A Brief History of Science
Part 4: The Renaissance

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The social background of renaissance

We have seen in the last instalment of this essay that the medieval period or the "dark age" was characterized by predominance of belief systems and the absence of scientific enquiry. The social structure was feudal, characterized by landowner-serf production relation. The kings, aristocrats and noble-men ruled in collusion with the Church, which propagated ideas conducive to the maintenance of the feudal society. The necessity of trade and commerce was minimal due to the self-sufficient nature of the village economies. There was no division of labour: the same people, who tilled their allotted land, would play the role of barber, iron-smith, or carpenter in their free times. The methods of agriculture and other crafts became stagnant, with little innovation occurring for a long span of time.

Yet, within the womb of such a static form of society, the seeds of change started germinating in the fourteenth and fifteenth centuries. Some handicrafts like glassware, pottery and weaving slowly developed into a stage where the volume of production could increase. But there was no market. This development of the productive forces was incompatible with the feudal economy, where very limited trade and commerce existed only for the benefit of the aristocratic class. The towns had very marginal, almost parasitic role in the feudal economy.

All this began to change as the volume of trade increased. Towns gained importance as trading centres, and the traders, who were subdued through taxation by the kings and nobles, began to be financially powerful. Earlier, the traders used to buy goods from the village artisans, and sell them in distant places where the same things were not produced. But the "village artisan" form of production of the feudal times was very inefficient, and the amount of goods that could be traded was low. As the traders gained financial power, they tried to increase the volume of production by starting "manufactories" where a large number of artisans would work under the same roof, on the raw material supplied by the trader, to produce the finished goods.

But this form of production came in direct conflict with the existing order of things. In the feudal economy people were bound to the land. If they continue to be tied to the land, where would the workers for the manufactories come from? So there was a necessity to free the people from feudal serfdom, so that they can become wage labourers. But the people were bound not only by the landowner-serf relation, but also by the culture of feudalism, and by the value system created by religious beliefs. So there was necessity to break these in order to establish the new form of production. Thus it was in the interest of

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the nascent wealthy business class ("bourgeoisie" in French) to break the shackles of feudalism — in politics, in economy, and in culture. Not only that, increase of production demanded new technology, which in turn demanded correct understanding of nature. Thus the resurgent bourgeois class needed to break the belief systems and religious authority that stood in the way of advancement of knowledge.

In the Dark Age the cultural environment was such that most people were conditioned into the belief systems propagated by the religious authorities. The call of the day was "believe, don't question." People who questioned the established beliefs, or whose beliefs differed with the official credo of the Church were prosecuted and punished, and were brought to submission. Now came a time where these people found support from the wealthy business class that was slowly becoming powerful. More and more people started questioning the established beliefs. More and more people started harbouring views and opinions at odds with the Church-propagated views. Initially they were suppressed through the "inquisition", a mechanism of trial and punishment of the heretics. But, with the support of the bourgeoisie, the opposition became bolder, and a full-blown struggle broke out in the area of ideas.

This struggle, erupting in the area of culture from the fifteenth century, is called the renaissance. The call of the new way of thinking was "question, don't believe." The whole world-picture adopted by the Christian faith came under the scanner. So far God was at the focus of everything, individual men being insignificant creatures at the service of God. During renaissance, the focus changed. Man became the centre of everything. The old values, ethics, morality, justice — everything came under question. New values, new ethics, morality, and sense of justice emerged. It did not happen in a day. It took long and arduous struggle for centuries to win the day in favour of the new way of thinking.

In the political-economic sphere, feudalism was giving way to capitalism, which was won through prolonged struggles with the ruling elite: the monarchs, kings, nobles, and feudal lords. In England and Holland bourgeois rule could be established only in the mid-seventeenth century, in France only in the late eighteenth century, after the French revolution (1789-1799).

The renaissance was to have profound impact on the development of science, since it gave birth to modern science as we know today. It gave birth to the methodology of doing science, the approach towards knowing what we don't know yet.

