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Reason in Motion

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This essay will explain the historical models of the solar system, which was the known universe for most of human history. There is far more to each model than simply positioning different celestial bodies at the center of the system, and the stories of the astronomers who derived the controversial theories are not discussed often enough. The creation of these theories is part of a much broader revolution in scientific thought and marked the start of a series of observational discoveries that would change the the philosophy of science for centuries to come.

I. STUDY PURPOSE

Although science and history are seen as two very separate fields of study, they depend greatly on each other. At the beginning of most science classes, professors usually explain the origins of their specific field of study (i.e. chemistry, mechanics, etc). This is in order to better contextualize the class subject and show why it is important to learn for applications. However, this portion of each class is usually very brief and trivial to students. It is the duty of academia to show the true value of studying the process that scientific laws arose from. This essay seeks to explore the historical trends of enlightened thought and the scientific method. Specifically, this essay will look at the historical models of the solar system and the influential scientists and observers who gave rise to newer models such as Johannes Kepler, Galileo Galilei, and Isaac Newton.

II. ANCIENT HISTORY

Many ancient civilizations used the stars for charting and navigation, but the Greeks were among the first civilizations to notice trends among the heavens [5]. They created the modern constellations as well as observed that the majority of stars seemed to be stationary, with the exception of the sun, moon, and five "moving stars". It is worth mentioning that because there are seven major celestial bodies, there was the idea that the number seven was divine and fit within a very religiously aesthetic model of creation. In this case, it became known as the "Seven Heavens." The idea was that there were spheres that caused the planets to be rotating, because at the time, Newton's laws had not been constructed. The conventional belief was that in order for an object to move, there had to be a force acting on it constantly. Because the heavenly bodies and the celestial firmament appeared to be rotating around the Earth on an axis, the conventional thinking was that the Earth was the center of the universe. This is known as the idea of the Geocentric Model. This was also influenced by metaphysical notions of human importance. In other words, man saw himself as the most important and the most divinely endowed of all creation, and his worldview reflected that about himself. This is not only true for the Greek polytheistic religious system, but also evolved into other groups such as the western religious traditions throughout Judaist, Christian, Zoroastrian, and Islamic spheres of influence. Centuries of observations seemed to only further provide reason to believe that this was all there was to the celestial heavens, partly due to the fact that certain observations require centuries of study which was difficult considering the available technology and the ever-changing regional politics of the ancient world.

III. EARLY MODELS

Because of this, for two millennia, the primary idea was that the solar system model was geocentric or that the Earth was at the center of all orbital motions. However, it is a bit more complicated than simply observing that the heavens all move in one direction so therefore they are all orbiting around the Terra or Earth. On the contrary, over centuries of observation, by the time of Aristotle, it was noted that the planets were moving not in a linear fashion. Rather, the planets move in a series of cycles about two spheres, known as the deferent and the other as the epicycle. This was developed by Ptolemy and is known as the Ptolemaic model which was used to describe for the reason that the planets seemed to mysteriously shift their orbits backwards for a brief time until reverting to their original course. This is known as a retrograde motion and confused many astronomers, especially in the case of Venus where Ptolemy was forced to stretch the period of greatest elongation in order for the planets to relatively match his predictive model [3]. Aristotle also himself proclaimed using three arguments of "common sense" that claimed a moving Earth would be impossible. These arguments are that since the Earth is not spinning, things do not fly away, flying birds would not be left behind, and there is no parallax effect in the stars [2]. A parallax is the effect of noticing that when one is in motion, objects are observed to move at a slow rate. These arguments can be debunked using Newton's

