Accepted by

Certified by

August 21, 2001

Author

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

at the

Bachelor of Science in Physics

in partial fulfillment of the requirements for the degree of

Submitted to the Department of Physics

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By

Supernatural Inflation

Cosmic Microwave Background Predictions of
Abstract

Bachelor of Science in Physics

by

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Inflation

Cosmic Microwave Background Predictions of Supernatural
Acnowledgements
Contents
Various CMB experiments indicate roughly the range of multipoles and frequencies probed by foreground contribution to each multipole is minimal. The boxes in green, the heavy dashed lines show the frequency where the total emission (cyan), synchrotron radiation (magenta), and point sources of genuine CMB fluctuations. They correspond to dust (red), free-free, and is from [22]. The shaded regions indicate where the various constraints on the angular sensitivity of CMB experiments, and is from [21]. The red curve is the current best fit to the data. 1-2 The curve [21] summarizes the current experimental results as of June 2000. 

This figure [21] summarizes the angular sensitivity of CMB experiments.

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The magnitude of the spike generated by the field in superadiabatic in-

tion of 10 degrees. It is shown in mV.

Previously released public maps smoothed to an effective beam resolu-

tion of Galactic coordinates, and was made at a higher resolution than the

COBE-DR1 four year sky maps in the Healpix format [6] (see also

A. J. Banday, K. M. Gorski, G. Hinshaw and A. Kogut) to remake

COBE-DMR. This figure is a preliminary map of a collaborative effort (involving

scale. The values were chosen by the same criteria used in figure (2.2).

Parameters for superadiabatic inflation with \( \lambda \) at the intermediate
and is shown for comparison only. The data
curve has parameters (\(\mu, \nu, \sigma = 0.05\)) and resembles the best model fit for the Boomerang least
squares test for a Gaussian. The solid
appearance in this map, so that this is a test for data contamination. The shift
between the difference maps, \((V - B)/2\). Signials originating from the sky should
appear as green points. Two maps (\(V\) and \(B\)) were made from these
data sets divided into two parts corresponding to the first and second
halves of the time stream. The first green points
are completely correlated and is largest (11\%) at \(\tau = 0.09\). The green points
are the ends of the red error bars and the blue horizontal lines that is
creates an additional uncertainty in the distance between
current, \(\sigma\) uncertainty in the angular resolution of the measurement
to an overall re-scaling of the \(V\)-axis by \(20\%\), and it is not shown. The
large \(\sigma\) due to the signal attenuation caused by the combined effects of
are dominated by cosmic/sampling variance at \(\tau > 3\sigma\). They grow at
the uncertainty due to noise and cosmic/sampling variance. The errors
are negligible corrections with the adjacent points. The error bars indicate
from [5]. Each point is the power averaged over \(\tau = 0.0\) and has
Angular power spectrum measured by Boomerang at 150 GHz, taken
The bottom curve is a reproduction of the Lange et al. 1971 curve,  

supernumerary intuition at the CMB or Planck scales, with $n_s = 1.00$. 

The middle curve was calculated in the same way for 

using either the COBEFAST default or the intermediate scale 

anisotropy spectrum for supernumerary intuition at the intermediate 

CMB temperature $T_0 = 2.728 K$. The top curve is the CMB temperature 

eternal used: $(\Omega_m, \Omega_{\Lambda}) = (1.0, 0.0)$ or $(0.4, 0.4)$ or $(0.2, 0.7)$. 

In all the curves which appear above, the following cosmological param-
In results when the LSS prior is applied, interpreted as CMB-driven constraints; exceptions are the $\Omega_{\Lambda}$ and

influenced by the structure of the parameter space and should not be

is applied. Most of the parameters in columns 6-10 ($\Omega_{\Lambda}$ to Age) are

the CMB data, except for $\Omega_{\Lambda}$ and $\Omega$ when the strong BBN prior

and top hats; columns 1-5 ($\Omega_{\Lambda}$ to $\Omega$) are predominantly driven by

10Gyr prior. The LSS priors are combinations of Gaussians

prior are top hat functions (uniform priors) and include additional

reported after marginalizing over all other parameters. The weak $\Lambda$ in most cases; upper limits are quoted at 2.$\sigma$. The quoted values are

are 1.$\sigma$. The 2.$\sigma$ values are approximately double the 1.$\sigma$ values quoted

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Table is a sample of some results of parameter extraction using the

4.2 Energy Scales of Peak Parameters in Supernovae Inflation

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Hood of data from COBE and other CMB experiments (see figure 1-1) in the last ten years has revealed a wealth of information encoded in the CMB radiation field. Indeed, the hierarchy complicates the theoretical interpretation of the data in those experiments.

