Book Report
The Whole Shebang
By Timothy Ferris

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Concepts of Modern Physics
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In his book, The Whole Shebang, science writer, Timothy Ferris attempts the daunting task of summarizing the theories and findings of modern cosmology as it existed in the late 1990s. Ferris does an outstanding job in covering the vast history and understanding of the universe as we know it today. He follows the development of the expanding universe theory and its subsequent big bang model. Ferris manages to keep enough detail in his writing without going into so much technical detail as to bore the reader. He includes a chapter tying big bang cosmology to religion. This chapter makes for an interesting read, and provides excellent talking points to any religious debate without any negative connotations.

Throughout our history, the origin of the universe has been subject of many theories and debates. It is important to realize that our understanding of the universe is deeply rooted in society, where understanding the universe plays a role in the form of religion and other belief systems. The Greeks believed the universe to be a place of perfection, where planets were perfect spheres and that the Earth sat in the middle of concentric crystalline spheres that kept the various elements of the sky, including the Sun and the Moon, from crashing down to Earth. This belief was adapted by Ptolemy, in Alexandria, in the second century A.D. to include an additional circular motion of the planets, known as epicycles, to better account for their positions in the sky over time. The Ptolemaic model of the universe served as the standard view of the universe for Western Civilization, for more than 1400 years.

In the 15th century, a man by the name of Copernicus suggested a model of the universe in which the Earth was no longer at the center, and that it orbited our star the Sun. While Copernicus had inaccuracies in his model, he was correct in utilizing a heliocentric (Sun-centered) model and opened discussion for a move away from the traditional geocentric (Earth-centered) view at the time. Copernicus reluctantly added epicycles to his heliocentric model, to make it a more precise model of the motion of planets in our solar system. Two scholars, Galileo Galilei and Johannes Kepler later amended the Copernican model to resolve the inaccuracies in its prediction of planetary motion. Kepler realized that the planets must orbit the Sun in elliptical paths rather than perfect circles and Galileo realized the concept of inertia, or the resistance to change in motion by a mass, would keep people moving with a rotating earth when they jump so that they would return to the same point. This concept would later be more precisely defined, after Galileo's death in 1642, by Isaac Newton of England who was born in 1642.

Newton's realization of the gravitational force combined with the concept of inertia, provided an explanation for why people stay on Earth if it is indeed rotating as suggested in the Copernican, Kepler, and Galileo view of the universe. In 1687, Newton published his influential *Principia* publication, which would serve as a foundation for mechanical physics to this day. Utilizing Newtonian laws and the Keplarian model of our solar system, explorers and astronomers were able to accurately determine the size of the orbital path that Earth follows around the Sun. This accurate diameter of the orbital ellipse of the earth allowed for a distance measuring technique known as parallax to be used to calculate the distance to nearby stars with greater accuracy than ever before. In 1755, Immanuel Kant, a Philosopher, suggested that the spiral nebulae, that could be observed through telescopes, were other galaxies outside of our own, a new idea in a time where extragalactic scales had yet to be considered in the universe. Kant's idea would influence astronomical research for quite some time and by 1838 astronomers had accurately measured the distance to a star, 11 light years away from earth using parallax.

While this was a magnificent distance, it was still a fraction of the distance needed to understand Kant's extragalactic nebulae.

At the beginning of the 20^{th} century, Albert Einstein published his theory of relativity providing a more accurate model in which the effects of gravity could be explained in greater detail than Newtonian mechanics alone. Einstein's relativity also marked a significant advancement in the study of physics as it introduced new mathematics that united the dimensions of space and time into a curved surface. This surface could be warped or bent by mass creating the effects Newton called gravity. Einstein realized that his relativistic model of the universe predicted an expanding, dynamic universe. This seemed to be an error in his model and he attempted to correct for his error by adding a term to his equations called the cosmological constant. This constant altered the solutions to cancel the implied expanding effect of the universe. Einstein was disappointed that he had to add this constant to make his equations seem to describe a static universe. He had in fact covered up mathematical evidence to what would prove to be one of the biggest realizations of cosmology. Einstein's cosmological constant would remain in relativity until a young Russian cosmologist, Alexander Friedmann, and Belgian cosmologist Georges Lemaître both independently studied relativity and determined, around the same time, that relativity did require the universe to be dynamic, that is, in a state of expansion or contraction.

In 1925, Kant's question of the scale of the universe and extragalactic nebulae was confirmed by astronomer Edwin Hubble, who had access to a 100-in reflecting telescope. Using this giant optical telescope, Hubble's view of the universe was extremely detailed allowing him to make out individual stars of galaxies once thought to be gaseous nebulae. His research was based on the findings of another astronomer, Vesto Slipher, who had measured the red-shifts of many galaxies. Red-shifts are an elongation of emitted electromagnetic wavelengths due to the doppler effect. Hubble continued the work of Slipher as he felt that there must be some explanation to his findings. He measured the distance to these galaxies using his new telescope and realized that a constant red-shift must mean that the galaxies are speeding away from us at high velocities. His data also showed a correlation between distance and amount of red-shift, leading him to define what would become known as the Hubble law. The law stated that the farther away a galaxy was, the greater the red-shift or velocity away from earth. This was the first recorded observational evidence that the universe is expanding and seemed to support Einstein's relativity, without the need for a cosmological constant. The hubble law implied a linear relationship between distance and velocity with the slope value known as the Hubble constant. This constant gave us much insight into the universe by accurately representing the velocity of expansion. Utilizing the hubble constant and reversing the expansion model, theorists were able to calculate how long ago the big bang must have occurred. The value of the Hubble constant put that age between 12 and 15 billion years.

