Measuring the Universe **12 March 2020**

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Genesis, chapter one; verse one. “In the beginning, God created the heavens and the earth.” Regarding God, as scientists, we simply don’t know. When was the beginning? Scientists estimate that the universe is approximately 13.8 billion years old. The earth is approximately 4 billion years old. We will explore how the study of astronomy has developed over the centuries; specifically, how we measure time and space; and the continuing search to go back in time to find the ‘beginning’.

Humans started watching the night sky using their eyes. Eventually, after thousands of years of observation and inspiration; other technologies developed to better measure and predict astronomical events. By the way, humans can see about 6,000 stars and five planets unaided.

Astronomy was the first developed science. Early humans were thought to be looking out for the gods in heaven. Professor Anton Pannekoek from the University of Amsterdam, in his seminal book *A History of Astronomy* says, the study of astronomy “satisfied [humans] craving for truth. People learned to read the phases of the moon; they observed the wandering planets that would move across the night sky; as differentiated by the “stationary” stars.

Humans literally worked over millenniums, observing and measuring the length of days in a search for the first day of the month; the appearance of the crescent Moon. Pannekoek reports that the new Moon had significance in many cultures including the development of various calendars. Pannekoek says, “the purpose of all early astronomical practice was the measurement of time and this was based originally on the [phases of the] moon.”

Humans search for the universe had religious overtones. For example, harvest festivals were planned and scheduled according to celestial events. The Babylonians influenced astrology, namely the concept that the course of our life as a function of when we were born. Doctor

Pannekoek says “omens were to be found everywhere.” At the same time, philosophers began to describe the universe in natural terms.

In the 5th century BCE, there is evidence that humans started looking at the relative positions of the constellations. The Babylonians started keeping lists and tables of astronomical events. They connected and recorded positions of stars in ancient texts with notations such as “Orion rises as Sagittarius sets.” These events implied that the calendar had acquired a certain regularity.

Astronomical measurements were made possible by the development of geometry between approximately 350 BCE to 50BCE. Professor Pannekoek says geometry [anchored by *Euclid’s Elements]*, was the “miracle of the human mind.”

In 340 BCE, Aristotle and the Greeks understood that the Earth was round as they could see the curved shape of the Earth’s shadow during lunar eclipses. Despite the conventual wisdom at that time that the Earth was the center of the solar system, it was the ancient Greeks that discovered the rotation of the Earth and the yearly orbit of Earth around the Sun.

Around 250 BC, Eratosthenes from Egypt, using geometry, calculated the unknown circumference of the Earth by measuring the distance between two cities in Egypt; and the angles of the shadow of sticks in each city at high noon during the summer solstice. He was accurate to within two percent. Simon Singh, in his book *Big Bang* concludes, “it proved that all that was required to measure the planet was a man with a stick and a brain.”

Eratosthenes was then able, by using the now known circumference of the Earth to calculate the Moon’s diameter during a lunar eclipse. He compared the time the Moon traveled from touching the shadow of the eclipse to being fully covered, specifically 50 minutes, which gives us an idea of the Moon’s diameter. Then he measured the time for the front of the Moon to cross the entire shadow, an indication of the Earth’s diameter, specifically 200 minutes. As such, the Earth’s diameter is roughly four times the Moon’s diameter.

After the size of the Moon was determined, Aristarchus of Samos calculated the distance of the Earth to the Moon using the ratio of his outstretched thumbnail, which covered the Moon's sphere, to his arm's length. Singh reports, "an arm's length is roughly a hundred times longer than a fingernail, therefore the distance to the Moon is roughly a hundred times its diameter."

Aristarchus then calculated the distance to the Sun by using the fact that the Earth, Moon, and Sun form a right-angled triangle when the Moon is at its half-phase. Simple trigonometry and then known Earth-Moon distance was be used to estimate the Earth-Sun distance.

Once we determined the distance to the Sun; we could deduce the diameter of the Sun during a total solar eclipse and our knowledge of the Moon's distance and diameter. The distance to the Sun was later validated when, using the concept of parallax, astronomers watched and measured as the planet Venus traversed the face of the Sun, as predicted earlier by Edmond Halley.