The voyages

As the demands of trade increased, people started looking for better and efficient means of transport. In those days land transport was very inefficient: the load that could be carried was small, and the speed was also very low. In contrast, waterborne transport was much more efficient: much bigger load could be carried, and with the aid of a favourable wind the speed could also be much greater. So sea transport gained in importance. But there was one problem: how can one locate one's own position in the middle of an ocean? So long as this problem was not solved, the ships had to sail close to the shore, and as a result had to travel much larger distances in order to reach a destination. In the fifteenth century people started attempting to find the location by observing the stars and planets: if one knew how the positions of the stars and planets should look from different locations in the ocean, one could figure out one's location by tallying the observation with available charts.

Thus man's attention was again turned to the actual motion of the objects in the sky. In the Middle Ages nobody really looked at the sky with interest because the Church propagated the Aristotelian and Ptolemaic pictures of the universe, and people were content with that. But now the understanding of the motion of the heavenly bodies became a matter of paramount interest and practical need.

Another aspect of trade opened up new horizons. The primary items of trade of the late medieval period were the spices, silk, muslin, gemstones, etc., that were in great demand by the European aristocracy. These items were produced in Asia, mainly in India and China. So, establishing sea-routes between Europe and Asia became a matter of interest. Initially the route was through the Gulf. But the increasing military activity of the Turks made this route inaccessible to European traders. So they looked for alternative routes to reach India. One possibility was to sail around Africa all the way to the south-most tip, and then to turn North-East. Today, looking at the map we can easily identify this possible route. But for the people of that time it was not easy, because it was not known if the African continent extends all the way to Antarctica. Somebody had to explore that through arduously long journey through unknown oceans. The psychological roadblocks were even bigger. Many people in those times believed that the Earth is flat and ends at some point, and if you sail into it you fall into abyss. Anybody trying a voyage into unknown places had to overcome such mental blocks.

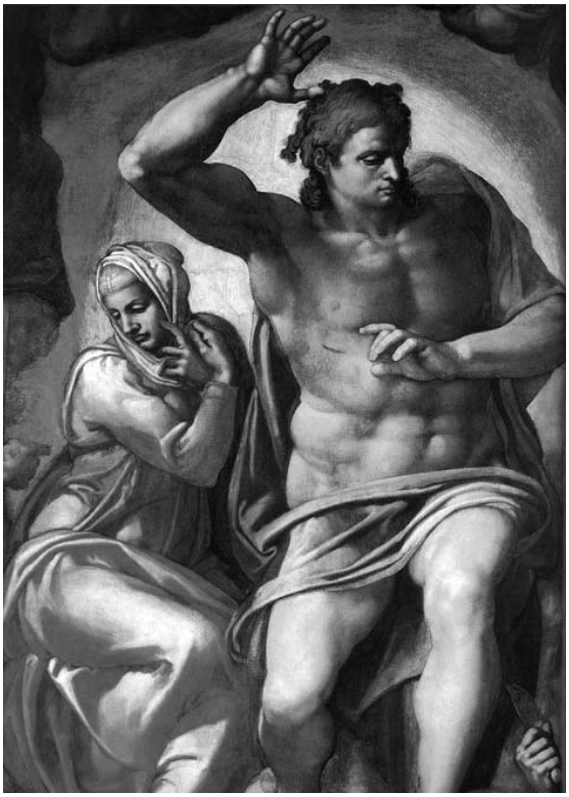
The first drive was initiated by the Portuguese and the Spanish. Bartolomeu Dias circumnavigated the African continent in 1486, and eleven years later Vasco da Gama travelled by the same route and landed in Kerala. Christopher Columbus, a penniless adventurer from Spain, had a different idea. He argued that if the Earth was really a sphere, it should be possible to reach India if one sails West straight through the Atlantic. After his funding proposal was rejected by one court after another, he finally managed to secure support and sailed — to reach the Bahamas in 1492. He thought that he had reached India, and the realization that this was a new land came much later, with the voyage of the Italian Amerigo Vespucci (after whom America is named). In 1519-22 Magellan attempted to circumnavigate the world but was killed in the Philippines by the locals. Fortunately one of his ships managed to reach Spain with only a handful of survivors — which finally convinced people that it is really possible to sail eastwards and to come back to the same land from the west.

These voyages and the stories of these adventures caught popular imagination, and helped in opening peoples' minds, making them receptive to new ideas.

