Air and Space this Week

Item of the Week

GALILEO DI VINCENZO DE GALILEI

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Galileo is perhaps the all-time greatest Astronomer. He was adept at Physics, and was an excellent engine, always eager to design, built, and use new tools. But Astronomy was his first love. His education and skill set earned the patronage of the Médici family of Florence, and access to the many other stars of the Italian Renaissance. He hit his prime in 1609 CE, when he acquired and began using one of the first newly-invented telescopes.

The then-prevailing view of the time regarding the visible motion of the planets against the starry background, and the rising and setting of the Sun was that the Earth was at the Center of All Things, and that the Moon, Sun, other planets, and the very stars above orbited around it. Galileo was skilled at geometry, and was dissatisfied with the "geocentric" model, because the motions of the planets, especially Mercury and Venus, required a complex system of movements.

Eighty or so years earlier, Copernicus had proposed a different model, one where the Sun, not the Earth, was the center of planetary motion. He also knew there was an observational test to determine which model was correct, based on whether or not Venus exhibited a lunar-like range of phases. But Copernicus lacked the technology to make that observation, but he did publish it anyway, for a future astronomer to use when a method of seeing Venus more closely was developed. Galileo's new telescope could magnify Venus to the point where its phases were visible. He saw a full range of phases, and knew Copernicus was right. The Sun was the center of planetary motion, justifying calling the Sun and its planets the "Solar System."

THE START OF OUR STORY: THE MÉDICI FAMILY AND THE ITALIAN RENASSANCE

Humanity suffered a serious setback during the "Dark Ages," a period between the 5th and 14th centuries CE. The development of a tradition of learning and scientific advancement that had taken hold in early Greece was absorbed by the Roman Empire some two thousand years ago. While Rome confiscated a lot of Greek art and science, it also built on it, culminating in the great library and learning complex at Alexandria. When Rome fell, and the Library burned, western civilization took a millennium backstep, and the seat of learning moved into the Arab world.

The ups and downs of Astronomy provide a good example. The Greeks made great strides in all of the physical sciences, but especially in Astronomy, which the Greeks considered one of the fundamental areas of basic education. Greek astronomers regularized the mapping of the sky into constellations, and made efforts to understand the organization and structure of the Solar System. Many of the textbooks likely once in the Library were lost, but the constellation names, and the belief that the Sun, planets, and the entire Universe revolved around the Earth, survived, especially in the works of Ptolemy, which were copied and distributed across Europe, including Arabia. Arabian astronomers adopted the constellation groupings and their basic names, but used their own names for individual stars, which were familiar to them because of their value in navigating the large tracts of deserts in Africa and the Middle East. The Arabic names, or contractions of them, were retained all the way to the present. That's why constellations, especially those in the northern part of the sky, "officially" bear Greek names, while individual star names are almost always of Arabic origin.

The Roman Empire was vast, and did not "fall" all at once. Rome itself fell to Germanic tribes in 476 CE, but the eastern half, the Byzantine Empire, preserved some Roman culture through the 800s, the records of which give us today much of our knowledge of early Greece and Rome. The Byzantine period also saw advances in architecture, art, and theology. Next up was Charlemagne and the Carolingian Empire (ca. 800-1000 CE). He was crowned Emperor by Pope Leo III, making a bridge to the Rome of the past that started the process of reviving the culture of learning. Education reforms under his management and an increased interested in the remaining information from the Greek/Roman days. But, alas, further setbacks awaited.

A prolonged series of strife blocked the promise of the Carolingian Renaissance in its tracks. Viking attacks across the area during the 9th, 10th, and 11th Centuries CE, the Norman Conquest in 1066 CE, and the Crusades in the period 1000 – 1300 CE disrupted societies across the continent.

Starting about 1400 CE, western civilization finally began groping its way to something better. The Renaissance cultural and intellectual movement began to spread gradually. A rediscovery of Greek and Roman accomplishment in science, engineering, and the arts may have started the process. Commercial activity and trade were also advancing rapidly at this time, making some of the people involved quite wealthy.

