XXXII. The Inflation Hypothesis and the Very Early Universe[2]

A hypothesis is an educated guess or prediction about the relationship between two variables. It must be a testable statement; something that you can support or falsify with observable evidence. The objective of a hypothesis is for an idea to be tested, not proven.

What is the concept of inflation? In a cosmological context, inflation can most generally be defined as the hypothesis that there was a period, early in the history of our universe, when the expansion was accelerating outward; that is, an epoch when the acceleration equation.

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\varepsilon + 3P), \qquad \frac{d}{dt}a = \sqrt{\frac{8\pi G\cdot\rho_\nu}{3}}\cdot a = H_\nu\cdot a$$

tells us that when $P < -\varepsilon/3$. Thus, inflation would have taken place if the universe were temporarily dominated by a component with equation-of-state parameter $w < -1/3$. The simplest implementation of inflation states that the universe was temporarily dominated by a positive cosmological constant Λ_i (with $w = -1$), and thus had an acceleration equation that could be written in the form

$$\frac{\ddot{a}}{a} = \frac{\Lambda_i}{3} > 0$$

the Hubble constant H_i during the inflationary phase was thus constant, with the value $H_i = (\Lambda_i/3)^{1/2}$, and the scale factor grew exponentially with time:

$$a(t) \propto e^{H_i t}.$$

During inflation, the universe is dominated by the vacuum energy. In a time interval, Δt the universe expands by a factor $\exp(H_v \Delta t)$. Define the Doubling Time, t_D, as the time it takes the universe to double in size.

In the early universe, when the scale factor is very small, then mass density ρ_m must be much greater than ρ_v.

Matter density ρ_m is diluted. Then Doubling Time, t_D, is:

$$\rho_\nu := 10^{71}\frac{gm}{cm^3} \qquad H_\nu := \sqrt{\frac{8\pi\cdot G\cdot\rho_\nu}{3}}$$

$$e^{H_\nu\cdot t_D} = 2 \qquad t_D := H_\nu^{-1}\cdot \log(2, e)$$

$$t_D = 2.931\, s\cdot 10^{-33}$$

To see how a period of exponential growth can resolve the flatness, horizon, and monopole problems, suppose that the universe had a period of exponential expansion sometime in the midst of its early, radiation-dominated phase. For simplicity, suppose the exponential growth was switched on instantaneously at a time t_i, and lasted until some later time t_f, when the exponential growth was switched off instantaneously, and the universe reverted to its former state of radiation-dominated expansion. In this simple case, we can write the scale factor as

$$a(t) = \begin{cases} a_i (t/t_i)^{1/2} & t < t_i \\ a_i e^{H_i(t-t_i)} & t_i < t < t_f \\ a_i e^{H_i(t_f - t_i)} (t/t_f)^{1/2} & t > t_f . \end{cases}$$

Note that the inflationary expansion is **superluminal**: the space can expand much faster than c.

Thus, between the time t_i, when the hypothesized exponential inflation began, and the time t_f, when the inflation stopped, the scale factor increased by a factor

$$\frac{a(t_f)}{a(t_i)} = e^N$$

where N, the number of e-foldings of inflation, would be

$$N \equiv H_i(t_f - t_i)$$

If the duration of inflation, $t_f - t_i$, was long compared to the Hubble time during inflation, then N was large, and the growth in scale factor during a hypothetical inflationary period would be enormous.

For concreteness, let's take one possible model for inflation. This model states that exponential inflation started around the GUT time, $t_i \approx t_{GUT} \approx 10^{-36}$ s, with a Hubble parameter and lasted for N e- foldings, ending at $t_f \approx (N + 1)t_{GUT}$. Note that the cosmological constant Λ_i present at the time of inflation in this model was very large compared to the cosmological constant that is present today. Currently, the evidence is consistent with an energy density in Λ of $\varepsilon_{\Lambda,0} \approx 0.69\varepsilon_{c,0} \approx 0.0034$ TeVm^{-3}. To produce exponential expansion with a Hubble parameter $H_i \approx 10^{36}$ s^{-1}, the cosmological constant during inflation would have had an energy density

$$\varepsilon_{\Lambda_i} = \frac{c^2}{8\pi G}\Lambda_i = \frac{3c^2}{8\pi G}H_i^2 \sim 10^{105}\,\mathrm{TeV\,m^{-3}},$$

over 10^7 orders of magnitude larger.

