Big Bang Essay, Research Paper

Big Bang Theory

Fifteen billion years ago, give or take five billion years, the entirety of our universe was compressed into the confines of an atomic nucleus. Known as a singularity, this is the moment before creation when space and time did not exist. According to the prevailing cosmological models that explain our universe, an ineffable explosion, trillions of degrees in temperature on any measurement scale, that was infinitely dense, created not only fundamental subatomic particles and thus matter and energy but space and time itself. Cosmology theorists combined with the observations of their astronomy colleagues have been able to reconstruct the primordial chronology of events known as the big bang.

Quantum theory suggests that moments after the explosion at 10 -43 second, the four forces of nature; strong nuclear, weak nuclear, electromagnetic and gravity were combined as a single “super force”(Wald). Elementary particles known as quarks begin to bond in trios, forming photons, positrons and netrinos and were created along with their antiparticles. There are minuscule amounts of protons and neutrons at this stage; approximately 1 for every one billion photons, neutrinos or electrons (Maffei). The density of the Universe in its first moment of life is thought to have been 1094g/cm3 with the majority of this being radiation. For each billion pairs of these heavy particles (hadrons) that were created, one was spared annihilation due to particle-antiparticle collisions. The remaining particles constitute the majority of our universe today (Novikov).

During this creation and annihilation of particles the universe was undergoing a rate of expansion many times the speed of light. Known as

the inflationary epoch, the universe in less than one thousandth of a second doubled in size at least one hundred times, from an atomic nucleus to 1035 meters in width. An isotropic inflation of our Universe ends at 10-35 second that was almost perfectly smooth. If it were not for a slight fluctuation in the density distribution of matter, theorists contend, galaxies would have been unable to form (Parker).

The universe at this point was an ionized plasma where matter and radiation were inseparable. Additionally there were equal amounts of particles and antiparticles. The ratio of neutrons and protons albeit small is equal. When the universe aged to one hundredth of a second old neutrons begin to decay on a massive scale. This allows for free electrons and protons to combine with other particles. Eventually the remaining neutrons combine with protons to form heavy hydrogen (deuterium). These deuterium nuclei combine in pairs and form helium

nuclei. The formation of matter from energy is made possible by photons materializing into baryons and antibaryons with their subsequent annihilations transforming them into pure energy (Maffei). Because of these collisions and annihilations matter was unable to remain viable for more than a few nanoseconds before a bombardment of electrons would scatter these photons. Like water trapped inside a sponge, radiation is so dense (1014g/cm3) that no light is visible. Known as the “Epoch of Last Scattering” the temperature has now dropped to a

mere 1013K with the Strong Nuclear, Weak Nuclear and Electromagnetic interactions now able to exert their force. (Chown)

As the gas cloud expands one full second after the initial explosion and the temperature of our Universe has dropped to ten billion degrees, photons no longer have the energy to disrupt the creation of matter as well as transform energy into matter. After three minutes and a temperature of one billion degrees, protons and neutrons were slowing down enough in order to allow nucleosynthesis to take place. Atomic nuclei of helium was produced as two protons and neutrons each bonded. For every helium nuclei formed there were about ten protons left over allowing for twenty-five percent of the Universe to be comprised of helium. The next important phase of the expansion occurred around thirty minutes later when the creation of photons increased through the annihilation of electron-positron pairs.

The fact that the universe began with slightly more electrons than positrons has insured that our Universe was able to form the way it has (Parker).

The universe for the next 300,000 years will then begin to expand and cool to a temperature of 10,000.K. These conditions allowed for helium nuclei to absorb free floating electrons and form helium atoms. Meanwhile hydrogen atoms were bonding together and forming lithium. It is here that the density of the universe has expanded to the point where light can be perceived. Until this point photons continued to be trapped within matter. Finally the expansion allowed for light and matter to go there separate ways as radiation becomes less andless dense. Matter and radiation therefore too, were bonded no longer and the oldest fossils in the Universe were born (Peebles).

In 1814 the science of spectroscopy was launched by William Wollaston, an English physicist who noticed that there were several dark lines that separated the continuous spectrum of the Sun. These lines came to the attention of Joseph von Fraunhofer, a German optician and physicist who carefully plotted the position of those lines. Then in 1850 German physicist’s Gustav Kirchhoff and Robert Bunsen refined the spectroscope. They then learned to heat different elements to incandescence and using the spectroscope identified an elements corresponding lines on the visible portion of the electromagnetic spectrum(Parker).

In 1863 Sir William Huggins, an amateur astronomer viewed a nearby star through his 8 inch refractor with a spectroscope attached. He found what he had originally hypothesized, the same spectrum lines that were observed in our own Sun. Meanwhile, Kirchhoff and Bunsen had successfully categorized the spectrum lines of many elements including those of hydrogen, sodium and magnesium. Huggins found these same spectrum lines in the distant stars he had observed and correctly predicted that some of the same elements that Kirchhoff and Bunsen were cataloging were emanating from these celestial bodies (Parker).