Scientific inquiry and the engineering/technology that enables it go hand-in-hand (a common theme for Air and Space this Week). Both were advancing at the start of the Renaissance, and by 1500 CE or so, engineers were able to begin making ever-improving tools that could support the study of the natural world, such as precise measuring and survey equipment.

Today, scientifically-advance countries support scientific activity at the national level, but 600 years ago, there was no such thing. Astronomers and other scientists were employed by persons of great wealth or royalty, as were the engineers that built the tools needed for science to advance. Italy is a good example, in large part because of …

THE MÉDICI FAMILY

Three separate lines of the Médici family ruled Florence and most of Tuscany from 1434 to 1530 CE. One line grew to dominance, with great wealth from cloth and silk manufacturing and later banking. The line was led by Cosimo de Médici, who was prominent in Florentine politics. His grandson, Lorenzo, would become known as "The Magnificent." One of Lorenzo's sons became Pope Leo X. The family tree and its many interactions is quite complex and the details are not important for this story. But know that Renaissance science and learning was largely based on the financial largess of wealthy (or royal) personages like the Médicis. This tradition persisted into the present era, especially in Astronomy, as witnessed by the names many prominent observatories bear (*e.g.* Lick, Hooker, Hale, and Simonyi). The wealthy of the time had a sharp eye for talent, and their patronage allowed artists like Michelangelo, Bernini, and Rafael; and inventors like Leonardo da Vinci, to flourish.

THE FIRST STAR OF OUR STORY: COPERNICUS

Nikolas Kopernik was born on February 19, 1473, in Toruń, Royal Prussia Province, Kingdom of Poland, now known as Thorn. His family was wealthy, but not overwhelmingly so. His father was a merchant from Silesia, a trader of copper, selling mostly in Danzig (Gdańsk). Both Danzig and Toruń were members of the Hanseatic League of independent cities. The Hanseatic cities at the time of Nikolas' youth were involved in the Thirteen Years' War, fighting the Teutonic Order, a group originally formed to support the Crusades. His mother was similarly situated, and her highly-educated brother, Lucas Watzenrode the Younger, was elected Bishop of Warmia when Nikolas was a boy and would serve as Nikolas' patron after the boy's father died. Watzenrode was friends with many of the leading intellects of Poland and elsewhere, ensuring Nikolas' successful education at the Universities of Kraków, Cologne, and Bologna. The former was particularly important, because it was at the forefront of astronomy, geometry, Greek history, and humanism. He was quite familiar with Aristotle's theories of the structure of the Universe, and with Ptolemy's theory of the structure of the Solar System. He was dissatisfied with both.

Nikolas spent three years at the University of Bologna (1496-1501 CE), spending much of his time on the study of canon law and astronomy, eventually receiving a doctorate in the former. He became assistant to Domenico Maria Novara da Ferrara, a leading astronomer of the time, and began to study Ptolemy's famous astronomy book, *Almagest*, in earnest. He also studied the writings of Pythagoras, Aristarchus of Samos, Pliny the Elder, Plutarch, Plato, and others.

After his time at Bologna, Nikolas went to the University of Padua to receive training in medicine with an eye toward becoming an advisor to his patron uncle. He also began to study Ptolemy's ideas of planetary motion more deeply, spurring on by observing several occultations and an eclipse of the Moon (11/6/1500).

We do not know for certain exactly when Nikolas came up with the idea that the Earth and other planets orbited the Sun, but by 1510 CE he was beginning to flesh out this idea and made an outline of his thinking in 1514; it's usually referred to as the *Commentariolus*. He distributed it to only a few of his astro-colleagues; Tycho Brahe would include a piece of it in his own work published in Prague in 1602.