The Arts

The effect of the opening of mind was felt first in the area of arts. When an artist paints or sculpts, he looks at the subject through his mind's eyes and expresses to the rest of the world what he sees. That is why, even when the artist is painting scenery, a natural object, or a human figure, his worldview dictates the way he sees it, perceives it, and paints it. The worldview is reflected in his choice of subject also. When this worldview of man was undergoing a radical change at the time of renaissance, naturally it was reflected most vividly in the area of art.

In the medieval times, in all pictures God or Jesus Christ was the central figure, and man was depicted as insignificant elements of the image. At the onset of renaissance, it all changed, and man became the central



The portrayal of Christ by Michelangelo in the great mural on the wall of the Sistine Chapel, Rome.

figure. God also had to be depicted, as the paintings or sculptures were mostly commissioned by the Church, Kings, or noblemen. But increasingly God was depicted in the form of a powerful man, devoid of the "other-worldly" features.

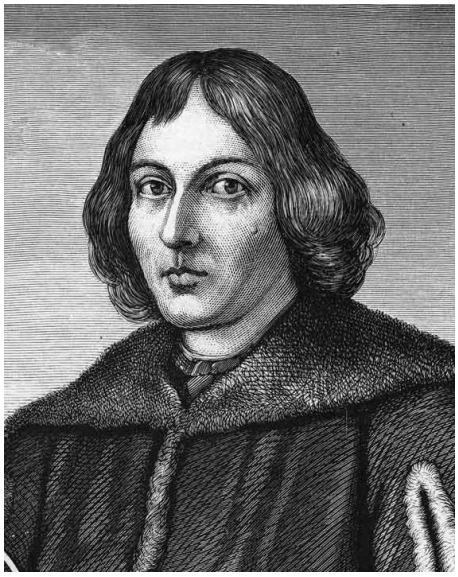
The artists of this time came out of the old mental images of the human body, and wanted to depict the human body in its real beauty. For that they had to learn from life. Not only that. They had to know what lies beneath the skin — the structures of the bones, muscles, arteries and veins. That could be learned only by dissecting dead bodies. Thus the great artists of that time like Michelangelo (1475–1564) and Leonardo da Vinci (1452–1519) ignored the Church strictures against touching the cadaver, and dissected human bodies. That is what made Michelangelo's sculptures of David or Moses so living. Leonardo went a step further. He was not only an artist who painted the famed "Mona Lisa," he was at the same time a scientist and an engineer. By dissecting dead bodies and sketching what he saw, he was the first man to discover the different chambers of the heart, the pipes going into and out of them, and the valves that regulate the flow of blood. He devised various devices for pumping water, for throwing projectiles, and even conceptualized a contraption for flying! We find all these in his notebook.

The renaissance personalities in science

Nicolas Copernicus (1473–1543)

Nicolas Copernicus was a Polish monk, who was well trained in mathematics and astronomy. He knew about the anomaly between the Ptolemaic picture of an Earth-centric universe with planets going in epicycles, and the actual observation about the motion of planets. The university scholars of the time tried to account for this anomaly by adding epicycles over epicycles, as a result of which the picture of the universe became immensely complicated. Copernicus noticed that all this complication can be avoided if we assume that the sun is at the centre of the solar system, and the Earth is a planet moving around it. Thus we see the other planets which are going round the sun, sitting on a planet which is also going round the sun. Using geometry he reasoned that the observed motion of the planets can be better explained using this alternative cosmological picture.

He being a monk knew very well that this view went against the official Church belief,



Portrait of Nicolas Copernicus.

and would be treated as heresy. Though he worked out the mathematical details early in his life, he did not publish it for many years. Finally, when he was ill and knew that the end is near, he entrusted the job of publishing the manuscript to his pupil Georg Joachim Rheticus. Rheticus in turn assigned the job to his friend and Lutheran theologian Andreas Osiander, who finally published the book. Copernicus got to see the book when he was in the deathbed.

Osiander's own theological beliefs went against that of Copernicus. So he changed the text here and there without the consent of Copernicus, and added a preface which basically said that the book contains matters of imagination of the author which do not reflect reality. Even the title of the book De Revolutionibus Orbium Coelestium (On the Revolutions of the Celestial Spheres) was given by him which did not have the approval of Copernicus.