In principle, it's possible to distinguish CMB anisotropies from other more local probes such as galactic surveys because non-CMB anisotropies in the universe were almost perfectly homogeneous. This linearity distinguishes CMB from other local probes. The CMB was produced when the universe was at its most homogeneous.

Not only are the equations involved relatively simple, but a linear approximation is well established. The equations involved are based on the idea that the CMB is a result of the early universe. The early universe expansion allowed the CMB to escape from local variations, leaving behind the cosmic microwave background. This background, robust to model changes, and enables cosmologists to explore the early universe.

---

Burke. An essay on the material and spiritual universe. Edgar Allan Poe

August. The reader with the most solen - the most comprehensive - the most difficult - the most profound sentence of this work: for of all conceivable subjects I approach the

If it is with humility really unassumed - it is with a sentiment even of awe - that I

Introduction

Chapter 1
One such inflationary scenario is the Randall-Sundrum model [11]. This theory and its application to the future of inflation have many interpretations. Indeed, since Guth's seminal paper of 1981 [7], there have been created a paradigm that has evolved with a greater variety of acceptability. The most general feature of which is the inflationary paradigm of the next decade. The size of the universe might just be just as definite.

In the past decade and that is homogeneous and isotropic on large scales, the potential of dramatically changing our understanding of the universe. In the last years has moved cosmology from a branch of philosophy to precision science, and has

2000. The red curve is tautological, best-fit to the data.

Figure 1.1. This figure [21] summarizes the current experimental results as of June.
range of multipoles $l$ and frequencies $\nu$ probed by various CMB experiments.

The boxes indicate roughly the foreground contribution to each multipole bin; in particular, they correspond to dust (red), free-free emission (cyan), synchrotron radiation (magenta), and point sources (green). The heavy dashed lines show the frequency where the total power is equal to the power in the foreground component. The shaded regions indicate the angular sensitivity of various CMB experiments.
...Cosmological parameters: $H_0$, $\Omega_0$, $\Omega_D$, $\Gamma$, $\Lambda$, $\Omega_{\nu}$, $\Omega_{\gamma}$, $\Omega_{\Lambda}$, $\Omega_{\gamma}$, $\Omega_{\Lambda}$, $\Omega_{\gamma}$, $\Omega_{\Lambda}$, $\Omega_{\gamma}$, $\Omega_{\Lambda}$, $\Omega_{\gamma}$...

Inflation parameters: $H$, $n$, $f$, $\eta$, $n_{\nu}$, in the
table of parameters to be fixed by comparison to the observational data, namely:
structure formation in inflationary cosmologies is a priori
unpredictably small parameters.

This is an unusual feature since most inflationary models contain one or more
models with parameters that appear naturally as mass ratios of supersymmetric par-

to both. If polarization is measured, then $\alpha$, the optical depth to the surface of last
be considered as a minimum since the temperature power spectrum is very sensitive
On the cosmological side, the Hubble constant $H_0$ and $q_0$, the baryon density, must
which allows little freedom in adjusting its amplitude.
the spike found in supernovae models arises from supersymmetric particle physics
power-law spectrum of most inflationary models is usually adjusted to fit the data,
the density perturbation spectrum at short wavelengths. While the amplitude of the
perturbation index $n_s \approx 1$, negligible tensor perturbations, and a novel large spike in
Hubble constant during inflation, on the order of $10^{-2}$, a scalar density

The predictions for these parameters under supernovae inflation are a very low

Inflation would provide information about the potential energy of the scalar field that diverges
fact, this would be extremely interesting for inflation if these are significant since they
approach this can be examined by considering derivatives such as $d \phi / d \chi$, and in
index, $n_s$ is related to $\eta$ by a consistency relation. Any derivatives from power-law
index, $n_s$ is related to $\eta$ by a consistency relation. Any derivatives from power-law
the ratio of tensor to scalar perturbations. The tensor spectral
and the spectral index, $n_s$. The general result would also include Baryon wave's
set of parameters, and a noninflationary plateau. In the inflationary picture, an absolute minimum, one would consider a

Of course, cosmologists would be very unlikely indeed if all these parameters were
Spectrum under superrelativistic inflation. and the modifications made to produce a plot of the CMB temperature anisotropy.

