Air and Space this Week

Item of the Week

Johannes Kepler

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Johannes Kepler's 450th birthday was last December 27. His mathematical skills built a framework for understanding the true nature of our Solar System, emphasis on the "Solar."

HISTORICAL SETTING

Human ego being what it is, people in the "Olden Days" naturally assumed that they were at the center of everything they could see. Some of the ancient Greek philosophers/scientists were skeptical that everything celestial revolved around the Earth, and Aristarchus actually deduced the truth, but senior thinkers overruled them. From Ptolemy on down, Geocentrism ruled supreme; the pull of the concept of some sort of Delphic Omphalos was too strong. After the burning of the Library of Alexandria, astronomical learning moved to the Arab world, but the Earth remained Center of All Things (CoAT) in everyone's mind.

The movements of the stars, Sun, Moon, and planets were well known in ancient times. Mercury and Venus would move between morning and evening skies with predictable regularity; the movements of Mars, Jupiter, and Saturn were different, and each had a path in the sky that showed steady movement, then a reversal of direction, then steady movement in the original direction. All could see these looping patterns in the sky over the months it took for the planets to make them.

Explaining the observed movement of the planets was difficult to explain if one had to keep the Earth at the CoAT. The model stipulated by Ptolemy and the majority of his contemporaries was that the Moon, Mercury, Venus, Mars, Jupiter, and Saturn orbit the Earth in concentric orbits, in the order listed. But to explain the movements of Mercury and Venus, he had to add a complexity to his model. The two actually made perfect circles (epicycles) around a point in Space (deferent) that orbited the Earth in a perfect circle. The deferent was always directly on the line between the Earth and Sun. It was a cumbersome system, and it could not predict planetary motions with accuracy, but it allowed Earth to maintain the fiction that it was the CoAT.

And the Catholic Church and others in positions of power weren't about to put up with anybody saying otherwise.

Such was the nature of western astronomical knowledge at the dawn of the 16th Century. William of Ockham had been dead for almost two centuries, but his simple maxim, "The simplest explanation is usually the best explanation," also known as "Ockham's Razor," was in play for some of the astronomers of the day. The complexity and inaccuracies of the geocentric model just didn't seem right.

In 1473, in what is now Poland, a boy was born into the Koppernigk family. He was a good student, and would become a physician, but his real love was astronomy. He was one of those with doubts about a geocentric system for the Universe, and he was able to think "outside the box" more than others. He assessed the weaknesses of the Geocentric model, and then made the inspired leap to use a Sun-centered model to see if it could explain the observed motions of the planets.

It could, and quite easily. He even saw that there was an observational test to prove conclusively which model was correct. In the Geocentric model, Mercury and Venus each moved as described above. Since the deferent was always on the line between Sun and Earth, those two planets would always be backlit as seen from Earth. We could never see more than a slim crescent of that planet's illuminated face. In the Heliocentric model, Mercury and Venus could be seen at times to be further than the Sun, and be front lit. Therefore, Mercury and Venus would show the same range of phases that the Moon does.

But alas, this was before the invention of the telescope, and Mercury and Venus are too far away for an observer to determine what phase it shows, using their unaided eye only.

Copernicus (his name was Latinized later) wrote of his ideas and the heliocentric "Solar System" model, and shared them with a few members of the scientific community. He rightly knew he would be punished by the Church should he publish them for wide distribution. A number of his colleagues wanted him to publish, but he held off until 1543, when he was dying. His *De revolutionibus orbium coelestium* was a masterpiece.

The telescope was still 65 years in the future, but the idea that the Earth went around the Sun inspired a number of astronomers to try their best to determine who was right. One of them was…

TYCHO BRAHE

Tycho Brahe was born in Denmark in 1546 to a family of wealth and privilege. He was raised by his uncle, who wanted him to become a politician. He entered the University of Copenhagen at age thirteen. There, he witnessed a partial eclipse of the Sun, an event that inspired an image the eclipsed his desire for learning statecraft. He switched schools and began studying math and astronomy in earnest. He was particularly interested in the positions of the planets, because he knew their apparent movements could help decide what was at the center of what.

He was adept at math enough to be able to calculate orbits of different bodies, and when he did so, he discovered that a lot of prior astrometric work had produced inaccurate data about planet movements. He knew he could better!

And he had the financial means to do so. But two significant life events came first.

By all accounts, Tycho was a jerk. He was unpleasant to be around, had few friends, and was apparently quite quarrelsome. On December 29, 1566, he had been drinking heavily with a distant relative, and they got into an argument over – no kidding now – who was the better mathematician! But rather than dueling with math (calculating pi to 20 places?), they chose swords. Tycho was probably the better mathematician, but the other guy was definitely the better swordsman, and he promptly slashed off a big chunk of Tycho's nose! Tycho had to wear a false nose the rest of his life (brass for everyday, silver and gold for special occasions).

Tycho's father died in 1571, and a rich uncle, intrigued by Tycho's interest in astronomy, helped him build an observatory/alchemy lab at a place called Herrevad Abbey.

