venice on March 12, 1610. It was sold out immediately so that another edition appeared in Frankfurt the same year (Slides 65 and 66). Galileo included some of his drawings of the lunar surface (Slide 67), explained his method of estimating the height of lunar mountains (Slide 68), and provided drawings of some star clusters (Slide 69). The discovery of the four satellites of Jupiter is described in Slides 70-72.

The impact of Galileo's *Sidereus nuncius* was enormous. A good example is provided by an original text of a letter from the British ambassador to Venice to the king of England (Slide 73). Please notice the differences in spelling compared with the modern English. Galileo instantly became the most famous scientist of the world but he was also ridiculed by the old guard (Slide 76) and made many important enemies who later contributed to his accusation and trial.

Galileo was firm supporter of Copernican system. The satellites of Jupiter provided another example (Slide 80) of a multicentre gravitation proposed by Copernicus (Slide 23).

In his numerous books (Slides 77 and 79) such as e.g. *Istoria e dimostrazioni intorno alle macchie solari* (1613), *Il Saggiatore* (1623) and *Dialogo* (1632) Galileo propagated the Copernican system and he did it in a simple Italian language accessible to all people, not only to skilled mathematicians. It prompted the Church to act and condemn the Copernican system as contrary to the Bible which clearly presented the Earth as the centre of the world (Slides 81-83).

The chronology of Galileo's trial is summarized in Slide 81. Slides 84-90 contain excerpts from the sentence in the trial. Galileo was treated as a heretic and he saved his life by the forced retraction of his Copernican views. He was sentenced to remain under house arrest to the end of his life.

The story of Galileo's trial is very depressing. It must have been extremely painful for the great scientist to be in the hands of intellectually inferior but very powerful men. It resulted in the split between science and religion which is growing ever since. Only in 1992 pope John Paul II publicly rehabilitated Galileo and admitted that he had been unjustly treated by the Inquisition.

New documents discovered in recent years in the Vatican archives by Pietro Redondi (Slides 92-95) seem to show that there could have been a hidden part in the trial of Galileo and that the real cause of his trial and imprisonment were his atomistic views (Slide 96). The Church had been fiercely fighting atomism (Slides 97 and 98) because it contradicted the dogma of Eucharist accepted by the Trident Council.

In spite of being old and increasingly ailing Galileo bravely endured house arrest. He wrote another great book in which he described his physics studies and results. The text of that work was smuggled to Holland, beyond the reach of Inquisition, and published in 1638 in Leyden (Slide 100).

One finds there among other topics a very intelligent argumentation against the Aristotelian views on motion (Slides 102-104) as well as information concerning Galileo's experimental procedure which led him to the discovery of the law of free fall (Slides 105 and 106). Other topics treated in the *Discorsi* include resistance of bodies, speed of light, relativity of motion, isochronism of pendulum and the principle of inertia (incorrect - because discussed only with regard to the curved surface of the Earth).

It must be added that both the *Dialogo* and the *Discorsi* are regarded as the masterpieces of Italian literature.

Slides 108-109.

Simon Stevin, a Flemish scholar, lived and worked during a similar period as Galileo but he decided to publish his books in Flemish so that his impressive discoveries and results in mechanics and hydrodynamics became known only later. Stevin is to be remembered because in the book *Thiende* he introduced decimal fractions.

Slides 110-115

French philosopher and scholar René Descartes made important contributions to mechanics and optics. Frightened by the trial and condemnation of Galileo he decided to work and publish in liberal Holland, beyond the reach of the Inquisition. His famous *Discours de la méthode* (*Discourse on the method,* Leyden 1638) summarized the inductive method of research. It included three additional books: *La dioptrique, Les meteors and La geometrie.* The first two will be treated later in „Optics from Kepler to Newton". The third one was a treatise of analytical geometry of which Descartes was a co-inventor.

Descartes' *Principia philosophiae* (*Principles of philosophy*) published in Amsterdam in 1644 contain his most important results in mechanics. He gave a very clear statement of the principle of inertia (Slides 112 and 113) that every „isolated body remains in its state, at rest or in rectilinear motion".

It follows that bodies in circular motion always tend to recede from the centre (Slide 114). To explain while nevertheless the planets remain contained in their orbits and not escape to infinity Descartes invented a picture of the universe filled with invisible subtle matter which rotates in separate vortices (Slide 115) similar to those that could be observed in our rivers. The rotation of these vortices exerts a pressure on contained bodies and counteracts their tendency to recede from the centre. Descartes proposed a similar mechanism to explain magnetic attraction.

Thus, for the first time since Aristotle, Descartes presented a unified description of physics in the whole universe, sublunar and supralunar spheres combined. It was an extremely important step in the development of physical sciences.

Slides 116-122 present a summary of the evolution of our views on orbital motion since Aristotle to Robert Hooke.

Hooke was the first who properly understood and described orbital mechanics and published it in 1670. He was an ingenious experimenter but lacked mathematical skill to present his ideas in the strict mathematical language. It had to wait until Isaac Newton.

Slide 128 gives examples of anagrams which several scientists used to secure the priority of a discovery or invention until it could be published in a book. Anagrams went out of fashion with publication of the first scientific periodicals (Slide 129) which allowed fast publication of articles. Paper was still quite expensive at that time so that the first periodicals were quite small; for example the weekly „Le Journal des sçavants" of 12,5 x 7,5 cm had similar size as todays small smartphones.

Another important step in the history of science was the formation of scientific academies (Slide 129) which became centres of progress and new ideas. The universities at that time remained very conservative.