This is followed by a description of CMB anisotropy formation in Chapter 3. Chapter 2 begins with a discussion of superrelativistic inflation. This thesis makes predictions for the temperature anisotropy spectrum of the

which can predict the temperature power spectrum to an accuracy of 1 percent.

ion power spectrum curves can be made using the publicly available code CMBFAST.'

Theoretical predictions for the temperature and polarization unprecedented accuracy. Theoretical predictions for the temperature and polarization
curves and contains sufficiently detailed structure to allow many of them to be determined to
predicted temperature power spectrum curve depends on a large number of param-
eters and small angular scales the

The crucial role of CMB experiments (see Figure I-2) as far as inflationary cosmology is concerned is parameter estimation. On mid- to small- angular scales the

more sophisticated manner than just a single redshift of instantaneous reionization,

that in a scenario with significant reionization, it may be necessary to model it in a

the inflation scenario is based. The remaining parameters could be fixed by assum-

redshift evolution and can be calculated using the particle physics model under which

represent the number of relativistic species. This determines the epoch of neutron

since the polarization power spectrum is quite sensitive to it. The parameter,

scattering (or, equivalently, the reionization redshift, zion).
Also desirable that inflation be sensible with particle physics, such that in the end it

**Supernatural Inflation**

*Chapter 2*
of interest in supersymmetric field theories include the Planck scale, \( W \approx 10^{19} \text{GeV} \), where the scale \( W \) depends on the mechanism of SUSY breaking. Scale breaking occurs and during inflation is typically dominated by SUSY breaking in the early universe additional SUSY breaking terms in the Lagrangian. In the early universe additional SUSY breaking survives the inflation and is presumed to be broken through the spontaneous breaking of supersymmetry, which at a partner. Since this is not observed SUSY must be broken in the present vacuum. This unbroken SUSY would require that each particle has the same mass as its superpartner.

It is expected to be a local symmetry, they are partners of left or right-handed fermionic fields with two components. Finally, in addition to a supersymmetric theory these scalar fields are complex because a unification with a number of fundamental scalar fields not introduced in the standard model. A unification theory -a no and a texture B implies the boson-symmetry breaking to be automatically cancelled. Each known particle must have a superpartner: boson to obtain sensible masses. However, SUSY provides a means for quantizing corrections on the order of the Planck mass, \( W \), and a delicate cancellation is required in order to obtain SUSY vacuum effects. Generally, SUSY is quite economical here.

Thus only the key points relevant to supernatural inflation are highlighted here.

The full mathematical implementation of supersymmetry (SUSY) is quite technical. It has been taken as a very real possibility in particle physics. Hierachy, supersymmetry has been taken as a very real possibility in particle physics. Fraction of the GUT scale, In the absence of any other idea for sustaining the gauge couplings would be expected to partitio the bare value of the \( W \) mass by a significant GUT scale, leading to a very large number of gravitational corrections. The idea of using the gravitational corrections would be expected to partitio the bare value of the \( W \) mass by a significant gravitational correction would be expected to partitio the bare value of the \( W \) mass by a significant GUT scale, leading to a very large number of gravitational corrections. The idea of using the gravitational corrections would be expected to partitio the bare value of the \( W \) mass by a significant GUT scale, leading to a very large number of gravitational corrections.