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laws of motion, since an object in motion along wit another object at the same rate would not "fly away" and birds would continue in the motion of the Earth. However, these laws were not discovered yet and were not empirically tested. Centuries later, there was a young astronomer by the name Nicolaus Copernicus, who had formulated a hypothesis that the Earth itself must orbit the sun because of the similar problems he was encountering when observing the orbit of Venus [3]. This was not the earliest recorded idea of a heliocentric model, as there are records to as far back as Aristarchus of Samos in 200 B.C. or Philolaus' "central fire" theory (this fire was not the same as the sun) [2]. This theory, however, was not taken as a legitimate scientific claim considering it could not explain the current observations any better than the Ptolemaic Model, since there was no observed parallax with the stars and the epicycles were already accounted for. There was also the problem of the resulting philosophical and theological backlash against the conventional wisdom that a humanity creation-centered existence held. Around 1580 AD, another astronomer, Tycho Brahe, who based on observation, created a self-goal for himself to create the first ever total astronomical theory that could predict the positions of each planet exactly. "Tycho admired the unification that Copernicus had achieved, the linking of the planets into a common systems of motions around the sun, motions that offered for the first time a natural explanation of the otherwise puzzling retrograde motion of the planets" [6]. This was contrary to the conventional Ptolemaic model, shown in figure 1.

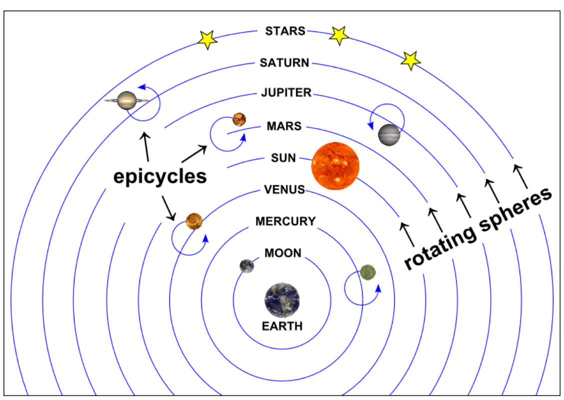

FIG. 1. The Ptolemaic Model as shown above accounts for the reversal in apparent orbits as epicycles of the planets as they rotate around the Earth within rotating spheres [10]

Tycho realized that the planets that had a retrograde motion, but the sun and moon did not. He reconciled this fact by claiming that the other planets were directly orbiting the sun, like in figure 2.

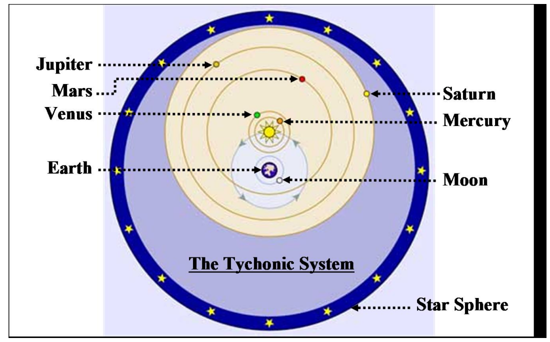

FIG. 2. Tycho Brahe's geo-heliocentric model is to this day a very unique perspective on how orbits function. This takes into account of epicycles and has no need for a stellar parallax. [11]

Tycho noted that the sun, moon, and the sphere of stars do not have a retrograde motion, and thus they must orbit around the Earth. This is known as a geo-heliocentric model and was revolutionary in that it showed bodies did not necessarily have to orbit the Earth. Each of the Ptolemaic and Copernican Models were able to give accurate predictions based on observations at the time, or at the very least, what they thought was accurate. The primary issue with the Copernican Model is that it still included a retrograde motion because its orbits were circular. It did not do a good enough job at predicting what would happen any better than the Ptolemaic. Also, the problem of a stellar parallax was detrimental to the validity of the Copernican Model and troubled its supporters. This is because there was no observed parallax, so the Earth could not possibly have been moving. This is due to the fact that the ancients believed that the stars were only as distant as the magnitude of a planet's orbit. Therefore, if the Earth truly was moving, then the stars would need to possess some sort of parallax effect. Thus, up to about 1600 AD, the best model of the universe was still the Ptolemaic.