Parallax is the apparent shift in the position of an object due to an observer's vantage point. Close your right eye and using your outstretched thumb focus on an object. Now, without moving your thumb, open your right eye and close your left eye and see how the vantage point changes. Next, move your thumb closer to you and repeat, you will notice a change in distance depending on the position of your thumb. That is parallax. Using parallax and trigonometry we could calculate the distance to the Sun and eventually the distances to other stars and galaxies.

In the sixteenth century, Tycho Brahe, a Dutch nobleman took observational astronomy to a new level using instruments such as sextants, quadrants in his lavish observatory funded by the state. Brahe would later team up with Johannes Kepler, a German mathematician and astronomer, who was able to interpret Brahe's observations and clarify the orbits of the planets. This cooperation is a continual theme throughout the history of astronomy; observations supporting a theory confirmed by experiments.

Up to the 16th century, and despite earlier conjecture that the Sun was the center of the solar system, people in general and astronomers believed the Earth was the center of the universe.

This was fueled by a combination of conventional wisdom at the time. First, common sense told us we are standing still; after all, we do not perceive by simply standing in place that the Earth is rotating or the Earth is orbiting the Sun. Also, the stars seemed to be stationary.

In 1512, Nicolas Copernicus, a Polish priest, proposed the idea of the Earth and other planets orbiting the Sun. In this heliocentric world, the Earth was not the center. Later, building on Copernicus' theory, Galileo using the newly developed telescope, discovered Jupiter's moons. The moons revolving around Jupiter was indisputable evidence that not everything orbited the Earth.

As it turned out, Galileo famously defended the idea of a Sun centered universe. This theory round afoul of the Church's belief of the Earth as the center of the universe from interpretations of the Bible. Galileo was tried by the Inquisition and remained in house arrest for the remainder of his life.

Sir Isaac Newton's big idea was explaining gravity, inspired by the idea of an apple falling from a tree, eventually leading him to develop his famous three laws of motion. Newton's development of calculus to support his theories was monumental. Up to this point, astronomers relied on trigonometry to calculate astronomical objects; calculus was needed to understand circular orbits and such. The physicist Richard Feynman once said, "calculus is the language God talks." It is a remarkable fact that the universe follows mathematical laws, which we cannot explain. Imagine what the Greeks would have accomplished if they had calculus?

Approximately In 1867 the science of light developed. Light is another word for electromagnetic radiation. Light dispersed through a prism reveals its spectrum and enables scientists to study light and its elements by wavelength. Different atoms emit and absorb specific wavelengths of light. Astronomers could start to see the composition of a star.

Earlier, in 1620 Gian Domenico Cassini proved that the speed of light was finite; others calculated the actual speed of light. Eventually, Albert Einstein's work would lay the ground rules for studying the universe. Building on these papers, astronomers found that the wavelengths in starlight was shifted, explained by the Doppler effect. Think of the sound of a train coming toward you; and the different sound of the train traveling away from you. The difference in sound is caused by the Doppler effect. The conclusion, by measuring the wavelengths, the galaxies were racing away (redshifted) from the Milky Way.

Additionally, Edwin Hubble's measurements and observations helped support the idea that the universe started in a small condensed sate and then expanded outward, what is known as Big Bang, theorizing that the universe originated about 13.8 billion years ago, a moment of infinitely dense conditions; in other words, close to the origins of our universe. We believe that the universe continues to expand today, however, we do not know what happened at the exact moment of the Big Bang. Ian White, in his book *a measure of all things* states it is not possible to know what happens less than one Plank time after the Big Bang. Plank time, for our conversation, is an infinitely short distance. As such, we don't know the conditions present at the precise moment of the Big Bang.

In 1912, women were not allowed to use observatory telescopes. Henrietta Leavitt working as a computer behind the scenes, showed that Cepheid variable stars, a type of star that pulsates, could be used to indicate their actual brightness and therefore estimate their distance as a function of the interval between pulses. Astronomers now had a ruler for measuring the universe.

As an example, in 1923 Edwin Hubble built on Leavitt's work and identified a Cepheid variable star in a distant nebula and proved that is was far from our own Milky Way galaxy. Leavitt's big idea could have been worthy of a Nobel prize, as Edwin Hubble recommended after Leavitt died at age 54. Unfortunately, Nobel prizes are not awarded posthumously.

Advances in other fields include the development of instruments that attach to telescopes such as cameras and spectrographs. These telescopes capture all forms of light; visible light, infrared ultraviolet, and X-Rays. NASA telescopes can detect gamma rays. Each wavelength tells us something about the composition of a star, or other stellar object.