Prior to the inflationary period, the universe was radiation-dominated. Thus, the horizon distance at the beginning of inflation was

$$d_{\mathrm{hor}}(t_i) = a_i c \int_0^{t_i} \frac{dt}{a_i(t/t_i)^{1/2}} = 2ct_i.$$

The horizon size at the end of inflation was

$$d_{\mathrm{hor}}(t_f) = a_i e^N c\left(\int_0^{t_i} \frac{dt}{a_i(t/t_i)^{1/2}} + \int_{t_i}^{t_f} \frac{dt}{a_i \exp[H_i(t - t_i)]}\right)$$

If N, the number of e-foldings of inflation, is large, then the horizon size at the end of inflation was

$$d_{\mathrm{hor}}(t_f) = e^N c(2t_i + H_i^{-1})$$

An epoch of exponential inflation causes the horizon size to grow exponentially. If inflation started at $t_i \approx 10^{-36}$s, then the horizon size immediately

$$d_{\mathrm{hor}}(t_f) = a_i e^N c\left(\int_0^{t_i} \frac{dt}{a_i(t/t_i)^{1/2}} + \int_{t_i}^{t_f} \frac{dt}{a_i \exp[H_i(t - t_i)]}\right)$$

$$d_{\mathrm{hor}}(t_i) = 2ct_i \approx 6 \times 10^{-28}\,\mathrm{m}.$$

For concreteness, let's assume N = 65 e-foldings of inflation, just a bit more than the minimum of 60 e-foldings required to explain the flatness of today's universe. In this fairly minimal model, if we take the horizon size immediately after inflation was

$$d_{\mathrm{hor}}(t_f) \approx e^N 3ct_i \sim 15\,\mathrm{n}$$

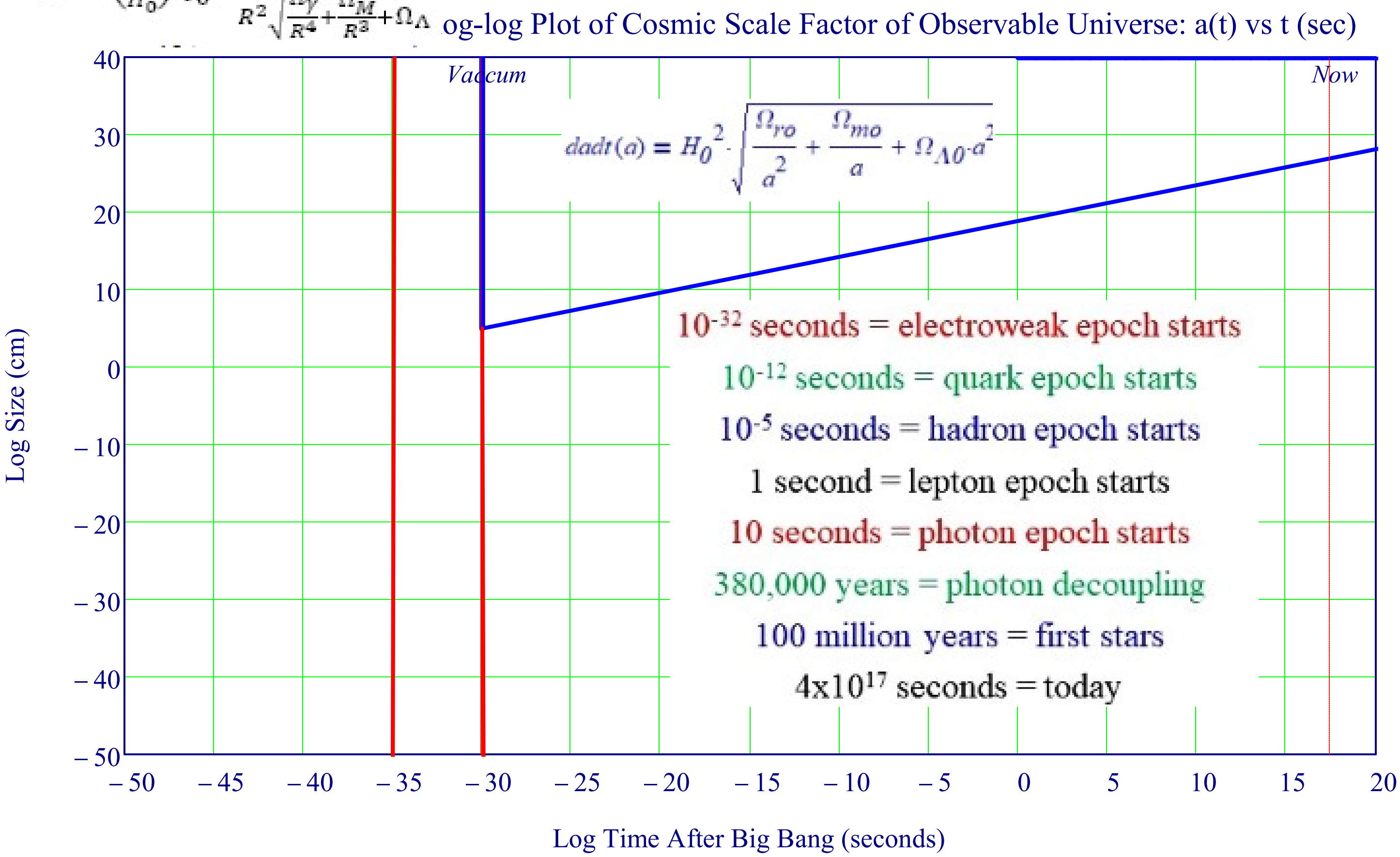
During the brief period of ~ 10^{-34}s that inflation lasts in this model, **the horizon size is boosted exponentially from submicroscopic scales to something the size of a whale**.The exponential increase in the horizon size during inflation is illustrated by the solid line in Figure 10.3. In the post-inflation era, when the universe reverts to being radiation-dominated, the horizon size grows at the rate dhor ∝ a ∝ $t^{1/2}$, as points that were separated by a distance $d_{hor}(t_f)$ at the end of inflation continue to be carried apart from each other by the expansion of the universe.