IV. JOHANNES KEPLER

Enter a Renaissance astronomer by the name of Johannes Kepler around 1600 AD, who noticed what Tycho Brahe was doing and inherited the works of Tycho, including his universal model and the observational records. Unlike other astronomers, he was an advent supporter of a heliocentric theory and saw it as a religious manifest of God's providential design of the universe. He saw this model as a representation of the trinity, with the Father representing the life-giving sun, Jesus Christ as heavenly firmament guiding moral bodies, and the intermittent space as the unseen force of the Holy Spirit [6] [4]. Kepler defied the conventional scientific community at the time because astronomers were grouped in two different schools, one focused on mathematics and the other on cosmological philosophy. What made him interesting is that he dared to not only side with one school but attempted to bring them together under one theory [6]. His metaphysical approach to the model pushed him to further explore how creation works and was committed first and foremost to the physical reality of the heliocentric system. Using observations obtained from Tycho along with his own about the orbit of Mars, he was able to triangulate the position of the Earth's orbit using the position of Mars as a guide. However, in his analysis, he noticed that applying his expected values of eccentricity in the orbits were not predicting what was actually happening. This delicate analysis of such triangulation made it evident that the eccentricity of Earth's orbit as measured before had to be halved [3]. " At last he realized that an ellipse (which he had been using as an approximating gure) gave just the right area if he placed the sun at one focus of the ellipse. It was as if another miracle had occurred, and Kepler himself said it was like awakening from a deep sleep" [3]. Once he had this revelation, he could start to formulate his laws of planetary motion based on his evidence presented. He had not fully realized the laws of inertia and the laws of motion yet, but because of these observations, he paved the path for Isaac Newton and other physicists to derive such laws. He created some mathematical hypotheses to help explain the phenomenon such as the following: The planetary orbits are elliptical and the velocity of a planet's motion transverse to its radius vector [10]. This led him to discovering that, based on empirical observations, the square of a time period of an orbital revolution is directly proportional to the cube of its semi-major axis.

$$\frac{T^2}{r^3} = k \tag{1}$$

This became known as Kepler's Third Law of Planetary Motion and is essential in studying the nature of orbits. It is also worth mentioning that Kepler, almost by pure accident but mostly through careful analysis, discovered that the area swept out by every orbit in the same time period is out the same area every time, regardless of where it lies on the orbit [3]. For example, if Mars orbits the sun for exactly 3 days, the area between the sun, Mars' old position, and Mars' new position would be the same no matter where Mars is in its orbit, whether at its perihelion or elsewhere. This is better shown in figure 3:

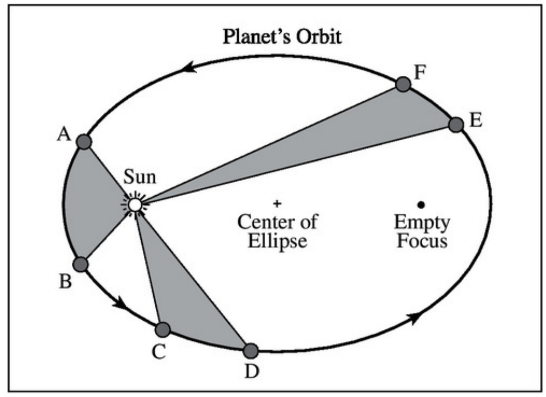

FIG. 3. Note how regardless of the location, as long as the orbital period is the same, the displaced distance is the same [12].

This developed into Kepler's Second Law of Planetary Motion. This paved the way for Kepler's Laws of Planetary Motion and were key essentials to how Newton would develop his Laws of Motion as well.

V. GALILEO GALILEI

With the invention of the telescope, much more detailed observations were able to be made like never before. Around 1610 AD, an Italian astronomer named Galileo Galilei used this technology in order to peer directly into the surface of the planets, including Venus, which he noted had a full range of phases much like the lunar phases. At the beginning of his studies, he was considered to be a timid Copernican because at the time Kepler was a high school teacher, Galileo was a university professor who wrote to him that he, too, was a Copernican albeit secretly. Galileo was already involved in numerous political issues and did not want his name to be slandered with some form of heresy. However, he became much more of an open-book when in the summer of 1609, a Dutch spectacles maker invented a magnifying defice with two lenses that brought distant images closer. He achieved up to 20 times power, and he created a watercolor image of the moon's surface using the telescope with some paper and a brush. One night, he noticed Jupiter was relatively close to a gibbus moon cycle, and as fate would have it, he found three small stars all in a line around Jupiter. The next few days, he noticed that they seemed to move about an axis on Jupiter, and he discovered the new satellites of Jupiter!