### 2.1 Motivations for Supersymmetry

occurring in Nature. Will belong to a complete theory that describes all of the particles and interactions

\[ \text{Motivations for Supersymmetry} \]
Physicists have suggested a solution to this problem [1]. Models in which these parameters are ratios of known particle experimental bounds. Models that result in density fluctuations with magnitudes within the preferred ranges can provide the flat potential required. A strong criticism of most inflationary models is that they use unnatural small made in the context of superpotential inflation. numerically always much less than the Planck mass; a more detailed discussion will be given. In superpotential inflation, for a much more model evolution of the scalar field, the expectation in superpotential inflation is the effective field or hybrid inflation models can be related to interactions between two scalar fields and utilize the flat potentials. The development of a class of models known generally as hybrid inflation. These models rely on interactions between two scalar fields and utilize the flat potentials. However, superpotential corrections tend to generate a steeper potential that is un-In quantum field theory, the effective potential in the perturbative regime is given by

\[ \Lambda^2 \approx \frac{\text{superpotential breaking scale}}{\text{intermediate scale}} \]

The GUT scale, the intermediate scale, and the

2.2 Tree-level potential
(2.4)

\[ J^{m\mu} + \frac{\partial H^{m\mu}}{\partial \varrho^{m\mu}} \varrho^{m\mu} = \mathcal{L} \]

Varying \( \varrho^{m\mu} \) in the action principle gives the Einstein equation (see [16]) with

by the second term, the matter Lagrangian.

there are other fields present beside the gravitational field, which can be described

space-time derivatives. To obtain the full field equations, it must be assumed that

ion. The space-time curvature, \( H \), is to be regarded as a function of \( \varrho^{m\mu} \) and its first

The first term is the Einstein Lagrangian and represents the Lagrangian for Gravita-

(2.3)

\[ \frac{\partial \mathcal{L}}{\partial \varrho^{m\mu}} = \mathcal{J} \]

the Einstein-Hilbert Lagrangian density.

principle, \( \delta S = 0 \) yields the Einstein equation. The most general possibility leading

By making a small variation, \( \delta \varrho^{m\mu} \), whose first derivatives vanish at infinity, the action

(2.2)

\[ \mathcal{J} - \frac{\partial}{\partial x} \int = S \]

system will be of the form

Because the volume element in generic coordinates is the action of a

the loop correction mentioned earlier.

and the main effect of other fields, as far as inflation is concerned, is likely to be in

what follows we consider only scalar fields since they are what is needed for inflation

respects to space and time. Higher derivatives would not lead to sensible physics. In

dimensions, energy. It is a function of the fields and their first derivatives with

form \( \mathcal{J} \varrho^{m\mu} \), where the Lagrangian density is Lorentz-invariant and has

To have a Lorentz-invariant action, the Lagrangian for the fields must be of the

(2.1)

\[ \varrho \mathcal{J} \int = S \]

specified by its action.

As far as we know, the properties of any system in fundamental physics can be

General Relativity and the action principle
The analysis considers the limit of flat space-time, where \( \mathcal{G} \) tends to zero, but this position, relativistic, and how is effectively described using the sources of energy and taking the energy-momentum tensor to be a smoothly varying function of space-time.

By asserting that the right-hand side of the above equation is the source of gravity, Newton's gravitational constant, \( G \), is the curvature scalar, \( \nabla^2 \phi \) is the Ricci tensor, \( \mathcal{R} \) is the metric, \( \mathcal{R} \) the curvature scalar, \( n \) is the cosmological constant, \( \mathcal{C} \) is Newton's gravitational constant.

\[
\nabla^2 \phi = \nabla^2 \phi + \mathcal{R} = \nabla^2 \phi
\]

The Einstein field equation for this system is:

Using this equation and by following the above prescription for varying the action,

\[
(\phi)^2 (\phi^2) + \phi \frac{\phi^2}{\phi_0} \phi \phi^2 = \nabla^2 \phi
\]

The stress-energy tensor for two scalar fields is therefore

\[
\nabla^2 \phi - \phi \frac{\phi^2}{\phi_0} \phi \phi^2 = \nabla^2 \phi
\]

The Lagrangian density for the real parts of these scalar fields in a generic form:

\[
\Phi = (\phi + \phi) \phi \phi^2
\]

In the case of a hybrid inflation model like superrealistic inflation, this is just

\[
\Phi = \frac{\phi}{\phi_0} \phi \phi^2
\]

When \( \phi \) and \( \phi \) appearing, but when \( \Phi \) and \( \phi \) appearing, superrealistic expression would be replaced by \( \frac{\phi}{\phi_0} \phi \phi^2 \).

