HSS 102, 2016

Galileo Galilei –I (Telescope and Astronomy)

The Historical significance of Galileo:

1. Galileo made fundamental contributions to the science of motion, astronomy and to the development of the scientific method. His insistence that the book of nature is written in the language of mathematics changed natural philosophy from a verbal, qualitative method to a mathematical one in which experimentation becomes an established method for discovering the facts of nature. His discoveries with the telescope revolutionized astronomy and lent powerful support to Copernican model of the cosmos. These discoveries and his open support of Copernicus landed him in trouble with the Catholic Church and he was made to recant.
2. Freeing science from philosophy and putting it on an experimental foundation. Not speculations but a method of demonstration and reasoning capable of human pursuit. Marrying hands-on manipulation of natural objects and phenomena to accurate quantitative measurements and mathematical analysis.
3. How? Over the Aristotelian Why?
4. Writing in the vernacular –first popular science writer. He wanted to write for those without college degrees who still had the “horse sense” for science:

“What inspires me [to write in Italian] is my seeing how students in the universities sent indiscriminately to become doctors, philosophers, apply themselves to professions unsuited for them, while others who would be apt are preoccupied with family cares or with other pursuits…. Though well provided with horse sense, such men being unable to read things written in Latin containing the latest discoveries of logic and philosophy must forever remain over their heads. I want them to see that just as nature has given them, as well as philosophers, eyes to see her work, so she has also given them the brains capable of grasping and understanding them…

**Who was Galileo Galilei?**

Born on Feb. 15, 1564 in Pisa, Italy, the same year that Shakespeare was born in England. He died in 1642 in Arceti, near Florence (the year that Newton was born).

He was the eldest of seven children of Vincenzo Galilei, an innovative and experimental musician who actually did experiments on musical strings and challenged musical theory of his time. This is Galileo’s *father* writing:“those who in proof of anything simply rely on the weight of authority, without adducing any argument in support of it, act very absurdly. I, on the contrary, wish to be allowed to raise questions freely and to answer without any adulation of authorities as becomes those who are in search for truth.”

Like father, like son…

Being the eldest son, he took care of his family after his father passed away – which meant that he had to worry about his financial position all the time. He had two daughters and a son with a woman Marina Gamba with whom he had a long-standing relationship but who he did not marry. He continued a long exchange of letters with one his daughters – Maria Celeste -- who was a nun in a convent. The letters from the daughter to her father have been preserved and help to place Galileo in his social context.

Galileo was first sent to medical school, but he discovered a love for mathematics. [It was while at med school that Galileo did some work on pendulum: the pendulum swung back and forth in equal time, regardless of the size of the arc. i.e. the time of the swing remains the same, even when the pendulum is losing motion and coming to a stop.]

 Dropped out of med school and made a living by giving private lectures and demonstrations.

His first professional job as a mathematician was at the University of Pisa where he did his work on motion which circulated as a manuscript called *De Motu.*  At this point, G still supported Ptolemy, even though he was beginning to question Aristotle’s ideas about falling bodies… [not clear if he did his famous leaning tower experiment. …]

He then moved to Padua, the more famous university. Lectured on military architecture, surveying, mechanics and related subjects. It is here that he figured out that the actual path of projectiles is a parabola. It is here that he developed an interest in astronomy which was not until 1595 when he hit upon the explanation for tides…

He was in touch with Kepler: Kepler had sent him his *Mysterium Cosmographicum*. G. had written warmly to Kepler congratulating him and praising him for standing up for the Copernican system. But at that time, he was not an open Copernican himself. Later, Kepler will come to Galileo’s defense (see below)

Inclined plane

INVENTIONS:

His work at Padua involved a number of inventions, including the telescope – which increasingly drove his research

He invented a mechanical calculating device in 1597 which was found to be very useful for all kind of calculations useful in navigation, land surveying and everyday use. He hired craftsmen to make these devices and sold them for money.

His most important invention was of course the telescope which he was the first one to turn to the skies.

The credit for the invention of telescope actually goes to a German eye-glassmaker who lived in the Netherlands, Hans Lippershey (1570-1619).