The Big Bang model comes from the common sense approach that an expanding universe must have started expanding from some initial point, leading back to the beginning of the current universe. Conservation laws of nature prevent the creation of matter and energy from nothing and therefore suggest that all matter in the universe today must have been present at the beginning. Combining conservation laws and the expanding universe model gives us an idea of what the universe must have been like some 13 billion years ago. Conservation laws require that energy be conserved and therefore imply that compressing the universe from its current size back down to just one light year across or less would result in extreme heat and dense matter. This super-heated, highly energetic, primordial matter is what scientists believe the universe was like in the first three to five-hundred thousand years after the big bang. Space in the universe at this time was so dense that light could not pass through it. It is believed that this early universe eventually expanded and cooled to a point where light could pass through it after approximately three to five-hundred thousand years. Physicists call this point in the history of the universe photon decoupling, as it was the moment that space became transparent to light.

The results of this photon decoupling would have allowed light to begin to move through the universe. The theory suggested that this early light should still be uniformly scattered across the universe. As the universe cooled and expanded to the state that it is in today, the wavelength of the original emitted photons was stretched to the point that they should be detectable today in the form of low frequency microwaves. These microwaves, known as the Cosmic Microwave Background, gave astronomers a testable theory to research after Ralph Alpher and George Herman first predicted them in the 1940s. However, in the late 1940s the big bang theory was not widely accepted and their prediction was not granted much status. It was not until 1965 that experimentalists began to listen for the CMB. If they could be detected it would be great evidence in support of the big bang model.

More evidence to support the big bang model involves hydrogen, the simplest element in the universe. As the universe cooled, matter would have begun to organize into simple atoms, starting with hydrogen. If matter organized in this fashion, hydrogen should be the most abundant element in the universe and a product of the primordial matter cooling. Today, satellites such as the COBE (Cosmic Background Explorer), and more recently, WMAP (Wilkinson Microwave Anisotropy Probe) have provided detailed information on matter in the universe. The data has shown that the universe is comprised of 73-percent hydrogen, 23-percent helium, and the remaining matter consists of all the other elements such as carbon, oxygen, and nitrogen. These and the remaining heavier elements on the periodic table are believed to have been created in early star cycles and supernovae explosions.

In recent years, through continuing detailed observations of the Cosmic Microwave Background by the WMAP satellite, the Hubble constant has been more precisely measured since Ferris publish his book in 1997. The new value of the constant predicts the age of the universe to be approximately 13.7 billion years old, which is nearly centered between the upper and lower boundaries previously postulated. Our knowledge of the precise composition of the matter in the universe is also a result of WMAP's research. In the last 20 years, through COBE and WMAP, astronomers have found compelling evidence in support of the big bang model of the universe and little evidence against it. Astronomers will continue to utilize the latest technology to explore the vast expanse of the universe in the hope of discovering the ultimate answer of the universe.

Appendix

Parallax

Used to measure distances to nearby stars, parallax is dependent upon an accurate diameter of Earth's orbit around the Sun. Then using trigonometry an observer can obtain an approximate distance to a nearby star by observing its position relative to background stars.

Spectroscopy and spectral class

By grouping stars in to spectral classes, astronomers can determine relationships in absolute magnitude and a star's spectral lines. Once an absolute magnitude can be determined it is a matter of knowing that light intensity decreases by a square of the distance traveled, by comparing absolute verses visual magnitude.

Quasars

Applying Hubble's law to red-shifts shows that they tend to be farther than 3-billion light-years away presumably relics of a more violent time in the history of the universe

Cepheid Variable Stars

Absolute magnitude can be determined found by utilizing a known relationship, discovered by Henrietta Leavitt, between the period of pulsation and luminosity of the star. Once one has obtained the absolute magnitude, the distance can be calculated by comparing it to visual magnitude. Cepheids are useful out to about 60 million light-years using the Hubble Space Telescope, and 15 million light-years using ground-based telescopes.

Supernovae

Type I supernovae emit neutrinos and can be detected at a distance of approximately 165,000 light-years. Type II supernovae are detectable across 1/3 of the observable universe but vary in brightness causing Type II to be less useful in determining distances.

Gravitational lensing

Through quasars light travel time implies billions of light-years and provides distances to clusters that produce the lensing effect by measuring time differences in light observed to be on either side of the lens. Once this difference is determined it is possibly to triangulate the location of the center of mass of the cluster.

Sunyaev-Zeldovich effect

Distance is based on temperature differences in the CMB caused by galaxies that emit x-rays that warm the CMB.

Brightness Fluctuation Technique

By observing fluctuations in galaxies out to about 1/2 billion light years, a telescope viewing a nearer galaxy will "see" light from fewer stars and therefore pick up fluctuations in brightness. The same telescope fixed on a more distant galaxy will have less resolving power and therefore pick up light or radio waves from a large number of stars and therefore cause less fluctuation in the observed brightness.

Tully-Fisher method

Observes spiral galaxies and relates absolute magnitude to it 21-centimeter line width. The line is widened by doppler shifting caused by the rotation speed of the galaxy and the rotation speed is related to the luminosity of the galaxy. This method works out to about 300 million light-years or more and produces a hubble constant around 70.