Understanding the Big Bang Theory

By Mike Hill

I have always been intrigued by space and the origins of the universe, often struggling to reconcile my desire for a logical explanation with my desire to believe in a creator. Over the years I have vacillated between confidence that our universe is the result of a divine creator, and confidence that it can only be the result of a random explosion, both points of view being largely uninformed.

Recently, however, I followed through on a commitment to participate in a Faith and Physics class taught by Rodger Price. At the end of the course I still had more questions than answers, but I also had a pressing desire to better understand the prevailing scientific theory on the origin of our universe. That lead me to this paper, which is my attempt to summarize what the Big Bang theory is: where or who it came from, the proof supporting it, and the questions it leaves unanswered.

So what is the Big Bang Theory?

According to Merriam Webster, the Big Bang Theory is a theory that the universe originated billions of years ago in an explosion from a single point of nearly infinite energy density. It is likely all of you have heard of this theory, at least in passing, and most would agree that today it is generally accepted as the most likely scientific explanation for the origin of the universe; however, as recently as the early part of the 20th century, this wasn't the case. Therefore, before I review the key components of the theory, I believe it is important to understand its evolution.

Key Concepts

As I learned from the outset of my research, one can quickly find themselves in over their head when diving into the Big Bang Theory. While I can't profess to fully understand all of the concepts, there are a few key pieces I'd like to review before proceeding. They are, in no particular order:

Quantum – **Slide 2**

Merriam Webster defines quantum as "any of the very small increments or parcels into which many forms of energy are subdivided." Much of the supporting evidence for the Big Bang Theory occurs at the quantum level; however, I will endeavor to keep things on the macro level as much as possible.

Spacetime – **Slide 3**

One of the most complicated, and mind bending concepts one must wrestle with when working to understand the big bang is the concept of Spacetime. While it was Albert Einstein who proposed that space and time could not be interdependent, it was Herman Minkowski who, in 1908, proposed that space and time were one unified fabric. (Stanford)

> The spacetime of our universe has historically been interpreted from a Euclidean (x, y, and z axis) space perspective, which regards space as consisting of three dimensions, and time as consisting of one dimension, the 'fourth dimension'. By combining space and time into a single manifold…, physicists have significantly simplified a large number of physical theories, as well as described in a more uniform way the workings of the universe at both the super-galactic and subatomic levels. (Wikipedia)

Theory of Relativity

Much of the foundation for the Big Bang Theory lies within the Theory of Relativity, which encompasses two additional theories by Albert Einstein: Special Relativity and General Relativity.

Special Relativity

In 1905, Albert Einstein published the theory of special relativity, which explains how to interpret motion between two different bodies moving at constant speeds relative to reach other. The theory is based upon two key assumptions:

- The principle of relativity, which states the laws of physics don't change, even for objects moving at the same speed relative to one another.
- The principle of the speed of light, which states that the speed of light is the same for all observers, relative to the source of the light.

While a key building block to the understanding of the how the universe works, the theory of Special Relativity had a flaw. The theory only applied in the case where motion between two objects is uniform. In the event one of the objects accelerates, or turns, the theory ceases to apply. Therefore, Einstein had more work to do, which brings us to General Relativity.

General Relativity

Published in 1915, General Relativity is Einstein's theory of gravity, which built upon Special Relativity to include bodies that were not moving at the same speed in a straight line. While Newton's laws described the strength of gravity with great accuracy, he had no idea how gravity actually worked. In his view, gravity pulled on objects to keep them in place. For example, it is the pull of the sun's gravity that keeps the planets in our solar system in orbit. According to Newton, if the sun instantaneously vaporized, the planets it affects would immediately careen out into space. Newton believed that the effects of gravity are felt immediately; however, for this to be the case gravity would have to travel faster than light. Einstein knew this couldn't be possible, because nothing is faster than light and it takes light eight minutes to travel the 93 million miles from the sun to the earth. Therefore, we couldn't experience a change in gravity before we'd experience the loss of light. Einstein discovered that the velocity of light is a cosmic speed limit, which nothing can exceed. What Einstein had discovered was that rather than gravity working as a force pulling someone or something, gravity was in reality a pushing force resulting from an object bending the fabric of space.

(Relativity Video) Slide 4

Doppler Effect

The Doppler Effect, named after Austrian physicist Christian Doppler, is the change in frequency of a wave for an observer moving relative to its source.