Special relativity corresponds to a pair of real fields, which are the relevant fields for scalar fields; which contribute to the Lagrangian density, there are two scalar fields, which describe the fields in the absence of gravity. In going from a Lagrangian density, which describes the fields in the absence of gravity, to be identified with the special-relativistic first derivative of \( \phi \), because it should be expected that the matter Lagrangian involves only the
2.4 Equations of motion for the scalar fields

\[(\phi, \phi)_{d} - (c_{d} + c_{\phi}) = d \epsilon + \phi \]

Supernatural inflation can also be written as a two-field hybrid inflation model. The condition for a two-field hybrid inflation model is:

\[
\frac{1}{V} \left( d \epsilon + \phi \right) d \frac{\epsilon}{d \epsilon} = \frac{\rho}{d \epsilon}
\]

By inserting the Robertson-Walker metric describing a homogeneous and isotropic universe into the Einstein field equations, the time derivative of the Friedmann equation is the acceleration equation. The acceleration equation is:

\[
(\phi, \phi)_{d} - (c_{d} + c_{\phi}) \frac{\epsilon}{d \epsilon} = d
\]

\[
(\phi, \phi)_{d} + (c_{d} + c_{\phi}) \frac{\epsilon}{d \epsilon} = d
\]

Energy density and pressure for this system are given by:

\[
\rho = \frac{1}{V} \left( d \epsilon + \phi \right)
\]
Note that the comoving volume in an inflating universe is given by
\[ \frac{\rho}{v} = H, \]
where the Hubble parameter is $H = \frac{\dot{a}}{a}$. The Friedmann equations
\[ \left( \frac{\dot{a}}{a} \right)^2 = \frac{8\pi G}{3} \rho - \frac{4\pi G}{3} \phi \]
Using the Friedmann equations,

(2.16)
\[ 0 = \frac{\dot{\phi}}{\dot{a}} - \dot{\phi} H + \phi \]
It follows exactly similarly for the field

(2.13)
\[ 0 = \frac{\dot{\phi}}{\dot{a}} - \dot{\phi} H + \phi \]
By requiring that $\rho = 0$, the equation of motion for the field is given by

(4.2)
\[ 0 = (x)^\phi \left( \left( \frac{\phi^\phi}{\rho} \right) \phi^\rho - \frac{\partial \phi}{\partial \rho} \right) x_{\rho} \int = S\rho \]
Integrating by parts the above expression gives

(4.1)
\[ \left\{ \left( \frac{\phi^\phi}{\rho} \right) \phi^\rho + \phi^\rho \frac{\partial \phi}{\partial \rho} \right\} x_{\rho} \int = S\rho \]
the boundary gives
\[ 0 = \phi^\rho \phi^\rho \quad \text{and assuming} \quad \phi^\phi \phi^\rho = \phi^\rho \phi^\rho \quad \text{Varying the action with} \quad \mathcal{J}(\phi)_{\phi} = \mathcal{J} \]
where can be written as

(2.2)
\[ \mathcal{J} x_{\rho} \int = S \]

(2.11)
\[ \mathcal{J} \delta - \wedge x_{\rho} \int = S \]
the action,

(2.10)
\[ \varepsilon \mathcal{J}(\phi)_{\phi} + \varepsilon \delta \mathcal{J} = \varepsilon \mathcal{J} \]
Using the flat H-W metric
\[ \phi, \phi \text{ principle gives rise to the scalar wave equations for} \quad \phi \text{ and} \quad \phi \]
In general, an interaction potential should have a quadratic dependence on the approach taken here. The potential, \( V(\phi) \), is given and then checked against experimental bounds. This is the approach taken here.