In the hypothetical model we've adopted, where inflation started around the GUT time and lasted for N = 65 e-foldings, the scale factor was $a(t_f) \sim 2 \times 10^{-27}$ at the end of inflation, estimated from Equation 10.30. At the time of last scattering, the scale factor was $a(t_{ls}) \approx 1/1090 \approx 9.1 \times 10^{-4}$. Thus, in our model, the horizon distance grew from $dhor(t_f) \sim 15$ m at the end of inflation to $d_{hor}(t_{ls}) \sim 200$ Mpc at the time of last scattering. This is 800 times bigger than the horizon size $d_{hor}(t_{ls}) \approx 0.25$ Mpc that we calculated in the absence of inflation, and is large enough that antipodal points on the last scattering surface are causally connected.

This model states that exponential inflation started around the GUT time, $t_i \approx t_{GUT} \approx 10^{-36}$ s, with a Hubble parameter and lasted for N e- foldings, ending at $t_f \approx (65 + 1) * t_{GUT}$.

$$D_c = \left(\frac{c}{H_0}\right) \int_0^{R_c} \frac{dR}{R^2 \sqrt{\frac{\Omega_\gamma}{R^4} + \frac{\Omega_M}{R^3} + \Omega_\Lambda}}$$

$$GUT := 10^{-35}$$



$$\text{Time after Big Bang (s)} \quad t = \left(\frac{1}{H_0}\right) \int_0^{R_c} \frac{dR}{R \sqrt{\frac{\Omega_\gamma}{R^4} + \frac{\Omega_M}{R^3} + \Omega_\Lambda}}$$

The solid line shows the growth of the horizon distance in a universe where exponential inflation begins at $t = 10^{-36}$s and lasts for N = 65 e-foldings. The dashed line, for comparison, shows the horizon distance in a radiation-dominated universe without an inflationary epoch.

Biggest Weakness of The ΛCDM Theory - the Inflation Hypothesis

The Weight of the Vacuum - The Worst Scientific Prediction Ever

- A "natural" Planck system of units expresses everything as combination of fundamental physical constants; the Planck density is: $\rho_{Planck} = c^5 / (hG^2) = 5.15 \times 10^{93}$ g cm^{-3}
- The observed value is: $\rho_{vac} = \Omega_{vac}\, \rho_{crit} \approx 6.5 \times 10^{-30}$ g cm^{-3}
- This is modestly called "the fine-tuning problem" The above shows that it requires a cancellation to 1 part in 10^{123})
- The Physical Origins of the Dark Energy are completely unknown at this time,

The Inflation Hypothesis

The ΛCDM Theory starts with the assumption that the universe sprang from a "singularity". Singularity is a mathematical concept and it has no meaning in the realm of Physics. It may be Mathematics, but it certainly is not Physics. It is disturbing that the two main ingredients in ΛCDM, Cold Dark Matter and Dark Energy, are not understood.

The ΛCDM Theory is based on the concept of Inflation. Inflation postulates that after 10^{-36} seconds that the universe expanded by a factor of a thousand billion billion billion and then at the right moment the inflation stopped. What is the physical mechanism for inflation? An Inflaton field? How did the inflation know when to stop? How could it have stopped everywhere at the same instant.

