Inflation and its Inaccuracies

Nishant Mysore

April 3, 2018

Contents

1 Introduction to the Inflation **2**
1.1 History of the Inflationary Theory . . . 2
1.2 The Flatness Problem . . . 2
1.3 The Horizon Problem . . . 3
1.4 The Monopole Problem . . . 5

2 Problems with Inflation **5**
2.1 CMB and Cosmic Gravitational Waves . . . 5
2.2 Problems with Initial Conditions . . . 6
2.3 Quantum Fluctuations and the Multiverse . . . 6
2.4 Big Bounce . . . 7
2.5 Conclusion . . . 7

1 Introduction to the Inflation

1.1 History of the Inflationary Theory

For decades, cosmologists had difficulty explaining the lack of certain predictions of the big bang theory. Big bang cosmology tended that the universe would become increasingly curved as time passed on. However, the universe was determined to be very close to flat. Additionally, it claimed that regions of space at opposite ends of the universe could have never been in contact with each other, though it was easily shown through the uniformity of the cosmic microwave background (CMB) that all areas in the universe must have been in contact at some point in time. Finally, our universe had a complete lack of magnetic monopoles that big bang cosmology claimed would emerge in the first stages of the universe.

In the early 1980's, a physicist named Alan Guth was working on solving the above discrepancies, respectively named the Flatness, Horizon, and Monopole problems. He revised and formulated a theory of rapid expansion in the early universe that would provide a bridge between big bang cosmology and present day cosmology. After experimentation and revisions to his theory, Guth and two others were awarded the Dirac prize in 2002 for originating the theory of cosmic inflation.

Inflation is the theoretical explanation of the extreme expansion of the universe a short period of time after the big bang. It is speculated that the inflationary period only lasted about 10^{-32} seconds, and expanded the volume of the universe by an order of 10^{26} in just that time period. The effects of inflation have continued to present day, as the universe is still expanding though at a significantly slower rate. In this paper, we examine the solutions Inflationary Theory provides while also examining the problems that arise with this untestable model.

1.2 The Flatness Problem

The Friedmann equation can be written as:

$$1 - \Omega(t) = \frac{-\kappa * c^2}{R_0^2 * a(t)^2 * H(t)^2} \tag{1.2.1}$$

$$a_m(t) \sim t^{2/3} \tag{1.2.2}$$

$$a_r(t) \sim t^{1/2} \tag{1.2.3}$$

Where $\Omega(t)$ represents the density parameter as a function of time, κ represents the curvature of the universe, $a(t)$ represents the scale factor, and $H(t)$ represents the Hubble Parameter. Equations (1.2.2) and (1.2.3) represent the scale factor under a matter dominated universe radiation dominated universe respectively.

In the current benchmark model of our universe containing matter, radiation, and a cosmological constant, the sum of Ω values for each component is set to ~ 1. Looking at Figure 1, we see that unless Omega is at or very close to unity, it will deviate farther and farther away as the universe aged. If Ω was signficiantly higher 1, then our universe would have recollapsed into itself quickly before being able to form galaxies. Instead, if Ω was significantly lower than 1, it would have expanded too fast for any structure to be created. This means that Ω in the early universe was extremely close to 1, and thus the universe was extremely flat at around the time of creation.

We have measured that at Planck's time of 5.39 x 10^{-44} seconds, Ω was within a range of 10^{-60} from 1. The Flatness problem results from the fact that the big bang could not have created such a fine tuning of omega to be so close to that arbitrary value. The odds of that happening were extremely unfavorable without some other factor in play. There must have been some unexplained event that guided the universe to that specific density parameter value.

Imagine standing in a field with no trees or mountains in sight. You would not be able to tell that the earth is curved no matter what direction you walk in. The earth would appear completely flat. Now imagine standing on an earth shrunken to the size of a house. It would become apparent that there is curvature in every direction.