That did not save the book from the Church's wrath, however. It was banned from circulation. But by then some people, especially the ones with an open mind, had read it, and a few copies remained unnoticed here and there.

Giordano Bruno (1548–1600)

In a place close to Naples, Italy, Giordano Bruno was studying to be a monk, when one day he noticed a copy of the book in the Church library. He read it, and agreed with the arguments. Thinking about Copernicus' heliocentric theory, he also became convinced that the stars in the sky are not bright spots in a dark canopy as was believed at that time; rather they were like our sun, each one having a planetary system around it. Then he took it as his life's mission to propagate this new view of the universe. Soon he realized that the Church is not the place for doing that. So he left the Church, left Italy, and toured the countries of Europe to propagate his views. He went to Geneva, Toulouse, Paris, Oxford, Prague, Frankfurt, and was driven out of one city after another — catholic or protestant — because of the views he propagated. Believing in a sun-centric view of the solar system was a heresy by itself; harbouring a different view about the realm of stars only increased the dimension of the crime. That is why, all the while Bruno was travelling through Europe, the Church authorities in Italy grew more restless to capture and punish the heretic.

Finally a trap was laid: Giordano received an invitation from a wealthy young man of Venice to be his tutor. Tired of a travelling life away from his homeland, he fell into the trap, and accepted the offer. Soon after he landed in Venice, he was arrested and put in prison.

The Inquisition started its work: interrogation accompanied by inhuman torture — aimed to force him to admit that he had erred in his views. But nothing could break the determination of Bruno. After eight

Statue of Giordano Bruno at the Campo dei Fiori square in Rome.

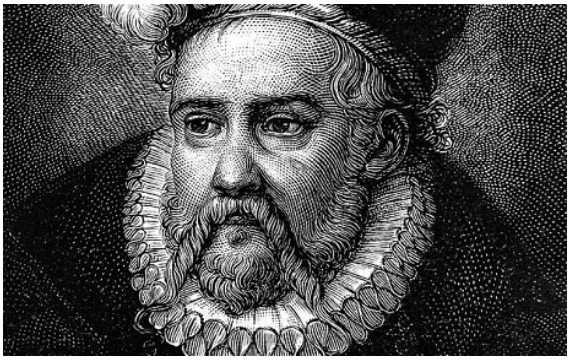
weeks of torture he was brought to Rome. This time the prison was a small metal box which became unbearably hot in the summer and unbearably cold in the winter. He was kept there for six years. Still they failed to make him admit that he had erred. Finally an Inquisition court pronounced its verdict: He will be killed in a "merciful" way, shedding no blood! Hearing the verdict, Bruno commented "Perhaps you who condemn me are in greater fear than I who am condemned."

On the 17th of February, 1600, he was burnt at stake at the Campo dei Fiori square in Rome. He was the first martyr for the cause of science.

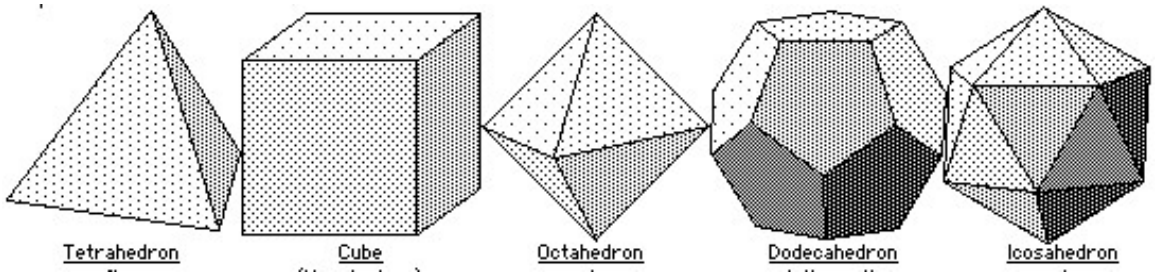
Tycho Brahe (1546–1601)