Christian Doppler of Austria discovered twenty years earlier that the frequency of a sound wave was dependent on the relative position of the source of the sound. As a sound moves away from an observer the pitch will lower. Likewise if the source is not moving but the observer is, there will be a corresponding change in the wave frequency of the sound. Doppler theorized on this same shift for light waves yet it was the French physicist Armand Fizeau who proved in 1848 that when a celestial object moves away from an observer, the lines in the visible spectrum would shift toward the red end. Conversely, when an object moves toward the observer, Fizeau found that the lines in the spectrum shifted toward the blue end. Huggins observed a shift in the hydrogen lines of Sirius toward the red end of the spectrum. This “redshift” indicated that Sirius was moving away from us. A few years later he was able to calculate the radial velocity of the star Sirius at

between 26 to 36 miles per second (Parker).

During the 1890’s the Lick Observatory in California began to track and chart the radial velocity (which is actually the velocity at which the line of sight that the star is observed) of many stars, as well as gaseous and planetary nebulae. Astronomers at Lick calculated the measurements of 400 stars including their radial speed and velocity. In 1910 Vesto Slipher measured the velocity of the Andromeda Nebula at 300 km per second, thirty times greater than previously observed. Four years later, Slipher had confirmed the radial velocities of 14 spiral nebula, with the overwhelming majority shifting to the red end of the spectrum. Slipper’s observations showed that the majority of spirals he measured were moving away from us (Parker).

Around 1913 several astronomers, among them Edwin Hubble, used a variable star known as a Cepheid (a star that fluctuates in intensity) to measure their period-luminosity relationship. This would accurately determine the distance to any Cepheid in the observable vicinity. Hubble became the first astronomer to discover an independent galaxy outside the confines of the Milky Way. Hubble calculated the distance of the Andromeda Galaxy to be 900,000 light years away; larger than the predicted size of our own galaxy. Using the radial velocity measurements of Slipher along with Hubble’s own calculations he began to notice a correlation between the distance of these galaxies and their radial velocities. The proof was conclusive: the further away a galaxy was relative to the Earth, the greater the velocity of that galaxy. Hubble had irrefutable proof that the Universe was expanding. By 1936 Hubble had received data from galaxies more than 100 million light years away. The redshifts at this distance were so large that the spectral lines had changed color (Weinberg).

As astronomers were collecting data on the Universe based on their observations, theorists were busy developing models that attempted to explain the cosmos. Recently equipped with Albert Einstien’s Theory of Relativity, Einstein was one of the first to attempt an explanation of the physical Universe. Einstein believed the Universe to have a static, uniform, isotropic distribution of matter. Einstein’s own calculations however proved to result in the exact opposite, an oscillating universe that had the potential for expansion or contraction. He was certain that the universe was stable. Einstein was compelled to amend his original equation. He used the term cosmological constant, which created a spherical, four-dimensional closed universe (Parker).

Around the same time the Dutch astronomer Willem deSitter used Einstein’s general theory of relativity to develop his own model of the Universe. His model was unique in that it did not take into consideration the existence of matter in the Universe. However it did go beyond Einstein’s model in that it predicted the redshift, even though de Sitter felt it was an illusion, and did not at the time link it to any recession of celestial objects. The academic community of 1930 did not fully embrace either model of the universe. Then the Secretary of the Royal Astronomical Society in England was made aware that three years previous, one of his students had written a theory of the universe independent of the two major forces in cosmological theory. Georges Lema tre created a cosmology that predicted a universe that was forever in a state of expansion. When this theory was rejuvenated by its republication in the journal Monthly Notices, it brought to the table another similar theory that was devised ten years earlier. Aleksander Friedmann, a Russian mathematician, analyzed Einstein’s

cosmological constant that produced a static universe. Friedmann proved that there are three possibilities for the universe when the cosmological constant is zero. If the matter in the universe is greater than the critical density, the universe would ultimately collapse back onto itself. If the inverse is correct the universe would expand forever. If the universe were flat with a constant of zero at critical density, the universe would again expand infinitely. Both Lema tre and Friedmann’s solutions were analyzed by Einstein and were summarily dismissed. It was not until Hubble had proved that galaxies were in fact receding in 1932 that Einstein was forced to drop his static universe model. The observational proof that the universe was expanding, combined with the models of Friedmann and Lema tre that predicted an expanding universe unified the cosmologist and the astronomer in agreement. The only question remained was if the universe is expanding, what was the origination of this expansion? Lema tre used the second law of thermodynamics as his starting point. Based on the assumption that the expansion of the universe was an increase in the disorder of a system, originating from a singularity of neutrons, this primordial nucleus would then explode where an increase in the entropy of the universe would be apparent. On May 9, 1931, Lema tre published his theory of the universe in the journal Nature and it was met with general skepticism (Parker).