> The Doppler effect is of intense interest to astronomers who use the information about the shift in frequency of electromagnetic waves produced by moving stars in our galaxy and beyond in order to derive information about those stars and galaxies. The belief that the universe is expanding is based in part upon observations of electromagnetic waves emitted by stars in distant galaxies. Furthermore, specific information about stars within galaxies can be determined by application of the Doppler effect. Galaxies are clusters of stars that typically rotate about some center of mass point. Electromagnetic radiation emitted by such stars in a distant galaxy would appear to be shifted downward in frequency (a red shift) if the star is rotating in its cluster in a direction that is away from the Earth.

On the other hand, there is an upward shift in frequency (a blue shift) of such observed radiation if the star is rotating in a direction that is towards the Earth. (physics classroom)

Redshift and Blueshift – **Slide 5**

Redshift and Blueshift describe how light changes as objects in space (such as stars or galaxies) move closer or farther away from us. Visible light is a spectrum of colors, which is clear to anyone who has looked at a rainbow. When an object moves away from us, the light is shifted to the red end of the spectrum as its wavelengths get longer. If an object moves closer, the light moves to the blue end of the spectrum as its wavelengths get shorter.

Background

The Big Bang Theory, as it is known today, is the culmination of hundreds of years of observation and contributions by some of the greatest minds in science. In 1610, Galileo published his book, "The Starry Messenger, starting a new discussion based on the concept that the earth may not be the center of the universe. He did this by arguing, based upon observations made with his telescope, that the dome of fixed stars was not a dome at all but rather had depth. In addition, he noted that Jupiter too had moons, which orbited that planet rather than orbiting the earth.

In 1676, Danish astronomer Ole Romer laid another block in the foundation of the Big Bang theory by being the first to roughly calculate the speed of light by measuring the discrepancies in the time between eclipses of Jupiter's moons. He concluded that the difference, approximately 16.7 minutes over a year's time, was the result of the distance between the earth and Jupiter and additional time it took light to travel to the earth.

Possibly one of the biggest steps to achieving a unified theory for the origin of our universe was taken by Isaac Newton around 1687. Prior to his observation that the physical laws which govern our lives on earth are the same that govern the starts and planets, it was generally accepted that Aristotle's 2000 year old ideas about separate laws for the heavens and earth were correct. "His three laws of motion and the universal law of gravitation made it possible to understand the motions of the planets of the solar system, the formation and movements of stars and galaxies, and to some extent, the past and future of the universe itself" (Carnegie Institution for Science).

Other key contributors to the understanding of the origins of the universe include William Herschel, who created the first truly large telescopes in the late 1700's through which it was confirmed that we live in a massive collection of stars called the Milky Way. He also discovered the existence of interstellar clouds of dust, hydrogen, helium, and other ionized gasses. These nebulas are often star-forming regions. Another key contributor was Friedrich Bessel, who pioneered the method to measure the distance to a star in the mid-1800's, and building upon that William and Margaret Huggins were the first to detect the same elements in stars as those that are in the sun. This confirmed that stars are in fact suns that are very far away, and that that the sun is in fact a star.

Beginning in the early 20th century, the theory known today as the Big Bang began to take shape, although the term "Big Bang" wouldn't be used until 1949 by English astronomer Fred Hoyle. During a BBC radio broadcast, Hoyle referenced a Big Bang when describing an alternative to The Steady State theory which he fully supported.

> …In 1912 Vesto Slipher measured the first Doppler shift of a "spiral nebula" and soon discovered that almost all such nebulae…. were receding from Earth. He did not grasp the cosmological implications of this fact, and indeed at the time it was highly controversial whether or not these nebulae were "island universes" outside

our Milky Way. Ten years later, Alexander Friedmann, a Russian cosmologist and mathematician, derived the Friedmann equations from Albert Einstein's equations of general relativity, showing that the universe might be expanding in contrast to the static universe model advocated by Einstein at that time. In 1924 Edwin Hubble's measurement of the great distance to the nearest spiral nebulae showed that these systems were indeed other galaxies. Independently deriving Friedmann's equations in 1927, Georges Lemaître, a Belgian physicist and Roman Catholic priest, proposed that the infrared recession of the nebulae was due to the expansion of the universe.