Involving phase transitions, probability arguments for the form of the effective potential involve a thermal bath of background particles. As is often the case in problems quantum system is technically complex, since it involves allowing for quantum inter-

Classically, fluctuations in thermal equilibrium would be treated as follows: at zero temperature a system of fixed volume will not minimize potential energy but instead the fields evolve to reach their vacuum expectation values. Classical statements cannot be true, since the fields would experience quantum fluctuations, and at zero temperature. However, in the quantum system of scalar fields, this classical statement be found at the potential minimum in equilibrium.

\[ 2.5 \] Superpotential Inflation Potential Function

This approximation, and is the one employed in superpotential inflation, and the same for \( \phi \). This standard approximation technique is known as the slow-roll approximation, and is the one employed in superpotential inflation.

\[ \frac{\phi^2}{(\phi, \phi) \phi^2} \approx \phi H \phi \]

The and terms are of the same order, retaining them gives

In fact these terms are normally taken to be negligible from the start, and since

The Friedmann equations are rendered less and less important.

Note also that once inflation gets underway the curvature terms in its potential. Note also that once inflation gets underway the curvature terms in come to be obeyed, provided that the scalar field is displaced away from the minimum substantially if potential, even if this condition is not satisfied initially. It is very quickly satisfied if potential is satisfied provided that the effective energy density and pressure, with

\[ V(\phi) \phi^2 > \frac{\phi^2}{\phi, \phi} \phi^2 \]

the scalar wave equations and the forms of the effective energy density and pressure,

\[ e^{-\frac{\phi^2}{\phi, \phi}} \phi^2 \]
Perturbations in the slow-roll regime were chosen for consistent inflation and to fit the experimental constraints from density \(dN\) and \(r\). The mass scales, and hence the cosine function is not required since a Taylor series expansion demonstrates that the potential is not a very special form for the potential was

and is represented graphically in Figure 2.2.

\[
(9.19) \quad \frac{dN_8}{\Phi^2 + \epsilon_8} + \frac{dN_7}{\Phi^2 + \epsilon_7} = \left( \frac{\epsilon^2_{80}}{\epsilon} \right) \Phi^2 \quad \text{can be written as}
\]

be real. Thus, taking \(z = \frac{\epsilon^2_{80}}{\epsilon} \equiv A\) and similarly for the potential of the real fields, the scalar fields can be taken to again, for the purpose of an inflationary model, the scalar fields can be taken to

\[
(9.18) \quad \frac{dN_8}{\Phi^2 + \epsilon_8} + \frac{dN_7}{\Phi^2 + \epsilon_7} + \left( \frac{\epsilon^2_{80}}{\epsilon} \right) \Phi^2 \quad \text{can be written as}
\]

super symmetric breaking potential for the system can be written as

\[
(9.17) \quad \frac{dN_8}{\epsilon} \frac{dN_7}{\epsilon} = M
\]

one might then assume the existence of a superpotential, \(\epsilon\). Under this requirement, essential to have an additional interaction between \(\phi\) and \(\Phi\). Under this requirement, rise to density perturbation predictions far below the observational. It is therefore

\[
\text{and near the origin, the simplest models involving supersymmetric breaking give}
\]

\[
\text{which couples the two fields, and is modulated by some characteristic mass scale,}
\]

\[
\text{which couples the two fields, and is modulated by some characteristic mass scale,}
\]
Dynamics of the scalar fields

Although the illustrative example of how such a model could work is assumed that their potentials are very different. The effective potential is given by

$$V_{\text{eff}} = \left(\frac{\phi_{\text{pp}}/\phi_{\text{pp}}}{\phi_{\text{pp}}/\phi_{\text{pp}}}ight) \frac{dW}{d\phi}$$

Figure 2.2: Graphical representation of a supernumerary inflation potential.

\[ V(\phi) \]

\[ \phi \]

\[ 0 = \phi \]

\[ \phi_{\text{Low}} \]

\[ \phi_{\text{High}} \]
from the time-dependent mass parameter in the potential.