George Gamow expounded on Lema tre’s work, using recent discoveries in quantum theory. Lema tre formulated his model based on the theory that a giant nucleus began to entropy, breaking down into individual constituents. Gamow believed that a nucleus containing not only neutrons but protons and electrons as well was the starting point. Due to the very high amount of radiant energy in the early universe, temperature would be in excess of one billion degrees Kelvin. At five minutes old, Gamow speculated, this universe would have particles that could not combine. But as the expansion began the temperatures would decrease and nuclear fusion would occur. Atoms would form as protons and neutrons would attach themselves to one another. Gamow then Hypothesized that all the elements in the Universe were created at this time. One year later however, it was proven that Gamow’s math didn’t stand up to scrutiny as it was shown that atomic mass 5 could not have been created from this primordial nucleus, as well as mass 8 (Gribbin).

Although all of the elements in the universe were proven not to have originated from the Primordial Fireball, the theory gained momentum until it received a worthy adversarial cosmology known as the Steady State Theory. Fred Hoyle (who despairingly coined the term Big Bang) and his colleagues constructed a model of the universe that was widely accepted for religious reasons if not so much for its scientific hypothesis. Hoyle suggested that the universe is infinitely old and has remained in a steady state except that the universe was indeed

expanding. However galaxies are not receding from one another but space is constantly being created between galaxies. In order for the average density to remain constant, Hoyle suggested that matter had to be created in these new areas where space was expanding. Only one hydrogen atom needed to be created every year in an area the size of a 100 meter cube to account for the expansion. This spontaneous generation of matter Hoyle argues would allow for the formation of new galaxies between ancient ones and the Universe would maintain its steady state. It would then follow that astronomers would be able to detect young galaxies in the midst’s of very old ones. This was one of the many inconsistencies that were found with the Steady State Theory. In the 1950’s Steady State Theorists took a heavy blow when radio galaxies were discovered showing that, consistent with big bang Cosmology, galaxies evolved and were very active billions of years ago (Parker).

Finally the empirical evidence big bangers had predicted was observed in 1965 by Bell Labs Arno Penzias and Robert Wilson. Robert Dicke of Princeton University was the first to search for fossil remains of the big bang. Dicke suggested that the Big bang emanated from a previous universe and that a temperature in excess of one billion degrees was necessary to create our new universe. This energy would in turn produce an infinitesimal amount of radiation that should be measurable to this day. Based on Planck’s law that all bodies emit energy that can be documented on an electromagnetic diagram. Depending on the length of the wave they can register anywhere from X rays to radio waves and everything in between. A bodies emission of energy is contingent upon the constituent elements of the body, the amount of surface area of the body and the surface temperature of the body. The body that emits the greatest amount of energy is a so called black body. Using Planck’s Black Body Curve as a guide Dicke theorized that the Cosmic Background Radiation of the Big Bang should be about 3. above absolute zero. Dicke’s colleague Jim Peebles also concluded that when the Fireball’s remnants cooled to 3000. Kelvin nuclei would be able to form and helium was able to form from hydrogen. This left a universe with a mixture of approximately 75% hydrogen and 25% helium, resembling the same amount of helium found in the Sun. Peebles concluded that since the two most abundant

elements in the universe were created when the Universe was at 3000. K and since then the universe has expanded by a factor of 1000 the radiation from the Big Bang should have a temperature of about 10. K. Later refinements to these equations revised the estimated temperature to 3. K. Dicke and Peebles were confident that there instruments would be the first to detect this Cosmic Background Radiation (Parker). At the same time Penzias and Wilson were busy attempting to measure radiation from the Milky Way Galaxy. They were narrowing in on their source when they were left with a noise that was interfering with their signal. This noise originated from cosmic radiation and had a temperature of 3.K. It seemed to be coming in from all directions and never fluctuated. With their original research corrupted due to the unexplained noise they resigned themselves to writing a paper on this unexplainable phenomenon. Months later Penzia’s discovered that Peebles group was searching for this relic radiation without success. Upon further examination they realized that Penzia and Wilson had stumbled upon the single most important discovery that confirmed the Primordial big bang Explosion(Parker).

Big Bang theorists made several predictions that have eventually supported the theory. The first is Hubble’s observation of the redshift-distance relationship. This relationship enables us to approximate the age of the universe with the help of three separate celestial bodies that all arrive at the same relative result. Hubble used what is known as “standard candles” to build a “cosmic distance ladder.” By knowning the distance of certain celestial bodies he would be able to incrementally construct an age for the Universe. These standard candles were: cepheid variables in neighborhood galaxies; bright stars in more distant galaxies and in galaxies millions of parsecs away, the brightness of the galaxy itself was used as a standard candle (Maffei).