In 1931 Lemaître went further and suggested that the evident expansion of the universe, if projected back in time, meant that the further in the past the smaller the universe was, until at some finite time in the past all the mass of the universe was concentrated into a single point, a "primeval atom" where and when the fabric of time and space came into existence. It is key to note though, that in the 1920s and 1930s almost every major cosmologist preferred an eternal steady state universe, and several complained that the beginning of time implied by the Big Bang imported religious concepts into physics; this objection was later repeated by supporters of the steady state theory. This perception was enhanced by the fact that the originator of the Big Bang theory, Monsignor Georges Lemaître, was a Roman Catholic priest. (Wikipedia)

During the 1930's and early 1940's, a number of different hypothesis as to the origin of the universe were proposed by many of the leading minds of that time, including Einstein. After World War II, however,

> *"Two distinct possibilities emerged. One was Fred Hoyle's steady state model, whereby new matter would be created as the universe seemed to expand. In this model the universe is roughly the same at any point in time. The other was Lemaître's Big Bang theory, advocated and developed by George Gamow, who introduced big bang nucleosynthesis and whose associates, Ralph Alpher and Robert Herman, predicted the cosmic microwave background….The discovery and confirmation of the cosmic microwave background radiation in 1965 secured the Big Bang as the best theory of the origin and evolution of the universe. (Wikipedia)*

Stages of the Big Bang: Slide 6

Singularity–

Using the theory of general relativity and playing the tape backwards results in the conclusion that at one finite point in time, approximately 13.8 billion years ago, the universe was single point with infinite temperature and density. The challenge, however, is that at this point, general relativity and all laws of physics break down. This period of time is known as Plank Epoch, the earliest period of time in the history of the universe, from zero to approximately 10−43 seconds.

Inflation–

> The earliest phases of the Big Bang are subject to much speculation. In the most common models the universe was filled homogeneously and isotropically with a very high energy density and huge temperatures and pressures and was very rapidly expanding and cooling. Approximately 10^{-37} seconds into the expansion, a phase transition caused a cosmic inflation, during which the universe grew exponentially. After inflation stopped, the universe consisted of a quark–gluon plasma, as well as all other elementary particles. Temperatures were so high that the random motions of particles were at relativistic speeds, and particle–antiparticle pairs of all kinds were being continuously created and destroyed in collisions. At some point an unknown reaction called baryogenesis, which is the generic term for the hypothetical physical process that produced an imbalance between baryons and antibayrons (Wikipedia, baryogenesis), leading to a very small excess of quarks and leptons over antiquarks and antileptons—of the order

of one part in 30 million. This resulted in the predominance of matter over antimatter in the present universe. (Wikipedia)

Cooling– **Slide 7**

After 10^{-11} seconds following the Big Bang, our knowledge about the evolution of the universe becomes more firm. This is due in large to a drop in particle energies to values that can currently be attained in particle physics experiments. “A few minutes into the expansion, when the temperature was about a billion kelvin and the density was about that of air, neutrons combined with protons to form the universe's deuterium and helium nuclei in a process called Big Bang nucleosynthesis” (Wikipedia). From this time up until approximately 379,000 years after the Big Bang, the universe continued to expand and cool, and quantum particles slowed and began to form atomic nuclei. These particles ultimately reached a point where they started to form hydrogen atoms, among others. It is worth noting that even up to and through this stage, the universe was too hot and dense for any light in the traditional sense to exist. The only “light” at that time was radiation, which was only visible on the microwave spectrum which will be discussed in more detail later.

Re-ionization/Recombination– **Slide 8**

It was during this period, roughly 400 million years after the Big Bang, that the universe had expanded and cooled to such a point that the first structures started to form. The emitted ultraviolet light from these energetic events cleared out and destroyed most of the surrounding neutral hydrogen gas. The process of re-ionization, plus the clearing of foggy hydrogen gas, caused the universe to become transparent to ultraviolet light for the first time. This period of time is the longest in the evolution of the universe. Our solar system is estimated to have been born a little more than 9 billion years following the Big Bang, making it about 4.6 billion years old. According to current estimates, the sun is only one of more than 100 billion stars in our Milky

Way galaxy alone, and it orbits roughly 25,000 light-years from the galactic core. “Many scientists think the sun and the rest of our solar system was formed from a giant, rotating cloud of gas and dust known as the solar nebula. As gravity caused the nebula to collapse, it spun faster and flattened into a disk. During this phase, most of the material was pulled toward the center to form the sun” (Chow).

So how Big is Big? Slide 9

The Hubble Space Telescope has given us the greatest glimpse back into the history of the universe ever. Released in September of 2012, the Hubble Extreme Deep Field (XDF) is the combination of thousands of photos taken over 10 years, which when stitched together paint a picture of just how immense the universe is. Hubble pointed at a tiny patch of southern sky in repeated visits for a total of 50 days, with a total exposure time of 2 million seconds. More than 2,000 images of the same field were taken with Hubble's two premier cameras: the Advanced Camera for Surveys and the Wide Field Camera 3, which extends Hubble's vision into near-infrared light. The universe is 13.7 billion years old, and the XDF reveals galaxies that span back 13.2 billion years in time. Most of the galaxies in the XDF are seen in their initial forms when they were young, small, growing, and often violently as they collided and merged together. The early universe was a time of dramatic birth for galaxies containing brilliant blue stars extraordinarily brighter than our sun. The light from those past events is just arriving at Earth now, so the XDF is a "time tunnel into the distant past." The youngest galaxy found in the XDF existed just 450 million years after the universe's birth in the Big Bang. Scientists project there are at least 100 billion galaxies in the universe, but acknowledge that with better technology that number may double. In fact, in 2013 a German supercomputer projected the number could be as high as 500 billion.