Tycho hit one of those career-defining moments not long after construction began at Hven, while at Herrevad, on November 11, 1572.

The understanding prevailing in 1572 of the stars in the sky held that they were eternal and unchanging. But Tycho was observing on November 11, and noticed that the constellation of Cassiopeia had a new, bright star that had not been there before. Most remarkable! And even weirder, Tycho immediately began making positional measurements of the new star, seeking to detect parallax motion from which its distance could be determined (see here). There was none.

No parallax meant that the new star had to be incredibly distant, hence incredibly bright. [It was both, we know it now as Supernova SN 1572.] Seeing something change in the heavens was quite a disconcerting event for many. Tycho published a book, *De Nova Stella*, with his description and parallax negative results, and it made him well-known. The new star became known as "Tycho's Star."

Tycho's family had been friends with King Frederick II for years; another of Tycho's uncles had once saved the King's life. He recognized Tycho's new fame by sanctioning the construction of a really good observatory on the Danish island of Hven, near Copenhagen. The place would be called "Uraniborg," the "Castle of the Heavens."

Tycho quickly became widely known for two things: he made positional measurements of stars of extraordinary accuracy and precision (his measurements were accurate to +/- 2 minutes of arc, equivalent to the breadth of a human hair held at arm's length!), and he treated his visitors with lavish hospitality. The end result of the former was the production of a good map of the heavens. He then turned his attention to making positional measurements of the planets, and he was especially interested in Mars. He had a gut feeling that high-quality positional measurements would prove scientifically-valuable someday, but he lacked the higher-level mathematical skills needed. His observations, for all their superb quality, would be doomed to being only numbers in a book if he couldn't find a sharp assistant who could use his observations to good effect.

Tycho's patrons were dying off, and the Hven locals and the next leaders pretty much hated him. But Rudolph II, the Holy Roman Emperor, still liked him, so he packed up his measuring instruments and decamped for Bohemia in 1599. His observatories on Hven quickly fell into ruins; nothing remains of them today. Old Rudy was a bozo, and the monies promised Tycho were seldom received, but that was the least of Bohemia's problems. Rudy would eventually be deposed in 1611.

Soon after arriving in Prague, Tycho took in an assistant who was chomping at the bit to get ahold of Tycho's planetary observations. The young man was a bit weird, even by the astrology/alchemy standards of the day. His name was Johannes Kepler.

JOHANNES KEPLER and his THREE LAWS of PLANETARY MOTION

Johannes Kepler was born on **December 27**, 1571, 450 years ago. He was a sickly child whose hearing and vision would be damaged by illnesses, but his mind was super sharp. His family was poor, but Johannes' skill was great and rewarded by a scholarship to the University of Tūbingen, where he was slated to study for the ministry. He was profoundly religious, and his family and Tūbingen were devoutly Lutheran, a factor that would affect his career. Kepler's thoughts paralleled those of Plato and Pythagoras, that the Universe was created be a carefully-constructed mathematical plan, and he felt it was his duty to use mathematics to better understand the works of God. He was particularly interested in the five known "Platonic" solids (tetrahedron, cube, octahedron, dodecahedron, and icosahedron).

Scholars of the 1570s regarded "mathematics" to include arithmetic, geometry, astronomy, and music, and the astronomy training Kepler received at Tubingen was that of Ptolemy and the Greek orthodoxy. But Kepler was not content on merely being able to calculate planetary positions, he wanted to understand the characteristics of planetary orbits and the forces that affect them. Many of his ideas on the subject were pretty bizarre by today's standards, but his teachers were impressed enough to allow him to take more advanced courses, where he would be exposed to the writings of Copernicus.

Kepler was astonished by the thought of a Sun-centered system, and immediately began to imagine how the underlying mathematical structure of a Solar System might look. He started with a sphere, a 3-D version of Saturn's orbit. If a cube were inscribed in the sphere, Jupiter's orbit would fit within it. Similarly, if a tetrahedron were inscribed within Jupiter's orbit, Mars' orbit would fit within it. A dodecadhedron inscribed within Mars' orbit would hold within it Earth's orbit, an icosahedron inscribed within Earth's orbit would hold Venus' orbit, and an octahedron inscribed within that would hold Mercury's orbit, with Earth at the Center of it all.

William of Ockham spun wildly in his grave.

Kepler published his model and other ideas in 1596, in a book called, *Mysterium cosmographicum*. However, Kepler, while raised Lutheran, refused to adhere to all their principles. He also refused to convert to Catholicism, which left him without a patron or a job during the Thirty-Years War. As a consequence, he moved to Prague. Fortunately, his book came to the attention of Tycho Brahe, who was greatly impressed. Tycho had found his mathematician!

Tycho asked Kepler to meet with him at his new observatory. Kepler stayed there for two months, working with some of Tycho's measurements of the position of Mars. Tycho was very protective of his observations, but Kepler demonstrated excellent analytical skills and Tycho knew he needed Kepler's help, so more access was granted. Good thing, for Brahe died in 1601, and Kepler inherited access to all Tycho's observations, although he would have legal hassles with Tycho's heirs over their use.