In order to explain the rotational velocity of galaxies and a few other phenomena, the concepts of dark matter and dark energy were proposed as explanations. The nature of dark matter is unknown and dark energy is presumed to be the cosmological constant. Quantum theory predict that this constant is 10^{120} times larger than the measured value. This has been referred to as the biggest error ever made in science.
The ΛCDM Theory predicts that the initial galaxies that were formed a few millions years after the BB, that galaxies would be formed that would be small in size. Contrary to the predicted, the JWT is finding that there are some large galaxies that were formed at this time.
The Model of GR assumes that the universe is isotropic and homogenous. This may be true locally, but it is not known is this is true in general.
To demonstrate inflation's problems, we will start by following the edict of its proponents: assume inflation to be true without question.

Neil Turok: Physics is in Crisis

Inflation is not a theory. It is a huge collection of models.

During the Planck Era, the symmetry of the matter gets broken due to the curvature of space-time and this is called a trace anomaly. What goes along with this, when you have all these Quantum fields which are describing the matter, so photons, electrons, all of them are associated with a Quantum field. The vacuum field is unable to stand still. The vacuum is not empty. The vacuum consists of all the vibrations of all the fields that you add in the standard model and the problem is those vacuum vibrations should produce huge gravitational waves. "Gravity" detects the energy of the vibrations of particle fields and should produce huge gravitational waves. There have been no primordial gravitational waves detected.

Physicists have essentially been cheating. Taking that vacuum energy of all the fields that we know about and just subtracted it. That is not really consistent. Feynmann acknowledged this. All the great physicists acknowledge this. That what we do is essentially when we do Quantum field Theory and couple it to gravity. This is essentially to cheat.

With Inflation we've found a way around that cheat. We've found a way to cancel the trace anomaly and to cancel the vacuum energy without adding even one particle to the standard model. That mechanism turns out to give fluctuations as a side effect and those fluctuations.
This may match the observations and we then have the best of all possible worlds.

Is the theory at the heart of modern cosmology deeply flawed? **Paul J. Steinhardt**

https://www.scientificamerican.com/article/cosmic-inflation-theory-faces-challenges/
"One thing it would tell us is that at some time shortly after the big bang there had to have been a tiny patch of space filled with an exotic form of energy that triggered a period of rapidly accelerated expansion ("inflation") of the patch. Most familiar forms of energy, such as that contained in matter and radiation, resist and slow the expansion of the universe because of gravitational self-attraction. Inflation requires that the universe be filled with a high density of energy that gravitationally self-repels, thereby enhancing the expansion and causing it to speed up. It is important to note, however, that this critical ingredient, referred to as inflationary energy, is purely hypothetical; we have no direct evidence that it exists. Furthermore, there are literally hundreds of proposals from the past 35 years for what the inflationary energy may be, each generating very different rates of inflation and very different overall amounts of stretching. Thus, it is clear that inflation is not a precise theory but a highly flexible framework that encompasses many possibilities."

Is the theory at the heart of modern cosmology deeply flawed?

https://www.jstor.org/stable/26002474

Summary:
Highly improbable conditions are required to start inflation. Worse, inflation goes on eternally, producing infinitely many outcomes, so the theory makes no firm observational predictions.
The basic idea of the big bang is that the universe has been slowly expanding and cooling ever since it began some 13.7 billion years ago. This process of expansion and cooling explains many of the detailed features of the universe seen today, but with a catch: the
universe had to start off with certain properties.

For instance, it had to be extremely uniform, with only extremely tiny variations in the distribution of matter and energy. Also, the universe had to be geometrically flat, meaning that curves and warps in the fabric of space did not bend the paths of light rays and moving objects. But why should the primordial universe have been so uniform and flat? A priori, these starting conditions seemed unlikely. That is where Guth's idea came in. He argued that even if the universe had started off in total disarray—with a highly nonuniform distribution of energy and a gnarled shape—a spectacular growth spurt would have spread out energy until it was evenly dispersed and straightened out any curves and warps in space.

What gave Guth's idea its appeal was that theorists had already identified many possible sources of such energy. The leading example is a hypothesized relative of the magnetic field known as a scalar field, which, in the particular case of inflation, is known as the "*inflato*n" field.

The inflaton's potential energy can cause the universe to expand at an accelerated rate. In the process, it can smooth and flatten the universe, provided the field remains on the plateau long enough (about 10^{-30} second) to stretch the universe by a factor of 10^{25} or more along each direction. Inflation ends when the field reaches the end of the plateau and rushes downhill to the energy valley below. At this point, the potential energy converts into
more familiar forms of energy—namely, the dark matter, hot ordinary matter and radiation that fill the universe today. The universe enters a period of modest, decelerating expansion during which the material coalesces into cosmic structures.