Slide 10

Proof

So how do we know that the Big Bang is the most likely explanation for the origin of our universe? There have been many discoveries in the last eighty years that support the notion of the universe expanding outward as the result one explosion, and all of them together make a very compelling case.

Hubble's Law

First proposed in 1929 by Edwin Hubble, Hubble's Law is considered the first observational evidence for the expansion of the universe, and it states the following:

- Objects observed in deep space are found to have a Doppler Shift interpretable as a relative velocity from Earth.
- The Doppler-shift-measured velocity of various galaxies receding from Earth is approximately proportional to their distance from the Earth for galaxies up to a few hundred megaparsecs away.

Hubble's law was based upon his years of observation of stars and the spectral lines they emit. He discovered that the spectral lines emitted by stars are not identical to the spectral lines observed in the laboratory, but rather they were shifted to the longer wavelengths towards the red end of the spectrum. He concluded that this Redshift was due to the stars being in motion away from the observer resulting in a Doppler effect.

At least three types of Redshift occur in the universe: from the universe's expansion, from the movement of galaxies relative to each other, and from "gravitational redshift," which happens when light is shifted due to the massive amount of matter inside of a galaxy.

This latter redshift is the subtlest of the three, but in 2011 scientists were able to identify it on a universe-size scale. Astronomers did a statistical analysis of a large catalog known as the Sloan Digital Sky Survey, and found that gravitational Redshift does happen– exactly in line with Einstein's theory of general relativity (Howell).

Cosmic Microwave Background (CMB) Slide 11

Accidentally discovered in 1965 by Arno Penzias and Robert Wilson, Cosmic Microwave Background is radiation that fills the universe and can be detected in every direction and is considered the oldest "light" in the universe. The reason this is so important is that scientists theorized that if the Big Bang theory was correct, the universe would be filled with background radiation left over from the creation event. By measuring the CMB, astronomers are able to "see" back in time to approximately 378,000 years after the Big Bang when the universe began to cool. Since the initial discovery of CMB, there have been a number of experiments and space probes which have confirmed the existence of CMB.

Launched in 1989, the Comic Background Explorer, was sent on a mission to measure radiation of a specific frequency over the entire universe. The objective was to prove the existence of the CMB, which it did precisely and as a result it confirmed the big bang theory.

Galactic Evolution and Distribution

> Detailed observations of the morphology and distribution of galaxies and quasars are in agreement with the current state of the Big Bang theory. A combination of observations and theory suggest that the first quasars and galaxies formed about a billion years after the Big Bang, and since then larger structures have been forming, such as galaxy clusters and superclusters. Populations of stars have been aging and evolving, so that distant galaxies (which are observed as they were in the early universe) appear very different from nearby galaxies (observed in a more recent state). Moreover, galaxies that formed relatively recently appear markedly different from galaxies formed at similar distances but shortly after the Big Bang.

> These observations are strong arguments against the steady-state model. Observations of star formation, galaxy and quasar distributions and larger structures agree well with Big Bang simulations of the formation of structure in the universe and are helping to complete details of the theory. (Wikipedia)

Primordial B-mode Polarization

As part of Einstein's theory of relativity, he predicted that gravitational waves exist in the fabric of spacetime, the result of rapid expansion in the moments following the Big Bang. In 2014, a group of researchers from Harvard University announced that they had specifically discovered a twist of light called Primordial B-mode Polarization. This refers to the swirling effect that enormous gravitational waves had on photons that escaped from the Big Bang and serves as proof that those gravitational waves actually exist (Estes).

Conclusions

After gaining a much better understanding of the big bang theory, I firmly believe that it is an accurate explanation for the origins of our universe. Unfortunately, however, the theory has limitations in that it cannot predict what happened in the earliest stages of the formation, nor what came before it which is truly what I set out to learn. Is it possible that a divine creator started the big bang in motion? Yes it certainly is, but at the same time there are thousands of other possible explanations for what came before. At this time, the next step for me is to dive deeper into the theological side of things in search of an answer.

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