Central to the question of the age of the Universe are two important theoretical terms. The Hubble Constant refers to how fast the velocities of the galaxies increase with their distance from the Earth. There is quite a raging debate on the value of this constant ranging from 50 Km/sec per Mpc (Mpc is a Megaparsec, about 3 million light years) to 100 Km/sec per Mpc. This explains the disparity in the x 5 billion year estimate for the age of the universe. The other constant of importance is known as q that defines the deceleration of the

expansion of the universe. Depending on the critical density of the universe that this q constant is based, the universe will prove to be either infinitely expanding as in the flat and open models, or an oscillating closed universe; a big crunch/big bang universe that will ultimately condense back into a singularity and begin the process all over again(Weinberg). Hubble’s succesor Allan Sandage predicted a closed

universe when he plotted a number of radio galaxies many billions of light years away. The evidence for this closed universe was quickly challanged a few years later and eventually fell out of favor. To this day the Hubble Constant and the q constant remain the two most important unanswered problems in modern cosmology.

Observations have also supported the predictions of theorists that certain elements could only have been created moments after the big bang. Based on the relationship between the amount of helium in the universe and the number of different types of particle “families” researchers concluded that there is one neutrino per family of particles. Due to the current energy density of the universe there will be a corresponding amount of helium produced. This in turn will create different types of neutrinos. When the predicted amount of neutrinos corresponded to what was observed it was another victory for the big bang cosmology(Wald).

After the discovery of the cosmic background radiation in 1965 scientists were eager to extend their research into outerspace through the use of a man-made satellite orbiting the Earth. From this vantage point an unimpeaded opportunity to study this phenomenon would be made available and by late 1989 the Cosmic Background Explorer

(COBE) was ready for action. COBE consisted of three seperate

experiments. The first instrument was known as the FIRAS, an acronym for the Far Infrared Absolute Spectrometer. This instrument was

created to confirm the research previously accumulated that the background radiation does indeed have a black body spectrum

(Hoverstein).

The next question COBE attempted to answer was, is the background radiation the same temperature in all directions? Big bang theory states that in order to have mass condense and form galaxies, there must be inhomogeneties left over from the Big bang that will be able to be detectable. The differential microwave radiometer (DMR) was designed to detect anisotropy fluctuations on the scale of 30 millionths of a degree. Inflation theory predicted such fluctuations and that quantum processes at work during the primordial stages of the big bang (when the universe was the size of a proton) allowed for clouds of matter to condense into galaxies (Sawyer).

The final experiment was known as DIRBE. The Differential Infrared Background Experiment was designed to look into the farthest

corners of the Universe; upwards of 15 billion light years away from the Earth, and accumulate data on the infrared light of these

primordial galaxies. DIRBE data is continuing to be accumulated with no conclusions having been drawn to date (Gribbin). John Mather

from the University of California at Berkeley was responsible for the FIRAS experiment. Not long after COBE was positioned into orbit

came the exciting data that was eagerly awaited and much anticipated. The background radiation fit the blackbody curve to within 1%.

Sixty-seven seperate points of frequency obtained by COBE fir the theoretical blackbody spectrum perfectly! Observation had accurately

confirmed what Big bang cosmology had long ago predicted. This finding proved to be the easy part (Parker).

George Smoot and his colleagues also from Cal Berkeley took three arduous years to sort through the billions of bits of data that the DMR provided. His announcement on the 23rd of April, 1992 at the annual meeting of the American Physical Society in Washington,D.C. said it best: “English dosen’t have enough superlatives…to convey the story [of the results] , we have observed…15 billion year old

fossils that we think were created at the birth of the universe.”(Parker). Although the temperature fluctuations were less than thirty millionths of a degree in variation, these areas of temperature and density fluctuation were more than 500 million light years in width. These miniscule perbutations that were formed during the big bang were the very density that was needed in order to create galaxies and thus life itself (Noble).

The Big Bang model that attempts to explain the origin and structure of the universe incorporates the talents of many individuals through the course of more than 150 years of study. Many times facing opposition similar to that of Galileo and Copurnicus, these cosmologists used a deductive approach in solving the greatest question in the history of science. The findings and observations of these emminant scholars forced them to draw the conclusions they arrived at. Every prediction that quantum physics and the theories of relativity have made regarding the origin and the state of the universe have either been observed and confirmed and/or not proven to be false. That is in essence the reason we have arrived at this cosmology, fully confident that our science and technology can look back in time 15 billion years and see the birth of our universe.

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