Dawn of Science

14. The Galilean World

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What was remarkable about the most misunderstood medieval scientist's discoveries was the way he arrived at them – by direct observation.

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Resonance, Vol.15: p.498, p.590, p.684, p.774, p.870, p.1009, p.1062. Vol.16: p.6, p.110, p.274, p.304, p.446, p.582.

Almost around the time when Kepler was perfecting the laws of planetary motion, another man was laying the foundations of theoretical mechanics. This was Galileo Galilei (1564–1642)[1] – probably the most misunderstood of all medieval scientists. Contrary to popular belief, he did not invent the telescope or the thermometer or the pendulum clock; nor did he discover sunspots; and he never threw weights down from the tower of Pisa nor was he tortured by the inquisition. All these and more are attributed to Galileo from time to time because of historical convenience.

Galileo was born on 15 February 1564 in Pisa, Italy. His father wanted him to do medicine – mainly because doctors used to earn considerably more than mathematicians even in those days. An accidental exposure to a lecture in geometry made Galileo turn to mathematics and later to physics. His first invention was a hydrostatic balance about which he wrote an essay in 1586. This contribution followed by a treatise on the centre of gravity of solids (published in 1589) won for Galileo the acclaim of Italian scholars, the sponsorship of the Duke of Tuscany, Ferdinand de Medici and, finally, the position of mathematics lecturer at the University of Pisa. Soon, in 1592, he became the professor of mathematics at the University of Padua where he remained for another 18 years.

[1] See *Resonance*, Vol.6, No.8, 2001.

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It was probably during this time that Galileo made his most fundamental contributions to mechanics regarding the nature and cause of motion (though he published these results much later).

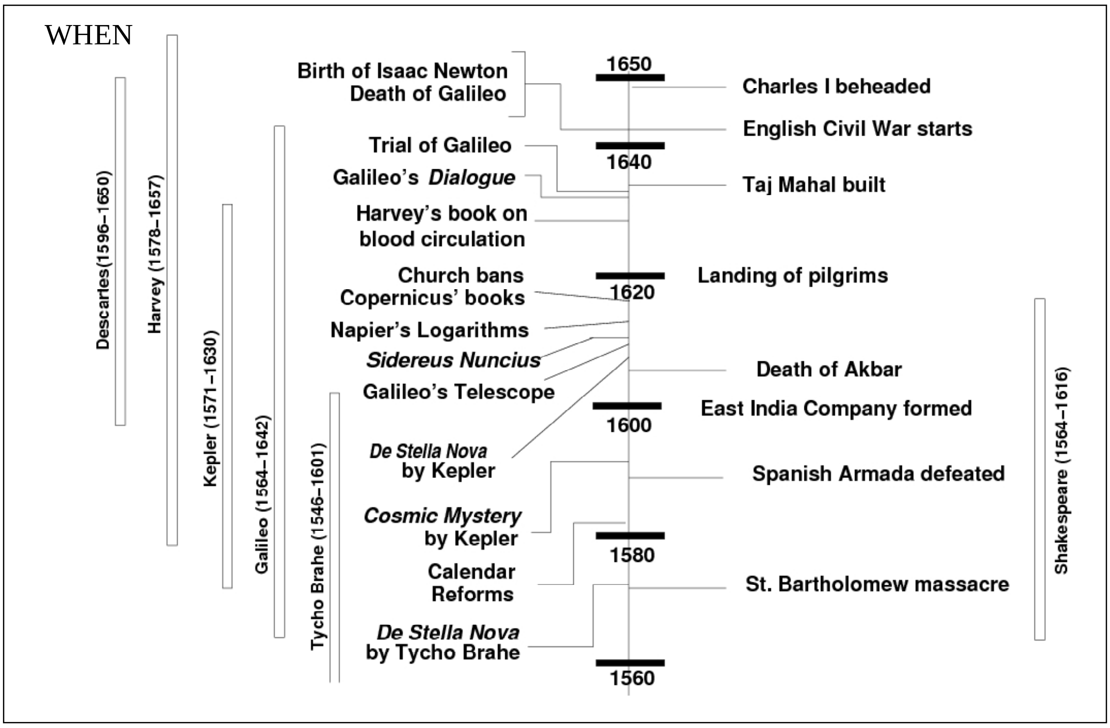

Figure 1.