Nikolas was not the first to come up with the idea of something else as the “center” of planetary motion. The Greek philosopher, Philoaus, wrote of some sort of unseen “central fire” around which everything in the Universe revolved circa 500 BCE. Aristarchus of Samos used astronomical observations make him think that the Earth was a sphere and that the Earth and other planets revolved around the Sun. But the prevailing dogma in Europe in the 1500s was thoroughly Geocentric. Nikolas knew nothing of these earlier efforts.

Nikolas acquired progressively-important positions that required high administrative competence in both secular and religious matters as well as a solid understanding of the economics involved. By this time, he had taken to using a Latinized version of his surnames, Copernicus. But his busy schedule of administrative and advisory duties did not stop him from making some important astronomical observations. He was particularly active in the period of 1512-1515 CE, making discoveries regarding the slight eccentricity in the Earth-Sun positions and others that reenforced his thinking about who orbits whom.

Copernicus had been thinking about expanding *Commentariolus* into a full-scale book. The political unrest in Poland and its effects on the governmental part of his life were taking more and more of his attention. Worse, in January, 1620, his astronomical instruments were destroyed in a raid by forces of the Teutonic Order on Copernicus’ town, Frauenburg. Undaunted, he continued his observations using more-primitive equipment, and also began conducting what Einstein would later term, a “thought experiment,” approaching the problem by logical thinking. And he slowly worked out his ideas in more detail.

Humanity had attempted to understand the movements of objects in the night sky for a long time before Copernicus. Prevailing doctrine requiring the Earth to be the center of objects and movements in the night sky, and that put constraints on how those objects moved. The Moon pretty clearly moved around the Earth, and the movements of Mars, Jupiter, and Saturn could be somewhat explained by orbiting the Earth, too. But explaining the observed movements of Mercury and Venus were much more difficult to reconcile with any Earth-centered model. This had bothered Copernicus in 1514, and it was still bothering him.

Copernicus pondered on what would things need to be like if the Earth were NOT at the center of all things, rather it moved in the same manner as the other five (known) planets?

The more Copernicus thought about the geometry of the problem, the more he realized that there was an observational test that would prove conclusively that the Sun or the Earth were the center of planetary motion! But there was only one small problem.

Consider the geometry required of both motion models.

The geocentric model of planetary motions was reasonably workable for the movements of the Sun, Moon, Mars, Jupiter, and Saturn, and they all would pass along the constellations of the zodiac (or nearby). However, the well-known movements of Mercury and Venus would have to be rather unusual if they had to orbit the Earth. The two always appear near the Sun, if they appear at all; the other planets could be near or far from the Sun in their motion. Several complex geometric schemes to accommodate the planetary movements were put forward. The most popular was published by Ptolemy a millennium before, in the *Almagest*.

Ptolemy envisioned a system where Venus moved in a circle ("epicycle") around an empty point called the "deferent" that was always in the same spot on the line between the Sun and Earth as the Sun orbited the Earth. Venus could appear on either side of the Sun (morning and evening), but it was always limited as to how far it could stray from the deferent.

If Ptolemy was correct, Venus had to be (mostly) backlit as seen from the Earth all the time! If Venus could be seen at all, astronomers would see only a sliver of Venus' illuminated hemisphere. In other words, Venus has to be crescent-shaped. The fact that it wasn't that way to the un-aided eye meant that Venus was very far away.

These same things apply to Mercury, too. It's excursions from the Sun were less-wide that Venus' and it wasn't as bright, so it must be smaller than Venus.

Ptolemy's model also meant that every time Venus or Mercury passed from one side of the Sun to the other, it would pass directly in front of the Sun as seen from the Earth, and should appear in silhouette against the Sun's face. This had never been done, since the Sun was much too bright and, even though it showed a disc, it was too small to see Venus or Mercury "in transit."

Mars, Jupiter, and Saturn also showed a different odd motion difficult to reconcile with an Earth-centered system. When they get the farthest they can relative to the Sun on the zodiac, they appear to reverse motion across the sky relative to the stars, and backtrack for a few weeks. If plotted on the sky, the planet's motion would make a backward or "retrograde" loop. This apparent movement would require some sort of other kind of epicycle. The whole Ptolemaic System is very complicated.