The field evolution ends when the amplitude is quickly reduced to zero, only the 
\[ \nu / a_0 \approx (i) m^2 \approx 0 \]
which allows the field to decay, the rate could be small as \( \mathcal{L} \) whereas it
re-nonmassable contributions proportional to other fields' decay rates. If
the natural interaction model is constrained under the supermass, the possible
identities of \( \phi \) are discussed in [171], and using these the

\[ 2 \phi((t), H^2 + \frac{2}{H^2}) = \phi \]

potential can be ignored. The envelope obeys the approximate equation of motion.

\[ \varepsilon \mathcal{W} / \varepsilon_\phi \phi \]

It can be seen that the interaction term in equation (2.1) can be neglected. By solving
the field evolution is when the field rolls towards the origin, and

\[ 0 = \frac{\varepsilon \mathcal{W} \phi}{\varepsilon_\phi} + \phi m^2 \phi + \phi H^2 \]
(26-2) \[ N^3 \propto (\phi) \]

of motion according to equation 0 = \( \phi \). After decay, \( \phi \) follows the equation \( (\nu_e H^8/\nu^4 V) \delta \eta(\nu/\eta) = (\nu^2/\eta^2) e/\zeta = \frac{e}{N} \).

The local number of e-foils in this case is approximately \( \frac{e}{N} \). The decay constant is \( \frac{e}{N} \), the result of the field \( \phi \) when \( \phi \) is non-zero. If the decay constant is \( \frac{e}{N} \), then this lasts for a field of \( \frac{e}{N} \) until the field decays. For a field \( \phi \) with decay constant \( \frac{e}{N} \) this lasts for a field of \( \frac{e}{N} \).

(23-2) \[ \frac{z/N}{z_N} = \frac{\nu^\phi m}{\nu^\phi m} \]

(42-2) \[ \frac{z/n}{(z/n-N)e} \approx \frac{\phi}{\nu} \]

The equation of motion for \( \phi \) at early times is solved by.

The equation of motion for \( \phi \) at early times is solved by.

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The equation of motion for \( \phi \) at early times is solved by.

The equation of motion for \( \phi \) at early times is solved by.
Note that if the density fluctuation constant \( \varphi / f_\mu H \sim \phi H \) and \( f_{\mu H} = N^\mu = \phi \), then

\[
\frac{\varphi}{f_{\mu H}} \approx \frac{1}{f_{\mu H}^2 H} = \chi \frac{d}{d\psi}
\]

Primordial density perturbations generated by the field are therefore given by:

\[
\frac{\varphi}{f_{\mu H}} = \chi \frac{d}{d\psi}
\]

Taking the derivative of equation (22.29)

\[
\frac{\varphi}{f_{\mu H}^2} \approx \chi \frac{d}{d\psi}
\]

With

\[
\frac{\varphi}{f_{\mu H}} \approx \chi \nabla f_{\mu H}
\]

In the case of the field, this is given by

Hubble length.

Of the order of the density perturbation, at the time the wavenumber re-enters the

time delay function, with the characteristic cosmological time scale, \( \chi \approx \nabla H \),

the initial conditions at different points in space are the same. One interpretation of the source of these density perturbations is

The initial density perturbations are generated both in the field and the fields due

Hagedorn's dual-Higgs regime. A spike in the density perturbation

the field is in its early quasi-equilibrium stage. The quantum fluctuations in the field

the number of e-folds is required because it must be that the density

on the decay rate.

The number of e-folds in this stage is

\[
\frac{2}{3} - \frac{4}{6} + \frac{\varphi H}{f_{\mu H}} = \tau
\]

where
oscillations are damped by either gauge or Yukawa couplings. The decay leads to a
later, the field reaches the minimum of its potential and oscillates about it. These
products are assumed to be quickly thermalized, giving an effective temperature, \( T \).
As discussed above, the field decays first, and the decay of
In this two field inflation model, the energy and entropy source is the decay of
perturbations of the universe at this scale \([10]\) where \( H \) is a particle physics scale under investigation and \( N \) is the field term

\[
(3.32) \quad (\frac{1}{H N})^2 \log \frac{\xi}{1} + (\frac{1}{101/H})^2 \log \frac{\xi}{\zeta} + 38 = \epsilon H N^1 N^\n
\]

structure fluctuations on the scale of \( 1/H \) are formed at, density fluctuations at short wavelengths (scales of \( 1/H \) or less, so as to avoid conflict with large scale
For superluminal models to be viable it is important that this spike is generated
imply that the density perturbations in \( \phi \) are given by a Gaussian which falls off from
Note that the density perturbations in \( \phi \) are given by

\[
(3.34) \quad \phi N + 3N + 1N + 0N = \phi N
\]

inflation ends and the classical evolution takes over. It is given by
where \( N \) is the field at which

\[
(3.32) \quad \epsilon \frac{\phi}{H} f_{\mu\nu} = \epsilon \frac{\phi}{H} f_{\mu\nu} \approx \frac{\Phi}{\delta \Phi}
\]