Along with Tycho's observations, Kepler also inherited the responsibility of providing astrological advice to Emperor Rudolf. He pursued both tasks religiously. He used Tycho's observations and other data to develop the best star and planetary position catalogue of the day, eventually published in 1627. He continued to call the catalog the Rudolfine Tables, in spite of the fact that Rudolf had been deposed years earlier.

The importance of his astrological role came in 1604, when he, as had Tycho, observed a supernova. He also showed that the new star was very far away. But the timing of the new star caused astrology-believers some pause; they linked it to a "Fiery Trigon" that linked the Star of Bethlehem and the rise of Charlemagne on an 800-year cycle.

While all of this was going on, Kepler was working hard on his book, *Astronomia Nova*, based primarily on his analysis of Tycho's Mars observations. No matter how hard he tried, he could not reconcile Tycho's observations of Mars' position with Mars having a circular orbit. But then, he had one of those leaps of inspired thought that occasionally come along – what if Mars' orbit wasn't a circle? What if Copernicus was right about the planets, including Earth, orbiting the Sun, AND that Mars' orbit was an ellipse, with the Sun at one focus? In that light, Tycho's observations could line up perfectly with the Copernican predictions!

The ellipticity of planetary orbits became known at *Kepler's First Law of Planetary Motion*.

But orbit shape alone was not enough to impress Kepler. His analysis showed that a planet's speed along its orbit increased when it was closer to the Sun, and decreased when it was farther away. A vector from the Sun's center to the planet's center would sweep out an equal area per unit time, no matter where the planet was in its orbit. Kepler used a complicated geometric analytical technique to derive the "equal area per equal time" characteristic of a planetary orbit, which would become known as *Kepler's Second Law of Planetary Motion.*

Both "Laws" were published in *Astronomia Nova*, in 1609. Many decades later, Newton and his Law of Gravitation were used to derive Kepler's Laws with mathematical rigor.

What a heady time this must have been! The telescope had been invented in 1608, and Galileo's first observations were published in 1610. Kepler was deriving important mathematical descriptions for the observed movement of the planets, and Galileo was overturning the Greek dogma that had paralyzed astronomy, finding that the Sun had imperfections (sunspots), Jupiter was the center of at least some of the movements of Solar System bodies, and that Venus showed a full range of lunar-like phases, meeting the observational test Copernicus had written about almost a century before!

The following decade was a difficult one for Kepler. In 1612, Lutherans were banished from Prague, so he had to move. His wife and two of his sons died. He remarried, but his new wife would lose two sons in infancy, he had several financial setbacks, and he had to take time off to help (successfully) defend his mother from charges of witchcraft. In spite of all of this, he was still able to make a number of other important contributions to astronomy.

Kepler had always been interested in geometrical things as worthy clues left by the Creator's handiwork; his nested Platonic solid model of planetary motion was an early example. He felt that harmonies in music were akin to harmonies in geometry, and that the harmonies of planetary orbits were expressed in musical tones, an updated version of Pythagoras' ideas of the "Music of the Spheres." He was particularly interested in the "harmonious" relationship between the size of a planet's orbit and its orbital speed. He did not have the mathematical or physics basis to derive their interrelationship with rigor, but he did eventually come up with a relationship that would become Kepler's Third Law of Planetary Motion: "The square of the periodic times (of a planet's orbit) are to each other as the cubes of the mean distances." He recorded in his journal that this relationship came to him on March 8, 1618, but no details of how this knowledge came about was given. He published the Third Law in 1619, in his book *Harmonices Mundi*. He went on to publish an even more important book, *Epitome Astronomiae*, in 1621, in which he gave a systematic explanation of heliocentrism. He even finished the monumental *Rudolphine Tables*, after inventing the use of logarithms to do so!

Kepler died in 1630, and his grave was destroyed in 1632, collateral damage of the fighting of the Thirty-years War. But his astronomical spirit lives on in our basic understanding of planetary motions, and his Third Law is still routinely used today to determine the mass of orbiting bodies.

REFERENCES

Overview: I actually used the very first astronomy book I bought with my own money in the preparation of this Item! Sir Patrick Moore, the famed English astronomy popularizer, wrote *The Picture History of Astronomy* in 1961; I have a copy of the third edition, published in 1967 by Grosset & Dunlap of New York. Its Library of Congress Catalog Card Number is 67-21116. Moore is a most interesting, but somewhat controversial, figure, befriended by Dr. Brian May, and perhaps the only person who actually met Orville Wright, Yuri Gagarin, and Neil Armstrong in person!

Just before I bought *Picture History*, still in 1967, I was given a copy of Moore's The Observer's Book of Astronomy." It was a pocket-sized marvel, and was the source of my interest in Astronomy. I've already passed it on to my daughter.

Copernicus

De Revolutionibus: here

Tycho Brahe

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Johannes Kepler

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