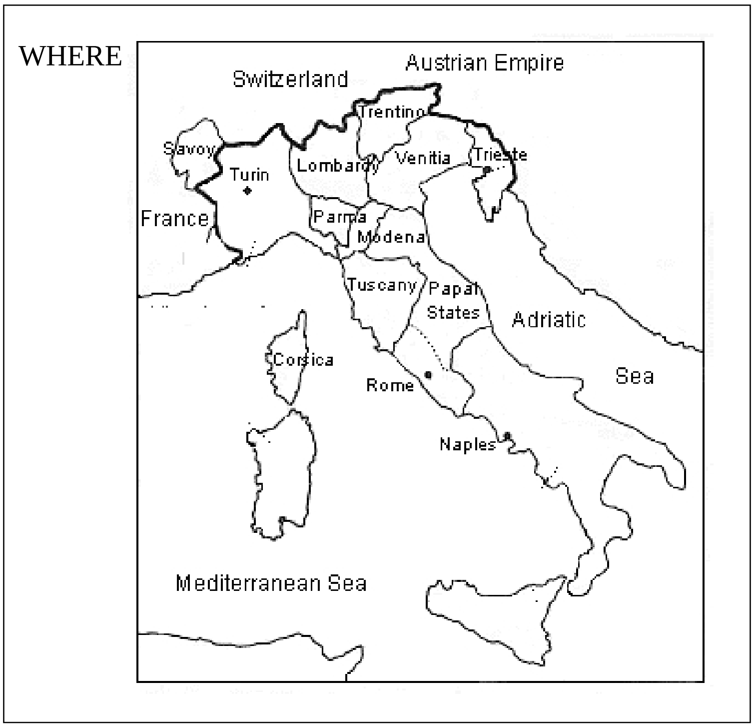

Figure 2.

Till then the ideas that prevailed about the motion of bodies were those of Aristotle. According to these doctrines, some force was necessary to keep a body in motion even at uniform speed. (Adherents of Aristotle used to argue that an arrow shot from a bow moves only because the air behind the arrow pushes it.) It was also believed that a body dropped from some height would fall with a steady velocity, that is, it will cover equal distances in equal periods of time. This speed was supposed to be larger for heavier bodies, making heavier bodies fall quicker than lighter ones.

Figure 3. Galileo.

Galileo's investigations proved all these to be incorrect. He realised that a body falling from a height acquires increasingly greater speeds as it drops. In fact, the distance it covers increases as the square of the time in flight. (If the body has travelled five metres in the first one second of its flight, it would have travelled 20 metres by the end of two seconds rather than ten metres.)

What was most remarkable about Galileo's discovery was the way he arrived at it. He decided that the proper way to settle such a question was by direct observation! This was quite difficult to achieve in those days because accurate time-keeping instruments were not available. Galileo bypassed this problem by making bodies roll down a gently inclined plane rather than drop them vertically. The inclined plane slowed down the bodies considerably and Galileo could time them using his pulse. (Curiously enough, Galileo did know that a swinging pendulum is an instrument, which maintains good periodicity. Somehow it never occurred to him to design a clock using the pendulum.) Galileo also realised that all bodies would fall to the ground from a height in equal time, if air resistance was ignored.