Tycho Brahe was a Danish astronomer who had enormous influence on subsequent development of science. His first scientific work started on 11 November 1572, when an interesting event happened. He was returning home at night when he noticed a new star. It was a faint star, but his knowledge about the objects in the sky was so thorough that he could immediately tell that he had not seen this star before. It was believed at that time as a part of the religious dogma that beyond the realm of the planets there lies a dark canopy containing the bright specks of light, and that in this domain everything is perfect, unchanging, and unchangeable. He noticed that this new star had no apparent motion with respect to the other stars, which implied that this object was a member of the dark canopy that was believed to be the end of the universe. This in turn implied that everything is not really unchanging and unchangeable in this domain. He trusted his eyes rather than the existing belief. He kept observing the star for months, which increased and then decreased in brightness over a period of time, and then disappeared from view. He published his results in a book "Da Nova Stella" (The New Star). This was the first demonstration that the domain of stars is also not unchangeable.

Tycho Brahe built the largest observatory of the time called Uraniborg at Hven, a small island on the Denmark coast. At this isolated place he spent 21 years from 1576 to 1597 recording the apparent motion of the planets — the most accurate ob-



Portrait of Tycho Brahe.



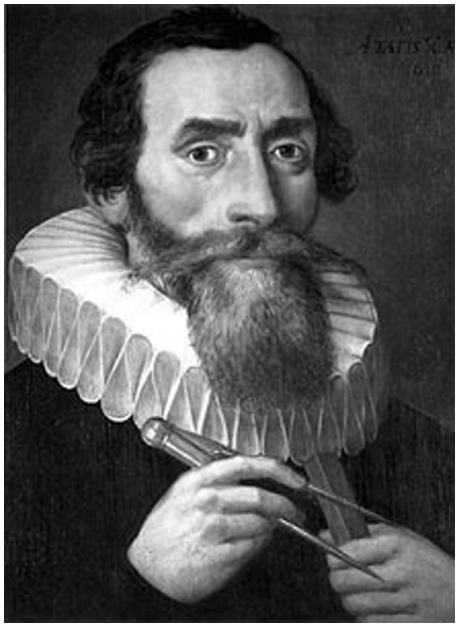
The five regular polyhedrons.

servation that was possible without the aid of a telescope. Subsequently he fell out of favour of the Danish king, and had to leave the country. He went from place to place appealing for financial support to set up another observatory. Fortunately he found support in Prague, and again devoted his time and energy to build the observatory and continue his recording of the motion of the planets. Soon he accumulated a mass of data that was to prove invaluable for the progress of science. He died in 1601, a year after Bruno's death.

Johann Kepler (1571-1630)

Johannes Kepler joined Tycho's team as an assistant at Prague in the year 1600. He was well versed in mathematics, but had no prior experience in observational astronomy. He had joined Tycho's team with a specific objective. He had a "pet theory" about the solar system. At that time only five planets were known: Mercury, Venus, Mars, Jupiter, and Saturn. He was intrigued by the question: Why was there only five planets? He knew that there can be only five regular polyhedrons: tetrahedron, cube, octahedron, dodecahedron, and icosahedron. So his pet theory was that these polyhedrons sit one inside the other, and the planets are placed at a corner of each polyhedron. This implies specific distances of each planet from the sun. So he went to Tycho to get access to the data with which he could test his theory.

After a year of his apprenticeship, Tycho died, and the mass of data came into Kepler's custody. He then sat down to test his theory. The more he checked the more he found the data to be at odds with his theory. He was depressed, torn in the struggle with his own self. But the wind of renaissance was blowing, and it had its effect. He believed Tycho's observations and jettisoned his own theory. Freed of the mental roadblock, he then sat down to work out the actual geometry of the orbits of planets. After many years of arduous work with mathematics and tallying with the data, he came up with the three laws now known as Kepler's laws. The conclusion that the planetary orbits are ellipses was particularly difficult because of the age-old belief that the circle is a perfect shape, and hence heavenly bodies must move in circles. Kepler tried in many ways to fit into this belief, by considering eccentric circles and equants, and the trajectories calculated by such means came as close as 8 minutes (one-sixtieth of a degree) from the observed data. Anybody else would have accepted the small difference as observational error. But Kepler knew Tycho's meticulous method of observation, and decided that it was impossible for Tycho to have erred by 8 minutes. So he again abandoned his preconceptions about the perfectness of the circle, and only after doing that, could find



Portrait of Johannes Kepler.

that the planets really move in ellipses with the sun at a focus.