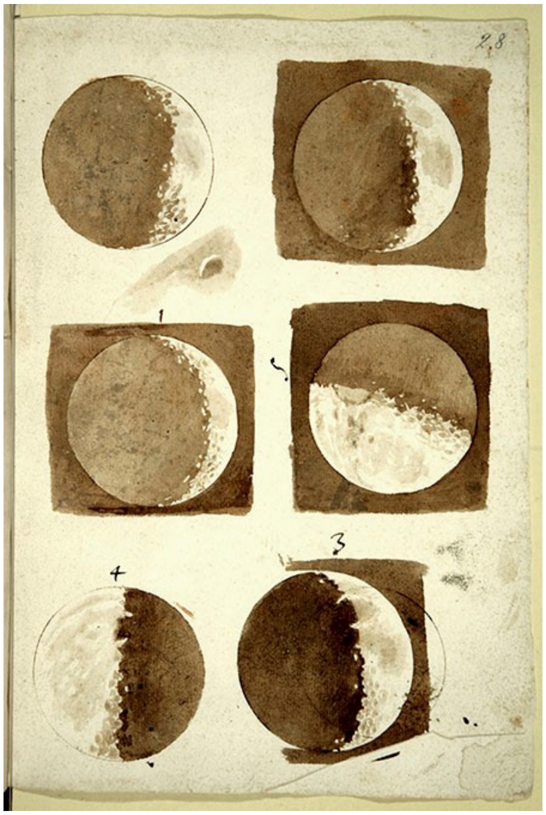

FIG. 4. The original copies of Galileo's observations of lunar cycles through a telescope [3]

From this point on, he became known for his telescope works in astronomy and, although the argument of moons around Jupiter proved not that the Earth itself moved, it was still now more respectable of a leap of logic to say that the Earth could do the same. He also soon realized that, " In the Copernican system, because Venus goes around the Sun, it would show a full set of phases (as the Moon does), that is, when it was beyond the Sun, the telescope would show the fully illuminated face in the Ptolemaic system, the epicycle carrying Venus always lies between the Earth and Sun, so a fully illuminated face would never be visible" [3]. However again, this does not prove the movement of the Earth, but it does disprove the Ptolemaic epicyclic arrangement, which was huge news at the time. Tycho's model could still suffice in this situation, but combined with Kepler's precise measurements, Tycho's model began to lose ground fairly soon after. Despite this, Galileo still pursued on seeking to prove the motion of the Earth. Of course, very powerful theological forces within the church noticed his disregard with the wisdom of the scripture and his lack of solid proof that the Earth moved. There are many misconceptions about this controversy, painting Pope Urban VIII as some tyrant against reason and Galileo as some scientific martyr. In truth, Galileo had many problems with the church before and after his discoveries of Jupiter's moons or the phases of Venus. The primary reason why he was put on trial was that he could not provide sufficient evidence and still taught the heliocentric model as fact [10]. It did not help that Kepler was a Lutheran, so their relationship had to be kept a secret because the church could have associated Galileo's association as heretical. This was all happening during a time period of rapid philosophical change throughout the Church and was also at the height of many religious wars fought between Protestants and Roman Catholics, that usually shunned open debate. Nevertheless, universities continued their research, and the models of a heliocentric universe persisted.