Galileo heard about it, and tried his own hand at making one.

He quickly produced a 8x version (equal to ordinary field glass). He offered it to Venitian senate which helped in military matters so they gave him a raise at Padua university, he became the highest paid professor.

He then quickly 20X version – and turned it on the heavens. (see picture below).

**Galileo’s evidence from the telescope: (Pl. see the powerpoint)**

G. was among the first scientists to turn the telescope to the sky. He reported his finding in a short book called *Siderus Nuncius*, or the *Messenger from the Stars* published in Venice in March 1610.  This was a short, merely 24 page-long book, but it had a huge impact, as it was reporting on things never seen before. Let us quickly review the evidence from the telescope reported in this book

1. Mountains on the moon: G. was one of the first to show the existence of mountains and craters on the moon. He wrote:

“the surface of the moon is not perfectly smooth, free from inequalities and exactly spherical, as a large school of philosophers think…. On the contrary, it is full of irregularities, uneven, full of hollows and protuberances, just like the surface of the earth itself...

This was a direct observational proof against the Aristotelian dogma of the perfection of the heavenly bodies which were supposed to be made out of ether.

Though this bit of evidence did nothing for the debate over earth – or sun-centered universe, it did provide an argument for the motion of the earth: if the moon which is a rocky, hard and uneven place like the earth could move in space, there was no reason the earth could not. ( It used to be thought that earth could not possibly move, as it was made of heavy element, while the heavenly bodies could, as they were made of ether or quintessence. )

1. Sunspots: G. focused telescopic images of the sun on a screen and showed the existence of sunspots. He further showed that these spots were on the surface of the sun itself, and were not cast by shadows of some passing planets.

This was another crack in the Aristotle’s worldview, as it showed the celsestial or super-lunar region to be imperfect and changing.

1. The rings or the “ears” of Saturn: G. showed that Saturn is not spherical, but had ear like bulges on the sides. G. was obviously looking at the rings, but his telescope lacked the resolving power.
2. The moons of Jupiter: G. was able to observe four small points of light, which vary their position with respect to Jupiter over time. Galileo reasoned correctly that they were the moons of Jupiter and he called them “Medicean stars” in honor of the Medici family (one of the most powerful families in Italy. He was rewarded for his efforts when the Medicis appointed him their chief astronomer and mathematician.)

This was yet another problem for Aristotle: in that system, the earth was the single center of rotation of all heavenly bodies. But G. showed that Earth is NOT the single center – moons move around Jupiter as well.

1. The phases of Venus: Galileo used his telescope to show that Venus went through a complete set of phases, just like the Moon. This observation was among the most important in human history, for it provided the first conclusive observational proof that was consistent with the Copernican system but not the Ptolemaic system.

The crucial point is the empirical fact that Venus is never very far from the Sun in our sky. Thus, as the following diagrams indicate, in the Ptolemaic system Venus should always be in crescent phase as viewed from the Earth because as it moves around its epicycle it can never be far from the direction of the sun (which lies beyond it), but in the Copernican system Venus should exhibit a complete set of phases over time as viewed from the Earth because it is illuminated from the center of its orbit.



It is important to note that this was the first empirical evidence (coming almost a century after Copernicus) that allowed a definitive test of the two models. Until that point, both the Ptolemaic and Copernican models described the available data. The primary attraction of the Copernican system was that it described the data in a *simpler* fashion, but here finally was conclusive evidence that not only was the Ptolemaic universe more complicated, it also was *incorrect*.

Other Observations

In addition to the observations noted above, Galileo made many other observations that undermined the authority on which the Ptolemaic universe was built. Some of these included

--showing that the planets were disks, not points of light, as seen through the telescope.

-- Showing that the great "cloud" called the Milky Way (which we now know to be the disk of our spiral galaxy) was composed of enormous numbers of stars that had not been seen before. This suggested that the universe was much larger – probably even infinite – than was imagined by the ancients.

**The reception of Galileo’s discoveries**

Galileo’s *Messenger from the Stars* was NOT well received.