Kepler's book "Astronomia Nova" was published in 1609, only nine years after Bruno was burnt at stake for believing that the sun was at the centre of the solar system.

Galileo Galilei (1564-1642)

The central figure of the renaissance was Galileo Galilei. Most other prominent figures of that time had some hangover of the earlier beliefs. Copernicus believed in the Pythagorean idea that the circle is a perfect shape and so the planetary movement must be in circles. Tycho Brahe believed in the geocentric theory, and that prevented him to see that his own observations supported Copernicus' heliocentric theory. Kepler, as we have seen, initially set out to find evidence in support of his own belief. But Galileo was free from all such hangovers from the past belief systems, and in that sense he was a true renaissance man.

At the time of Bruno's trial, Galileo was a young professor at the University of Pisa in Italy. Like all other professors, he had to teach Aristotle's theory in mechanics. To recall, Aristotle's theory was that 'force produces motion'. According to Aristotle, it follows from common sense that a bigger force produces a larger motion, and hence if a heavier object and a lighter object fall from a certain height, the heavier one will fall faster. While teaching this, Galileo told his students "let us test it".

So he took his students to the leaning tower of Pisa, and dropped a heavy piece of rock and a lighter piece of rock from the top of the tower. To everybody's surprise, they both fell with the same speed and one could hear a single sound when both touched the ground.

It was a simple experiment. But it completely changed the way we do science. All through history up to the time of Galileo, people have tried to obtain answers to their questions through personal realization. This was the "subjective" way of thinking, where one does not bother to test whether the answer was indeed correct. In contrast, what Galileo introduced was an "objective" way of thinking which recognizes the possibility that answers arrived at through personalized thinking could be wrong, and so it demands test of the theory by direct observation of nature or through experiments. "The simultaneous clang of these two weights sounded the death knell of the old system of philosophy, and heralded the birth of the new" (Sir Oliver Lodge, Pioneers of Science, McMillan, 1910).

Galileo laid the foundation of modern mechanics through experiments on the pendulum. He showed that the period of oscillation does not depend on the mass of the bob, nor does it depend on the amplitude of oscillation so long as the amplitude

is small. Through elaborate experiments on masses sliding down inclined planes he came to conclusion that force does not produce motion as was believed following Aristotle. Force in fact produces change in motion. These findings were later formalized as Newton's first and second laws. He also laid the foundation stones of the theory of relativity by showing that there is no difference between the state of rest and that of uniform rectilinear motion. He was the first to emphasize the importance of expressing physical quantities in terms of numbers, and expressing physical laws in terms of mathematical relation between these quantities (for example, acceleration is proportional to the force). Thus he can be rightfully called the pioneer of modern mechanics.

These discoveries, however, did not please his colleagues and superiors at the University of Pisa. They tried to defend the Aristotelian beliefs by quoting from ancient texts. When they did not succeed, they attacked Galileo with the allegation of being a non-believer. Galileo started facing numerous hurdles in continuing his research, and was forced to leave Pisa.

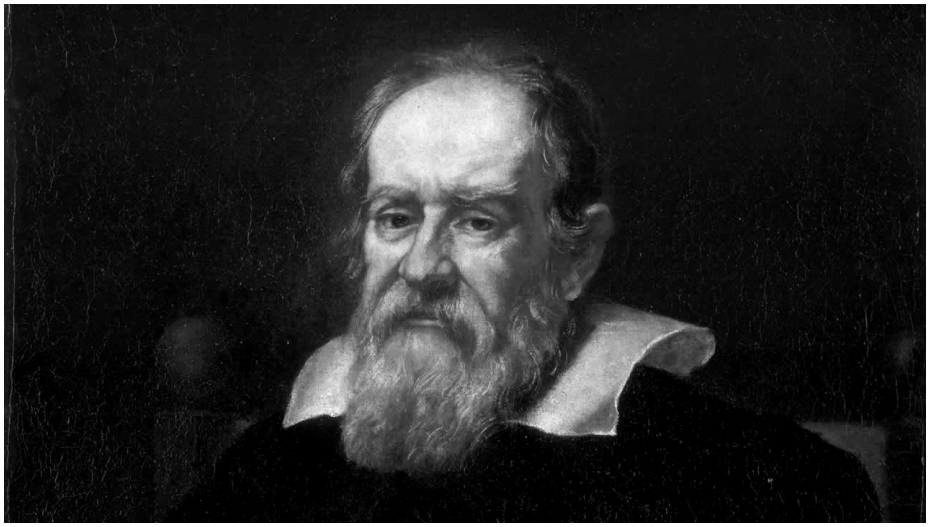
Fortunately, the University of Padua offered Galileo a professorship in mathematics. It was in Padua that Galileo made his most momentous contributions in astronomy. He heard from sailors that a Dutch lens-maker had made a device through which one can see distant objects larger. Using his knowledge of optics, Galileo figured out how that could be achieved using two lenses placed at the two ends of a cylinder. He fabricated a telescope of improved design. Then he did something no one had done before: He turned it toward the sky.