If you increase the size of the earth to extend to the entire universe, it would appear completely flat. You would not be able to guess that there was actually curvature. This is exactly what is theorized to have happened under the Inflationary Theory. Any initial curvature of the 3-dimensional universe was rapidly and exponentially stretched to near flatness.

In equation (1.2.1) above, the scale factor, as well as the radius, become extremely large during the inflationary period. Since all other values on the RHS are constants, as these values increase dramatically the value $1 - \Omega(t)$ goes to 0. This keeps Ω very close to 1 and sufficiently explains why how the energy density arrived at such a finely tuned value.

1.3 The Horizon Problem

The Planck observatory is currently observing wavelengths in the infrared, microwave and radio domains, attempting to map and analyze the cosmic microwave background that was formed in the epoch of recombination $\sim$ 380,000 years ago. The cosmic microwave background refers to the plethora of photons traveling at the microwave wavelength that appear

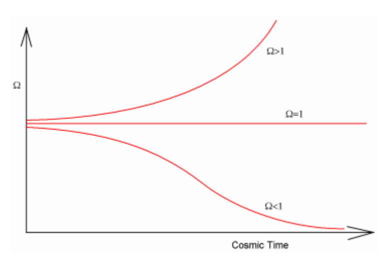

Figure 1: Ω as a function of time throughout the universe. Unless Ω is initially at 1, it will nonlinearly deviate away from unity. Density Parameter [Online image]. (2015). Retrieved June 6, 2017 from https://astro.umd.edu/~richard/ASTRO340/class23_RM_2015.pdf

everywhere in the universe. The CMB is extremely important to all areas of astrophysics because it is the closest way we can obtain information about the origins of the universe using light.

After the Big Bang, the universe was so hot that photons were attached to electrons, which caused the early universe to be completely opaque. However, after about 380,000 years, the universe cooled enough as such that electrons were unable to free themselves from strongly interacting with protons, leaving the photons aside. Without the forced attachment to free electrons, photons alone scattered throughout the universe, creating the first sense of transparency in the universe.

At t = 380,000 years, or at a redshift of ~ 1100, the size-scale represents an angle of about 2°. According to Big Bang cosmology, any two points in the sky separated by more than 2 degrees could not have ever been in causal contact with each other. If the universe started 14 billion years ago, there could be no possible way for the information one side of the universe to reach the information on the other side of the universe without traveling faster than the speed of light.

However, our measurements of the CMB taken by the Planck observatory have detected a nearly consistent temperature of 2.725 K everywhere in the sky. When this number is subtracted at every point in the sky, you obtain extremely small fluctuations that are described in Figure 2. No matter how close you zoom into Figure 2, the pattern of hot and cold spots is almost identical, something called scale invariance. There was simply no explanation for how the different sides of the universe were able to communicate their temperatures. Solving this Horizon problem would not only explain how opposite sides of the universe have been in causal contact but also in part explain why the universe is homogeneous and isotropic across large distances.

Inflation solves the Horizon problem by declaring itself a period of exponential expansion within the first few minutes of the universe. Before this expansion, it can be claimed that distant regions in our universe today were actually significantly closer to each other. The entire universe was just a tiny area of space that had the same overall temperature. The galaxies, stars, solar systems, and planets were all enclosed in a sphere of radius $4 * 10^{-29}$ meters. The areas such a small patch of space would have been in causal contact and therefore easily communicated and attained a uniform temperature before they rapidly expanded to opposite sides of the universe.

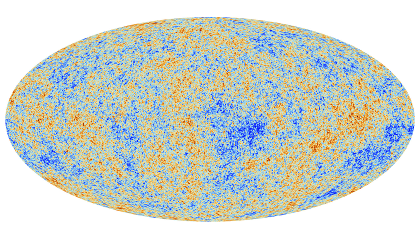

Figure 2: CMB temperature throughout the sky taken by the Planck Observatory. The temperature is close to a constant 2.725 K. The changes in color show extremely small fluctuations in temperature. These fluctuations can be measured to a millionth of a degree. Planck Satellite CMB Measurements [Online image]. Retrieved June 6, 2017 from http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_and_the_cosmic_microwave_background

1.4 The Monopole Problem

At high redshift or in the early universe, the universe was completely governed by particle theory. It was able to predict several topological defects that occur when there are phase transitions in the universe. Out of all of these defects in spacetime, monopoles are the most commonly predicted.