Astronomers can measure light digitally and computers combine many telescopes into one observation. We discovered black holes by what is not seen; other objects interacting with dark space. Photography uses time exposures to record faint objects; and the blink comparator allows one to quickly switch between two observations and was used to discover Pluto. As such we are capturing information further and further back in time.

We use coronography technique to block light to see the details around a star or our Sun. Microlensing enables us to measure a star's wave shifts, allowing us to locate planets, even if we do not see the planet. Interior of stars can be measured with helio-seismology, tracking Doppler shifts (a change in wavelengths); as different wavelengths penetrate to different depths.

Space probes have visited all the planets in our solar system. We have landed on Venus and Mars and have crashed a vehicle on Mercury. We landed a probe on Titan, a Saturn moon, and discovered frozen methane, which may indicate the presence of life.

In 1994, astronomers watched Comet Shoemaker-Levy crash into Jupiter. Similar impacts probably explained the end of dinosaurs on Earth. The Comet Shoemaker was named in part for a woman astronomer from New Mexico, Carolyn Jean Spellman Shoemaker, who along with her husband and one other scientist discovered the comet. At one point, Carolyn Shoemaker was credited with discovering more comets than anyone else.

We launched the Hubble Deep Field telescope in 1990. George Coyne, S.J., the former director of the Vatican Observatory, explains that the Hubble telescope, positioned outside the Earth's atmosphere, focused on a small part of the sky, about one-twentieth the size of my index finger and discovered one million galaxies. Do the math and we estimate 100 billion galaxies each with 200 billion stars. As a reference point, if you took three grains of sand and placed them in a large football stadium, the stadium would be more densely packed than the universe. Despite trillions of stars, the universe is largely empty space.

Scientists started out with sextants and other navigation instruments. The telescope enabled us to delve into the solar system and eventually interstellar space. Rocketry enabled us to deploy telescopes out of the Earth's atmosphere and launch planet rovers to land and explore the Moon and other planets. Computers enable scientists to calculate large numbers.

We measured the circumference of the Earth; then the size of the Moon; then the distance to the Moon; the distance to the Sun; the size of the Sun; using trigonometry, calculus, parallax, and Cepheid variable stars to measure the universe. Coupled with simple and diligent surveys of the sky and the ingenuity of scientists, we built on our body of knowledge to look back in time in our quest for the "'beginning."

Today, astronomers are monitoring the star Betelgeuse, which is expected to explode in a supernova in 100 thousand years or so and will light up the night sky. Supernovas occur when stars explode toward the end of their life, spewing elements into space. It is estimated that our Sun will explode in five billion years and will consume the planets Mercury and Venus and make Earth uninhabitable. The potassium in our bananas was created a long time ago during a supernova. In the same manner, humans are literally stardust.

We are planning a manned mission to Mars, possibly in the next twenty years and developing longer term plans to travel in interstellar space. The International Space Station continues to function. History was made in January 2020, for the first time ever, two women astronauts, Jessica Meir and Christina Koch, embarked on a tandem spacewalk. Their task, changing the space station batteries.

Jill Tarter, an American astronomer, continues to search for alien life. Debra Fischer, a professor of astronomy at Yale University, searches for exo-planets, planets where life may be present. Michio Kaku is working on String Theory, a mathematical model that may explain all physical phenomena.

More generally, astronomers continue to build bigger and bigger telescopes; documenting the positions of stellar objects, building their astronomical tables, doing what scientists do best; collecting data, searching for patterns in the data, and then explaining why patterns occur.

In the *2020 Farmer's Almanac*, there are seven pages dedicated to astrology. The *Appleton Post Crescent* prints an astrology column every day. In one sense, we never strayed from where we started; people looking to the Sun, the Moon and the constellations for guidance. On the other hand, we have dared to travel back in time, to the early beginnings of the observable cosmos.

I opened this paper with a quote and a question. "In the beginning, God created the heavens and the Earth." When was the beginning? In my view, humans will continue to search the skies, not only for new stars and planets, also for meaning and understanding. While we know there are trillions of stars for example; knowledge of where these stars come from is understanding. We will continue to look and explore.

References

Pannekoek, A. A History of Astronomy.

Singh, Simon. Big Bang.

Summers, Frank. New Frontiers: Modern Perspectives on Our Solar System.