He saw mountains on the moon. He saw spots on the sun. He discovered four satellites of Jupiter. The fact that the satellites go round Jupiter immediately proved those theories wrong which said that the planets are embedded on crystal spheres. He saw phases of Venus. He knew that a planet can exhibit phases only if its orbit is inside the Earth's orbit. All these observations pointed to the correctness of Copernicus' heliocentric theory. He invited his colleagues to look through the telescope, to see with their own eyes what he was observing. Blinded by Aristotelian beliefs, most of them refused.

He was cautious in exposing his findings. But events forced him to come out openly in favour of the Copernican system. In the year 1604, a star exploded (a nova), and there was quite a controversy centring round the question whether this object was located on the dark canopy (which was believed to be unchangeable) or was a nearby object. Galileo actively participated in the debate, to show that it was located far beyond the realm of the planets. This exposed his opposition to the age-old Aristotelian cosmology.

After his telescopic observations of the sun-spots were published, his opponents attracted the attention of the Pope to his heretic views. In 1615, the Pope invited him to explain his discoveries and their implications. Galileo saw this as an opportunity to make his theory accepted by those who mattered, and elaborately explained how his observations supported the heliocentric picture. That was a mistake: He was sternly warned against supporting and propagating the Copernican view and in 1616 the Church authorities banned all discussion, reading, and writing on the motion of the Earth.

For a few years after this debacle, Galileo refrained from getting into any controversy and continued his research in silence. At this time he found patronage from the Medicis — the progressive wealthy businessmen of Florence. Then in 1632 he



Portrait of Galileo Galilei.

again came out in the open by publishing the famous book "Dialogue concerning the two chief systems of the world, the Ptolemaic and the Copernican." In this book he adopted a peculiar style of dialogue between three characters, one representing the Aristotle-Ptolemy line of thinking, one representing the Copernican line of thinking, and the third an uncommitted person, who finally accepts the Copernican idea based on evidence. In this dialogue style, Galileo presented many of his theoretical work on mechanics, his telescopic observations in astronomy, and made a strong case for the sun-centric picture of the solar system.

The Church promptly sprang into action. The Inquisition summoned him in 1633; a trial ensued accompanied by torture. Galileo saw that things were going in the same direction as Bruno's trial. But he was a scientist. He had unfinished research to do, and had to inform the rest of the world about the results he obtained. So, weighing the options, Galileo took the strategy of recanting and signed a declaration reaffirming his faith in the Christian dogma. As a result, he did not receive the verdict that Bruno did, and was put under life imprisonment. Later it was changed to a house arrest in view of his age and ill health. He fully utilized the thin opportunity that the house arrest offered, and completed some of his unfinished research on statics and dynamics and published the results that paved the path for the emergence of a Newton. All this came to an end in 1637 when he was completely blinded. He died in 1642 — the year Newton was born.

After Galileo

Even though the Church tried its best to put down the rebellion in the field of ideas, the effort of Copernicus, Bruno, Tycho, Kepler and Galileo finally opened the window. More and more people started accepting the heliocentric view of the known universe, and within a few years it was accepted by most of the learned people of the time. Then came the time of a rapid development of science, which will be the subject matter of the next part of this essay. □