The geometry of a Sun-centered system is much simpler. No epicycles, deferents, or retrograde loops are needed. Planetary motions only require objects to be circling the Sun, with the speed in orbit was higher the closer to the Sun a planet was.

Even better, the heliocentric system would allow Venus to exhibit the full range of phases the Moon does: first quarter, full (when Venus would be on the far side of the Sun), last quarter and new (when Venus would be seen in transit)!

William of Ockham centuries earlier had come up with an analysis strategy that would be useful here. Simply put, "Ockham's Razor" states that the simpler of two possible explanations for something is more often correct that the more complicated explanation. Copernicus knew that no Razor of any kind would be needed, if he could only see if Venus showed lunar-like phases.

But alas, Venus was too far away. It was only a dot in the sky, too small for any of its actual shape to be seen with the unaided eye.

Copernicus finished his expansion of *Commentariolus* by 1540 CE, but he was reluctant to distribute it broadly, since it proposed a model for the Solar System at odds with rigidly-enforced religious dogma. He did, however, distribute a few copies to close associates. One of his supporters, however, spilled the beans and published a description of Copernicus' model in 1541. Copernicus, nearing the end of his life, finally relented, and published *De revolutionibus orbium coelestium* ("On the Revolutions of the Heavenly Spheres"), in 1543. In it, Copernicus described his heliocentric Solar System and provided several lines of geometric evidence in its support.

And it included the observational test involving Venus!

A scientific question had been proposed: Earth or Sun? The technology that would enable astronomers see Venus closely enough to provide the answer had not been invented yet. In this case, the natural oscillation between inquiry and technology-aided answer was far to the former, ***but change would be coming soon.***

GALILEO

Florence continued to flourish during the middle part of the 1500s. The Italian Renaissance was in full bloom. Michaelangelo was at his peak, building on the success of Rafael. Da Vinci and Bernini would soon follow. And into the mix of such genius, Galileo de Vincenzo de' Galilei was born in Pisa (February 15, 1564). While da Vinci is one of the greatest inventors and engineers of all time, but when it came to applied science, none eclipsed Galileo until Newton reached his prime, in large part because of his building on Copernicus' foundation.

Galileo knew well that the success of the scientist depended on the skill of those producing their tools of the trade, and the second half of the 1500s was a time where precision instruments and machinery were developed to an amazingly high degree. All fields leapt forward as a consequence; arguably none more so than astronomy, due to the invention of the telescope in 1608 CE.

Geocentricism was enforced rigidly at that time, on religious grounds. The prevailing dogma was that the Sun, as the heavenly provider of life, simply had to be "perfect," free from blemish in any way. Because no motion could be felt, the Earth had to be the unmoving Center of All Things in the Universe, including Motion.

Galileo acquired one of the first telescopes made, in mid-1610, and immediately turned it to the night sky.

His first view of the Moon showed mountains and varied terrain, troublesome because the Moon celestial status implied perfection. But the Earth has geographical variety, too, so the discovery that the Moon had geographical features, too, was not too upsetting.

Galileo then pointed his telescope toward the Sun. He didn't look through it and go blind; that's a myth. But he did project an image of the Sun on a screen behind the telescope, and shuddered when he saw spots on its surface, especially since the spots seemed to march across the Sun's surface from day-to-day. His view wasn't good enough to determine whether the spots he saw were actually on the Sun or were merely small objects seen in silhouette as the transited across the Sun's face. If the latter were true, the Sun could still be "perfect," but if the spots were on the Sun itself, that would be problematic. Telescopes would need another 40 years of improvements before the spots' true location could be determined. They proved to be blemishes on the Sun itself, but by then more astronomical trouble had ensued in the interim.