The first opposition came from the Aristotelian professors at Padua university. A month after the book was published, a memorable party was held at a house in Bologna where Galileo was invited to show the moons of Jupiter through his famous spy glass.

Apparently, not even a single guest was convinced of the existence of the moons when they looked through the telescope. Indeed, well known professors from Padua university even refused to look through the telescope, as they said that they were not convinced that telescope was not creating optical illusions which were showing up as dots which were being interpreted as moons.

At that time, it was Kepler who came to Galileo’s defense. Kepler received a copy of Galileo’s book on April 8, 1610. Kepler was at first worried that Jupiter’s moons may not fit in his beloved model of the spheres nested between Pythagorean solids. (see the lecture on Kepler). But once he saw that these were satellites of a planet, and not new planets, he was fully supportive of Galileo. He wrote a short essay in which he whole-heartedly supported Galileo’s findings.

By then, Kepler (who was the court mathematician at Prague) was a well-respected astronomer. His endorsement meant a lot to Galileo who immediately published Kepler’s comments as a pamphlet and circulated it widely.

As he became more confident, G. began to take a more realistic view of a sun-centered universe: he not only accepted Copernican model but believed that it was real – that it actually described how the world works – and not just a convenient mode for making predictions.

**Galileo and the Church**

But the opposition from fellow academics at Padua was nothing compared to the opposition that was building up from the Catholic Church. (Galileo was himself a devout Catholic).

If you recall from our study of Copernicus, the Catholic Church did not have much of a problem with Copernicus: He was even urged and encouraged by the pope to publish his theory of sun-centered universe. But the Church took a non-realist view of Copernicus – i.e., accepted it as a useful hypothesis.. This is actually what the preface (written by Osiander) to Copernicus’s book had recommended. (see the lecture on Copernicus).

But seventy years later, when Galileo came up with his astronomical findings, things were very different. For one, the Catholic Church had become much less liberal. After the Reformation which led to Protestantism, the church became strict about its doctrines and began to control what interpretation of the Bible were acceptable and not

The Churchmen, by and large, accepted the evidence of the telescope. Cardinal Bellarmine and other Jesuits (who were the intellectuals and the educators of the Catholics) actually replicated Galileo’s observations. (Unlike the university professors , they had no objections to looking through the telescope).

But while they accepted G’s data, they could not accept G’s increasingly open REALISITIC interpretation of the Copernican system because it conflicted with the literal meaning of the Bible. There are passages in the Bible which clearly say that the earth was in the center.

Galileo was aware that a storm was brewing. He tired to prepare ground for his defense. He wrote an essay in 1615 (published later as the *Letter to the Grand Duchess Christina*) in which he argued that the sole purpose of the Bible was to help achieve salvation of the soul. On matters which are within the reach of sensory experience and reason, God does not accept us to forget about these God-given abilities (ie, sense and the mind). So in matters of empirical knowledge, the priority has to be given to empirical knowledge and the Bible has to be read not literally but metaphorically, or as an allegory. This position was not original to G: this had actually been the position of the Christian church from the early years of St. Augustine (see the lecture on the Rise of Christianity).

But all this did not impress the Church. In 1616, the Church declared that the two positions – one, that the Sun was at the center; and two, the earth moved around it -- to be “philosophically absurd” and either “formally heretical” (the first idea, re. the sun being the center) or “erroneous in faith” (the second idea, ie, the earth moving around). At this point, Copernicus’s book, the Revolutions, was put on the Index of Prohibited Books “until corrected. It was removed from the list only in 1835.

Galileo was not formally declared a heretic. Because he was well-respected by the Church, the was invited for a discussion by Cardinal Bellarmino who told him about the Church’s position and advised him to stop teaching and defending a sun-centered universe as in the Copernican model.

Galileo went back to Florence and got busy with other, non-astronomy related work. He wrote a book called the Assayer, which is considered the foundation of mechanical philosophy (see the lecture on Newton).