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The fact that a steady force acting on a body increases its speed continuously, raises a question: is it at all necessary to have a force acting on a body to keep it moving at constant speed? Galileo thought – quite correctly – that motion in constant speed required no external agency. This principle – now known as the principle of inertia – played a crucial role in the later develop-

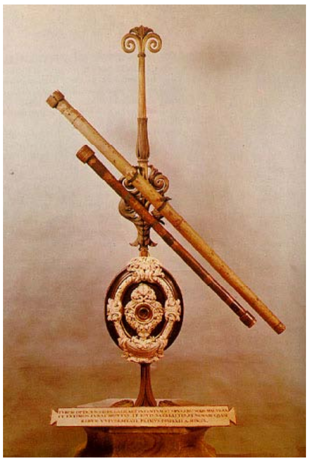

Figure 4. The telescope that Galileo designed and built.
Courtesy: http://rockdalerm1.wordpress.com/2009/12

ments of dynamics and the theory of relativity. Galileo also used this principle effectively in calculating the trajectories of projectiles thrown from the ground.

Yet, Galileo did not rise to prominence for these studies but for a very different reason. Around 1608, a spectacle-maker in Holland, Johann Lippershay, had invented an optical tube containing two lenses, which could make distant objects appear closer. Lippershay sold several of these models in the cities of Europe, and Galileo came to know of this invention in the spring of 1609. Galileo could easily make for himself a telescope with a magnifying power of about 30 and he turned the new invention towards the sky (*Figure* 4). Thus began the age of telescopic astronomy.

Using his telescope, Galileo discovered several aspects of nature, which were until then hidden from the human eye. He found that the Moon had mountains and the Sun had dark spots, once again showing Aristotle to be wrong in assuming that only the Earth had irregularities and distortions. (To be sure, there were other astronomers who were exploring the skies with the telescope at the same time; the first reports on observations of sunspots, for example, came from Father Scheiner, a Jesuit astronomer. Galileo entered into a long and bitter controversy over priorities in these discoveries thereby making powerful enemies.) The stars and the planets appeared very different through the telescope and Galileo could see many more stars than were visible to the naked eye.

All this made him conclude that stars were much farther away than the planets. More dramatically, Galileo found that Jupiter was attended by four subsidiary objects, which circled it regularly, and, within a few weeks of observation, he could work out the periods of each of these satellites. Called Io, Europa, Ganymede and Callisto, these satellites clearly showed that not all celestial objects went around the Earth. His telescope also revealed the phases of Venus and ring-like structures around Saturn.

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Galileo announced his initial discoveries in a periodical, which he called *Sidereus Nuncius* (The Starry Messenger). These announcements definitely caught the fancy of the public, especially because of the expository skills of the author. Peers in the scientific community were, however, initially a bit reluctant even to look through the telescope and were persuaded to come around only after the leading astronomer of the day, Johann Kepler, threw his weight behind the discoveries.

Figure 5. Galileo viewing through the telescope.
Courtesy:
http://en.wikipedia.org/wiki/Galileo_Galilei

In 1611, Galileo visited Rome and was treated with honour and delight. The Cardinal and Pope Paul VI gave him friendly audience and the Jesuit Roman College honoured him with various ceremonies which lasted a whole day. There were astronomers in that college who not only accepted Galileo's discoveries but also improved on his observations, especially on the phases of Venus. At this stage, at least, there was no open animosity between the Church and Galileo.

From such a friendly atmosphere, how a parting of ways between science and the Church arose is an interesting tale in the history of science. While the Church is universally condemned in this matter, a careful study of historical facts indicates that Galileo's personality did go a long way in aggravating the situation. The way Galileo acted and wrote, created for him several enemies most of whom were powerful and influential. The personality of Galileo and the antagonism of his 'scientific' colleagues were as instrumental in bringing about his conflict with the Church as the Church itself (see *Box* 1).

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Box 1. Galileo, Kepler and the Church

The trial of Galileo has attracted much attention in the history of science. It is rather interesting to see how events actually unfolded.