Galileo's next target was Jupiter. His telescope was just good enough to suggest that Jupiter had darker bands running across it. That wasn't too big a deal, but the fact that there were four "stars" that accompanied Jupiter was. Their motions relative to Jupiter showed Galileo that they were actually moons in orbit around Jupiter! We know them today collectively as the "Galilean Satellites;" they were given the names of four of Jupiter-the-God's many consorts: Io, Europa, Ganymede, and Callisto. The fact that they orbited Jupiter was intriguing, but since Jupiter itself was in orbit around the Sun, the new objects were therefore orbiting the Sun, too, so their discovery was not too "Earth-shaking."

But then Galileo looked at Venus!

His telescope may have been primitive by today's standards, but it was good enough to show Venus as a disc rather than just a point of light. Observations of Venus over a period of weeks/months showed that, indeed, Venus showed the full range of lunar phases.

His observations conclusively proved that Copernicus was right and Ptolemy was wrong!

Now Galileo was in a quandary. Other astronomers were acquiring telescopes. It would only be a matter of time before others would see Venus' phases, too. Going public with this discovery would no-doubt get him cross-wise with the Church; scientists had already been and would continue to be burned at the stake for heresy for daring to disagree with religious dogma (*e.g.* Giordano Bruno in 1600 CE). What to do, what to do?

Galileo was no coward, but he was no dummy, either. Scientist of that time period would sometimes announce their discovery in code, and Galileo followed that route. He composed an anagram that, when unscrambled, read "The Mother of Love Imitates the Forms of Cynthia." A bit weird, perhaps, to the uninitiated, but since Venus is the Mother of Love in mythology and Cynthia is a poetic name for the Moon, word got out to the scientific community of the day, without much trouble. At first.

Copernicus and Galileo provided us with one of the best examples of how the process of scientific enquiry, aided by technology, advances: Copernicus made an important prediction and Galileo, using better tools newly-available, provided the important confirmation.

Then the Church found out about it, too.

I don't want to go into his trial, forced recanting of heliocentrism, muttering under his breath on hearing his conviction that the "Earth still moves," spending the rest of his life under house arrest, and his ultimate vindication centuries later. Many studies and books have been made/written about his amazing contribution and its ultimate effects. I would be remiss if I didn't expand a bit about Galileo's other contributions to our future world.

The Greeks had developed a process by which thoughtful investigation could produce valuable insights. Today we call it the "scientific method," or the "process of scientific inquiry." It had fallen by the wayside during the Dark Ages, but Galileo was a big believer in it, to good effect.

In a nutshell, scientific inquiry goes as follows. Strange phenomena are observed. Further observation allows categorization of variations of the phenomena. Possible explanations, called hypotheses, are made, perhaps more than one. Additional observation, and careful experimentation, provide evidence to support/reject explanations. The **process repeats**, especially as new discoveries and tools become available. This thing the Greeks and Galileo called "science" is a living, fluid thing, changing and becoming more refined as new tools and techniques become available. Galileo's telescope was such a great example of this approach that its use spread across the natural sciences and continues to do so to this day. And the scientific method yields good results in medicine, physics, chemistry, and more, including crime scene investigation. [I'm amazed when I encounter a Science "denier" who is also a CSI fan!]

My list of Galileo's accomplishments would put his re-invigoration of scientific inquiry as most impactful, since it reached so many fields. Very closely behind would be his using Copernicus' test to prove the heliocentric model of the Solar System. But one more area got the Galileo touch.

Galileo was fascinated by fundamental Physics. He studied motion in a rigorous way; conducted experiments on falling and rolling bodies; developed fundamental concepts underlying the science of hydrostatics, and more; and the math behind all of them. He was able to demonstrate that the tides were caused by the movement of the Moon and the location of the Sun and able to predict them.

He was truly a "Renaissance Man!"

MUSEO GALILEO

I recently had the opportunity to visit Florence, Italy. It's filled with amazing cathedrals, artwork, and tourists. I skipped the Uffizi Gallery, the Duomo, the Santa Maria del Fiore, the Ponte Vecchio, and the Accademia Gallery and David. They were very crowded anyway.