Then by a remarkable stroke of luck (so it would have appeared to Galileo), one of his dear friends, Maffeo Barberini ascended to the Papacy (i.e. became the Pope, taking on the name Urban VIII). Barberini had a lot of respect for G. and had even written a poem in his honor. Galileo was thrilled to have a friend at the highest position in the Church and requested a meeting with him.

Bareberini and Galileo had six meeting in which they discussed the Copernican thesis . Barberini basically said that while he accepted the evidence of Galileo for a sun-centered universe, he could not believe that we, humans, can ever know the real truth which was known only to God. He said that it was OK to adhere to Copernicanism as a model for making astronomical predictions, but NOT as an accurate description of reality.

From these meetings, Galileo came to understand that he was free to write about helio-centrism (helio= sun) as a hypothesis. Although he was forbidden to declare it to be true, he could still write about pros-and-cons of the Copernican mode.

So, Galileo went back to Florence where he lived and completed his book, *Dialogue on the Two Chief World Systems* in 1629 – a book that got him in serious trouble with the Church. In this book, his goal was to treat helio-centrism as a hypothesis, but as the BEST hypothesis available. This book is set up as a dialogue between an Aristotelian (a somewhat buffoonish character who he named Simplicio) and a Copernican (a smart guy, who he called Slaviati, who is modeled after Galileo himself!) and an impartial bystander by the name of Sagredo whose role is to make a comment once in a while.

Even though G. claimed only to be presenting a hypothesis, it was clear to any reader that he was actually defending the Copernican model as true and Aristotle/Ptolemy as false. What was even worse, he basically modeled Simplicio, the rustic buffoon, on the Pope Urban VIII and put the words of the Pope in the mouth of Simplicio!! That was not a very diplomatic thing to do, considering the risks he was facing. But that is what Galileo did.

**The Trial and Recantation:**

Things got unpleasant after the *Dialogues* appeared in print. The Pope did not like that he had been so caricatured as Simplicio. Also, Galileo had brazenly disobeyed the Church’s orders NOT to defend Copernicanism as literally true.

So Galileo was summoned to Rome to appear before the Inquisition in Jan 1633. By this time, he was 69 years old and in bad health. Anyway, he made the long journey to Rome, albeit in comfortable circmsatances with servants etc.

The trial went on for a few months. The basic charge against Galileo was that of disobeying the decree of 1616 that had declared Copernicanism heretical. He had disobeyed orders. On June 21, 1633, Galileo was asked to announce, once and for all, what his beliefs were. This is when Galileo made his famous recantation , i.e., renounced his belief in Copernicanism. This is what his recantation said, in part:

A long time ago… before the decision of the holy congregation of the Index and before I was issued an injunction, I was undecided and regarded the two opinions, that of Ptolemy and Copernicus, as disputable, as either the one or the other could be true in nature. But after the above-mentioned decision [of 1916], all my uncertainty vanished and *I held, as I still hold, as very true and undoubted, Ptolemy’s opinion, namely, the stability of the earth and the motion of the sun.*

He was made to swear that “he will never again say or assert, orally or in writing, anything which might cause a suspicion [of heresy] on me.”

**The end:**

For the remaining nine years of his life, Galileo was under house arrest. He was not tortured or anything like that, but he was deprived of his freedoms. (see picture below)

Even though he was in prison, his ideas spread far and wide. His work on mechanics was translated into French by Marin Mersenne, a French churchman who was one of the leaders of mechanical philosophy (see lecture on Newton). His Dialogues which got him in trouble, was translated into Latin by a Swiss and was read all over Europe. His letter to Christina was also translated into Latin and printed in Holland.

He also completed yet another very influential book *Dialogue Concerning Two New Sciences* which was partly dictated to his young students as he had gone blind by the end of his life. This book deals with his work on mechanics which had been interrupted by his studies with the telescope.

Galileo Galilei died on Jan. 8, 1642.

(contrary to myths, GG died peacefully in his own bed, in his own house. He was not tortured by the Church. His eyes were not “gouged out” by the Inquisition of the church. He was deprived of his liberty, but not physically harmed by the church. )