In 1597, Galileo received a copy of Kepler's *Cosmic Mystery*, the preface to which contained detailed arguments in support of the Copernican theory. Galileo sent him a reply saying, "...I adopted the teaching of Copernicus many years ago ... I have written many arguments in support of him and in refutation of the opposite view – which, I dared not bring into public light... frightened by the fate of Copernicus ... who ... is, to a multitude an object of ridicule and derision." Kepler replied, pleading with Galileo, that he should come out in the open in support of Copernican models. Galileo refrained from doing so, and stopped

Box 1. Continued...

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communication with Kepler. And for another 16 years (a period during which the Church did permit discussions on the Copernican model), Galileo was teaching Ptolemy's ideas in his lectures!

During these 16 years, Kepler had repeatedly communicated to Galileo about his findings and to none of which Galileo responded; in fact he always ignored Kepler's scientific contributions (especially the elliptical nature of planetary orbits) and continued to use the old Copernican ideas of celestial bodies moving in circles and epicycles. In spite of this personal antipathy, Kepler treated Galileo with great generosity and wrote openly, in 1610, supporting the discoveries he made using the telescope. And this was the time when Galileo badly needed Kepler's support. Even so, Galileo refused to reciprocate the friendship.

In 1611, the head of the Jesuit Roman College, Cardinal Ballarmine, asked the Jesuit astronomers for their official opinion on the new discoveries. These astronomers – who had in fact improved upon the work of Galileo on the phases of Venus – had no hesitation in giving Galileo a clean bill and agreeing that *at least* Venus went around the Sun. The system of the world suggested by many Church astronomers of those days had planets orbiting the Sun with the Sun itself going around the Earth.

In the years to follow, Galileo was forced to enter into controversies with jealous colleagues, Church astronomers, powerful members of the nobility and many others on whether the motion of the Earth around the Sun can be proved. The Church was willing to accept Copernican ideas as a mathematical hypothesis but demanded – quite correctly – incontrovertible proof if the scriptures are to be reinterpreted. Galileo found himself at a loss in providing the "proof", especially because he did not want to give credit to Kepler for the elliptical orbits; with circular orbits, Copernican models were as bad as Ptolemy's and compromise models did much better.

In 1614–15 Galileo wrote a few open letters, in which he supported the Copernican model, emphasised the scriptures had to be reinterpreted and even tried to argue that the burden of proof should rest with the Church. To top it all, he went for a direct showdown with the Pope based on what he considered to be the "proof" for the motion of the Earth – the proof was based on a completely incorrect theory of the origin of tides.

From then on, things took an ugly turn. The Pope asked the Qualifiers of the Holy Office to take a clear stand on the matter and this they did on 23 February 1616 – categorically against the motion of the Earth around the Sun. Six days later, Galileo had an audience with the Pope and he was told not to exceed the limits set by the Church. (What precisely he was told is a matter of another major historical controversy.) The Holy Office put Galileo on trial in 1633, essentially on the charge that the contents of his book, *Dialogue Concerning the Two Chief World Systems* published in 1632, went against the decree of 1616. Found guilty, he was allowed to spend the rest of his life in house arrest.

During the years 1611 to 1633, Galileo completed his masterpiece, *Dialogue Concerning the Two Chief World Systems*, in which he had two people, one representing Ptolemy and the other Copernicus, present their arguments before an intelligent layman. Needless to say, Galileo made the Copernican theory come out on top.

Galileo died on 8 January 1642 while still remaining under house arrest in accordance with the verdict of the Church. His bones rest in the Pantheon of the Florentines, the Church of Santa Croce, next to those of Michelangelo and Machiavelli. His epitaph was written for him by posterity: *Eppur si muove* (nevertheless it moves).

Suggested Reading

[1] **Arthur Koestler, *Sleep walkers*, Penguin, 1959.**

[2] **Isaac Asimov, *Asimov's Biographical Encyclopedia of Science and Technology*, Doubleday. 1982.**

[3] **R Spangenburg and D K Moser, *The Birth of Science Volume I: Ancient Times to 1699*, Viva Books Pvt. Ltd, 2006.**

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