Monopoles are super-heavy masses at a particular point that contain a magnetic field which points radially outwards, away from the mass. Particle theory predicted that many monopoles should have formed in the hot and dense universe right after the big bang and that they would dominate the amount of matter in the entire Universe. They would also affect the curvature of the universe, and thus many other components of cosmology that we are able to measure today. However, no monopole or its effects have ever been detected. This lack of existence puzzled scientists in the 1900's and was the problem that Guth first examined before he came up with his theory of inflation.

The theory of Inflation allows monopoles to exist if they are created before or during inflation. If the monopoles are created at these points in time, the rapid expansion of the universe would dilute their densities. While their mass is kept constant, the extreme increase in the volume of the universe lowers their density by many orders of magnitude. With such small densities, monopoles would be extremely difficult to detect by our standards of measurement.

2 Problems with Inflation

2.1 CMB and Cosmic Gravitational Waves

Inflation is definitely not a precise theory, but a flexible mold that can fit many different possible models. This is because Inflation cannot be proven, and the inflationary energy that had to propel the universe to expand at such a rate is completely hypothetical. There are countless theories for what Inflationary energy is, each generating different rates of inflation and each generating differing views on what exactly happened during the inflationary era.

One observation common to all simple forms of inflationary energy is cosmic gravitational waves. While quantum fluctuations cause variations in inflationary energy causing inflation to end in certain areas faster than others, they must also create gravitational waves that propagate through the universe. These disturbances are expected to be the another source of the fluctuations in Figure 2, as they are predicted to have an effect on the temperature where they propagate. Cosmic gravitational waves produced by inflation have nothing to do with the gravitational waves of black holes colliding found by the Laser Interferometer Gravitational wave Observatory (LIGO).

Though scientists have tried to find cosmic gravitational waves expected from inflation, they have not succeeded. The lack of perfect scale invariance of the CMB and the inability to detect any cosmic gravitational waves are huge blows for the inflationary theory. While advocates rush forward to patch it, they cannot escape the direct observational evidence that renders it disfavored.

2.2 Problems with Initial Conditions

There are several more problems concerning the initial conditions of inflation. There needed to be a tiny portion of space that must have been described by Einstein's equations of General Relativity rather than quantum mechanics. Not only that, but that portion of space must have had to be flat and uniformly dense with respect to energy such that the inflationary energy could completely overwhelm all other types of energy. However, the probability of finding that space with those characteristics is extremely unlikely.

Furthermore, if that patch of space was so easy to find, it would make the need for inflation unnecessary. The entire reason for inflation was to produce a flat and uniform space that would solve the Flatness, Horizon, and Monopole problems. If the universe already had these solutions, there would be no reason for the inflationary theory to exist as the universe would have already been rid of all the problems that the inflationary theory had set out to solve.

2.3 Quantum Fluctuations and the Multiverse

Quantum fluctuations in spacetime also make it difficult for inflation to stop. Though the quantum fluctuations are tiny, they can have large effects on the inflation field, cause certain areas of the universe to expand much longer. These processes are rare but the regions that they happen to will expand dramatically compared to regions that do not. When that area stops inflating, it is surrounded by regions that are still undergoing inflation, who then cause more quantum jumps that create even more inflating volume. This process will cause inflation to continue forever, creating an infinite number of patches that each creates a universe.

However, only a universe like ours where inflation has slowed down would be suitable to form galaxies and solar systems.It can be claimed that most of these patches will not generate universes like ours. Most universes will not be flat, not have a smooth distribution, and will not contain a CMB that is nearly scale-invariant. Each patch spans an infinite amount of independent and random physical properties that have an equal probability of forming. The collection of these universes is something cosmologists term the multiverse. The multiverse doesn't explain why our universe is so unique but rather claims that our universe is an accidental and insignificant universe in a sea of different possibilities.