Instead, I visited the Museo Galileo.

I knew I would see Galileo's first telescope and other artifacts of his life and times. **But I was not prepared at all for the many other utterly amazing things in that beautiful museum!**

My mind was in a receptive mood because I had visited a Da Vinci exhibition in Rome a few days before. There is a chain of these mini-museum across Italy, with reproductions not only of da Vinci's writings and drawings, but also working models of many of his inventions, along with examples in use today. Forget the Mona Lisa; these places portray his true level of his genius.

Informative as it was, the da Vinci exhibition was nothing compared to the display of scientific, technological, and engineering prowess in the Museo Galileo.

The exhibits covered a MUCH broader range of Renaissance science than Galileo. Recall that governments did not fund much science in technology in those days, wealthy patrons did. The Museo might ought to have been named the "The Museum of Funding of Renaissance Advancements by the Medici Family and Others," or The Humongous Museum of Renaissance Science and Technology Developed for the Benefit of Humanity by the Medicis and Friends."

I enjoyed walking through room after room filled with many examples of the engineering art that underlay the scientific advances of that period in time. Precision measuring and surveying instruments, first globes of the Earth, barometers, thermometers, a giant armillary sphere, and much more were there. I was photographing everything in sight, as was another, taking selfies with some of the more physics-related artifacts in the background. When I asked him why he was taking those particular shots, he happily explained that he was a high school Physics teacher back in the State and the shots he was taking were going to be used to illustrate his talks in class. I had an inspirational Physics teacher in my time in high school, but this guy was something else! Those of us who value teaching and learning would do well to be inspired for excellence as he was.

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See next page for pictures from the Museo Galileo in Florence by Steven H. Williams

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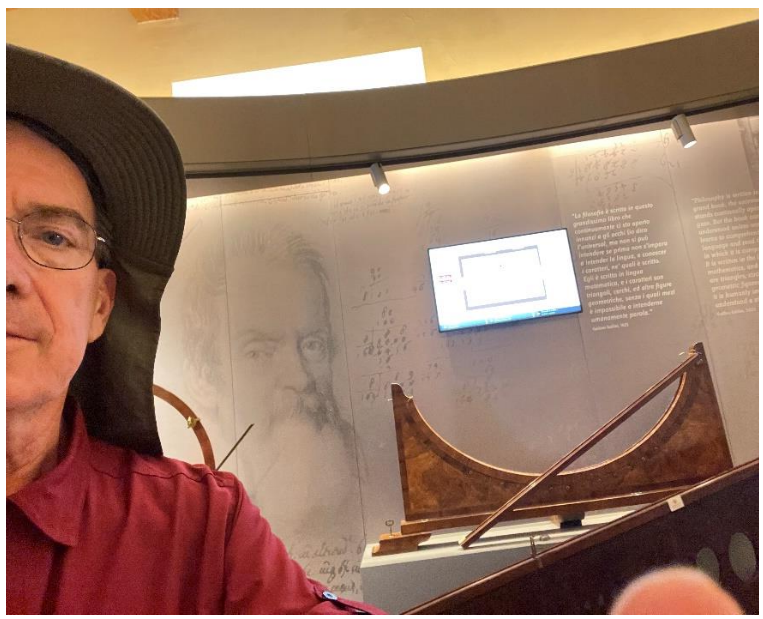
PICTURES FROM MUSEO GALILEO

Steven H. Williams (June, 2025)

Objective lens of the 1609 telescope.

Galileo's first two telescopes:1610 (top) and 1609 (bottom)

Armillary Sphere built by Antonio Santucci during 1588 -1593, showing the complexity of planetary movement if Earth was the Center of All Things.



Galileo looks over my shoulder, over the apparatus he used to study the mathematics of rolling bodies. His work with this tool, and his study of falling bodies, made a good foundation for Newton's study of forces and motion a century later.