VI. ISAAC NEWTON

Later in 1679 AD, an English mathematician and physicist Isaac Newton took notice of these new movements and discoveries. Although astronomy was not his strongest field of study, he was nevertheless intrigued in how the heavenly bodies acted with each other because, maybe, he could apply those same mechanics to objects that he could interact with himself. A moving Earth could seem preposterous to many people based on the way that humanity thought forces worked. As mentioned before with the Aristotelian mechanics of motion, it indeed made no sense why the Earth would move so quickly. Galileo's Second Law states that, " A moveable projected horizontally has a motion compounded from equable horizontal and from naturally accelerated downward [motion]. These horizontal and downward motions in mixing together do not alter, disturb, or impede one another", and Huygen's Second and Third Hypotheses states, " By the action of gravity, whatever its sources, it happens that bodies are moved by a motion composed both of a uniform motion in one direction or another and of a motion downward due to gravity. These two motions can be considered separately, with neither being impeded by the other" [10]. This language sounds very familiar, and indeed these ideas led Newton to formulating his Second Law of Motion in terms of compounded motions: "a body acted by any force has a motion independently compounded from the motion the body would have had if the motion of the body had been uniformly continued at the place and from the motion that would have been generated at that place by that force on that same body at rest" [10]. This is a different way of saying that the sum of forces applied on an object (assuming constant mass) has a constant acceleration, otherwise the velocity is constant in any inertial frame. By this time, the heliocentric model had been tested greatly, and so far, it had not only failed to be disproven but also was becoming ever-so more accepted as astronomical observations became much more detailed. In this field, Isaac Newton was clearly heavily influenced by Kepler's Laws of planetary motion and realized that the common center of gravity of all the celestial bodies and the Earth was the true "center of the universe" because all bodies were not orbiting a body, but rather, a center of mass. This better explained why there was a sun deviation as the sun appeared to wobble very slightly back and forth, mainly caused by the gravitational attraction of Jupiter. He created the well-known equation representing Newton's Law of Gravitational Attraction:

$$F = G\frac{m_1 m_2}{r^2} \quad (2)$$

This can also be represented as the centripetal force of a circular object as substituted for a gravitational force:

$$m_1 r\omega^2 = G\frac{m_1 m_2}{r^2} \quad (3)$$

Newton realized that the laws governing the universe's bodies must also govern how the laws of motion and gravity work on the individual level, and with every experiment, he could confirm his original hypotheses of how the universe is built. Even long after his death, many of his students continued his work and formulated theories of energy conservation and action.

VII. MODERN PROGRESS AND EVIDENCE

For the majority of history, humanity saw itself as the center of the universe and developed models to fit the observations. As the details of observations increase however, astronomers, the church, states, and humanity at large had to come to terms that the heliocentric model is more accurate. During the 19th century, the first infrared and ultraviolet radiations were detected in 1800 and 1801 respectively [1]. With this technology, the new planet of Uranus could be discovered as it was invisible to the human eye. This combined with highly precise measurements of the orbit of Uranus, the planet Neptune became the first planet located before it was discovered (since Uranus' orbit had irregularities) [1]. As time went on even further, many scientists began to ponder that perhaps the sun itself is not stationary and orbits a center of mass with other stars. In the mid-19th century, the parallax of distant stars were discovered, which implied that the universe was unimaginably larger than previously expected. In the early 20th century, it was determined that there were very faint stars in a small region of space, and with the advancements of satellite imagery, it became clear that these stars were not stars at all but, "island universes because they contained a large number of stars within them. They eventually became known as galaxies, and even they adhere to the Newtonian mechanics derived from Kepler's Laws.

VIII. CONCLUSION

It would be very difficult to fully appreciate how basic tenants of modern Science came to be and how they can be overlooked, especially when one studies the historical trends. Scientific theories are rarely proven, and as in the case of Galileo, when theories are taught as hard facts, misinformation can ensue. In reality, theories can be "given more academic credibility", and over time, they can emerge as the best explanation for natural phenomenon. As technology increases, certain measurements make certain theories much more fallible, in the case of the Ptolemaic model. The old models are still extremely helpful in determining how the modern scientific community can understand where these historical astronomers and observers came from and how physicists like Isaac Newton were able to collect their observations and create an entirely new perspective on how reality functions. Much like life, the solar system, and the universe at large, is mostly a matter of perspective and predictability.

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