Many scientists have been proponents of eternal inflation and the multiverse theory. Even Guth and some of his colleagues who initiated the theory of inflation have since moved on to support theories of eternal inflation and the multiverse.

2.4 Big Bounce

The problems with inflation can lead to a serious reconsideration of the origins of the universe. Taking a look at the beginning of the universe or the big bang, there is a possibility that it was actually a 'big bounce' transition from some previous cosmological universe to the present day universe. This model considers that the previous universe was collapsing unto itself, and is followed by a period of expansion that begins with the big bang. Unfortunately, there is zero evidence that can reveal whether the origin of the universe was due to bounce or bang. However, theories involving a big bounce do not require an inflationary era in order to create a universe, and thus represent a complete shift from the standard model that we have today. Though less accepted, these theories are completely plausible and should not be dismissed.

Before a theoretical bounce, a slow contraction for a massive amount of time would have been able to smooth and flatten the universe. Though it may seem unreasonable that slow contraction occurring for a massive amount of time can smooth and flatten the universe the same as rapid expansion, but it can be explained quite reasonably. Without inflation, a slowly expanding universe must become curved and nonuniform, since the effects of gravity on matter would have a strong effect. If you think about this situation backwards, a large and highly curved non-uniform universe slowly contracts to become smooth and flat. Thus, in the possibility of a big bounce, gravity works in the contracting universe in reverse in order to smooth it out.

Additionally, Quantum fluctuations fix the smoothing in bounce theories. These fluctuations change the rate of contraction in certain places such that some reasons cool before others. This leads to the pattern of near scale invariance generated by the Planck satellite.

One important advantage that bouncing theories contain is their lack of a multiverse. When the previous universe is contracting, it is set to be large and described by general relativity, and thus bounces back to our present day universe before it gets small enough for quantum mechanical effects to get in the way. Furthermore, In the big bounce theories, there is never a place for quantum physics. Everything is described by Einstein's classical general relativistic equations. And because there is no inflation to cause quantum fluctuations, it can be said that smoothing through contraction will not produce multiple universes.

2.5 Conclusion

Inflationary cosmology cannot be examined by the scientific method. The outcome of inflation is subject to small changes in its initial conditions which make it extremely wild and indeterminable that no experiment can be performed to fully measure its viability. Though scientists understand this fact, they are hesitant to abandon inflation since it has fit many scientists needs for an explanation of solutions to the Flatness, Horizon, and Monopole Problems extremely well. However, the massive amount of evidence against inflation that is forming through our current observations must be taken into consideration. We must be prepared to scrap inflation for a more suitable theory that agrees without measurements.

References

[1] Barnaby, Neil, and Zhiqi Huang. ”Particle Production During Inflation: Observational Constraints and Signatures.” [0909.0751] Particle Production During Inflation: Observational Constraints and Signatures. N.p., 13 Dec. 2009. Web. 10 May 2017.

[2] Ijjas, Anna, Paul J. Steinhardt, and Abraham Loeb. ”Cosmic Inflation Theory Faces Challenges.” Scientific American. N.p., 03 Jan. 2017. Web. 10 May 2017.

[3] Ryden, Barbara. Introduction to Cosmology. Cambridge: Cambridge UP, 2017. 185-203. Print.

[4] ”What Is the Inflationary Theory?” NASA. NASA, n.d. Web. 12 June 2017.

[5] Wanson, Gary Scott. ”AN EXPOSITION ON INFLATIONARY COSMOLOGY.” An Exposition on Inflationary Cosmology - G.S. Watson. N.p., n.d. Web. 12 June 2017.

[6] Esa. ”Planck and the Cosmic Microwave Background.” European Space Agency. N.p., n.d. Web. 12 June 2017.