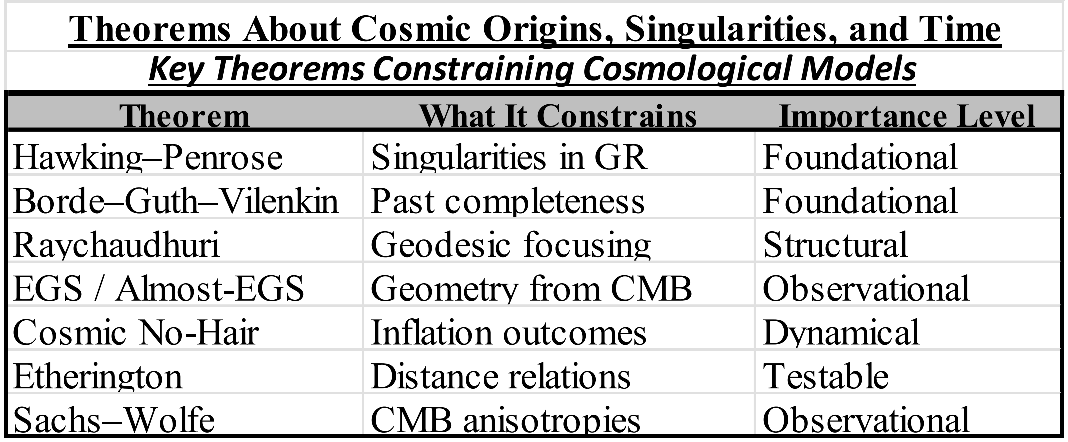
The self-perpetuating nature of inflation is the direct result of quantum physics combined with accelerated expansion. Recall that quantum fluctuations can slightly delay when inflation ends. Where these fluctuations are small, so are their ef affects. Yet the fluctuations are uncontrollably random. In some re regions of space, they will be large, leading to substantial delays.

Inflating points continue to grow and, in a matter of instants, dwarf the well-behaved region that ended inflation on time. The result is a sea of inflating space surrounding a little island filled with hot matter and radiation. What is more, rogue regions spawn new rogue regions, as well as new islands of matter—each a self-contained universe. The process continues ad infinitum, creating an unbounded number of islands surrounded by ever more inflating space.
What does it mean to say that inflation makes certain predictions—that, for example, the universe is uniform or has scale-invariant fluctuations—if anything that can happen wi happen an infinite number of times?

For inflation, the observed outcome depends sensitively on what is the initial state. That defeats the entire purpose of inflation: to explain the outcome no matter what conditions existed beforehand.

The naive theory supposes that inflation leads to a predictable outcome governed by the laws of classical physics. The truth is that quantum physics rules inflation, and anything that can happen will happen. And if inflationary theory makes no firm predictions, what is its point? The underlying problem is that procrastination carries no penalty—to the contrary, it is positively rewarded. Rogue regions that delay ending inflation continue to grow at an accelerating pace, so they invariably take over.

The Big Bang also leads to the conclusion that most of the matter in the universe is not the "normal" atomic matter with which we are familiar. One of the arguments for the Big Bang is that it appears to be able to account for the relative abundance of the "light" chemical elements such as hydrogen, helium, and lithium. However, the nuclear recipe that accounts for the abundance of these light elements also fixes the total number of protons and neutrons (classified as baryons) generated by the Big Bang. Since atoms contain protons and neutrons, atoms are classified as baryonic matter. Observations suggest the possible existence of large amounts of non-luminous dark matter in addition to the luminous matter (stars and luminous gas) that we can observe. The ratio of total matter to visible matter is often claimed to be roughly ten to one, which implies that dark matter would account for about 90 percent of the matter in the universe. Accounting for this "missing" dark matter is quite difficult, which is why both creationist and evolutionist cosmologists have suggested that what we perceive as large amounts of dark matter may actually result from unknown physics



Theorems About Cosmic Origins, Singularities, and Time

Key Theorems Constraining Cosmological Models

Theorem	What It Constrains	Importance Level
Hawking–Penrose	Singularities in GR	Foundational
Borde–Guth–Vilenkin	Past completeness	Foundational
Raychaudhuri	Geodesic focusing	Structural
EGS / Almost-EGS	Geometry from CMB	Observational
Cosmic No-Hair	Inflation outcomes	Dynamical
Etherington	Distance relations	Testable
Sachs–Wolfe	CMB anisotropies	Observational