Because the evolution is complicated by the evolution, the reader should refer to
The density perturbations generated by the field are given by, given in equation (2.20).
values but would make the masses uncomfortably large relative to the scale. Smaller would increase the values of $\phi_\Pi$ and $\phi_\Pi/1$ and large would decrease these. The range of plotted in these figures was chosen nothing that minimum consistent with a sufficiently rapid end to inflation, i.e. $\mu H/\phi_\Pi \equiv \phi_\Pi$. For the correct magnitude of density fluctuations (equation (2.80) and choosing the values shown were found by imposing the criterion

$$L \equiv \phi_\Pi \Pi \phi_\Pi$$

For the correct magnitude of density fluctuations (equation (2.80) and choosing the values shown were found by imposing the criterion

$$L \equiv \phi_\Pi \Pi \phi_\Pi$$

In figures (2-3) (2-4) (2-5) (2-6) (2-7) and (2-8) the values of the superpotential inflation model

$$\frac{w}{L} = H L$$

Therefore dominant, making

this study, the gauge coupling constant is taken as unity and the gauge coupling is $\gamma$ is the Yukawa coupling constant and $g$ is a gauge coupling constant [18]. In

$$\frac{w}{L} = H L$$

Instead temperature 80.6 K by
values were chosen by the same criteria used in Figure 2-3.

Parameter choices for supermortal inflation with $\Lambda$ at the GUT scale. The

\[
\frac{\Lambda^{\text{10}(\frac{\text{GeV}}{100})}}{\Lambda^{\text{10}(\frac{\text{GeV}}{100})}} = \Lambda^{\text{10}(\frac{\text{GeV}}{100})}
\]

Here is chosen to give the correct magnitude of density fluctuations for the mini-

\[
\frac{\phi w}{H} = \frac{\phi H}{H}
\]

Planck scale.
The values were chosen by the same criteria used in Figure 2.7.

Figure 2.7: Parameters for superrelativistic inflation with \( W \) at the intermediate scale.

\[ (\Lambda^{10.0}_{10}) / W \]

- \( \phi_{w}/H = \phi_{H} \)
- \( H/\phi_{w} = \phi_{H} \)
Chapter 3

CMB Anisotropy Formation
today.

This surface of last scattering became the anisotropies in the CMB temperature seen just streamed toward the observer at the present. Hence temperature differences on the "reionization" epoch at $z = 1000$ when neutral hydrogen formed. After the "reionization" epoch for short to identify the dominant dynamical components, which is called the photon-baryon combination. The photons and baryons are able to join the hydrogen in the universe. Combination electron-baryon (C/E) were hotter by a factor of $(1 + z)$ and hence the Cosmic Microwave Background (CMB) were hotter by a factor of $1000$, photons in combination, which leads to Doppler shifts in frequency and hence redshifts.

1. Gravitational (Sachs-Wolfe) perturbations. Photons from high-density regions into lower-density regions. Large angular scales.
2. Intrinsic (adiabatic) perturbations. In regions of high density, the combined of matter and radiation. Large angular scales with the current data.
3. Velocity (Doppler) perturbations. The plasma has a non-zero velocity at recombination, which leads to Doppler shifts in frequency and hence redshifts.

The basic idea of these primary effects is the importance of the dominant anisotropies being generated by scattering alone the line of sight. There are a few primary anisotropies that arise due to effects at recombination. See the gravitational instability that is consistent with the current data.
This assumes a Newtonian representation of perturbations of space rather
of the fluctuations in multipole space \( \ell \) (proportional to the inverse angle) rather
since the fluctuations are on the sky, this amounts to taking an angular decomposition
analyzed. This basically involves taking the power spectrum of the primordial noise.
To extract this sort of information a map of the CMB sky such as that
scale structure formation in the universe.
as those of the seed perturbations which can be used to pin down the nature of large
dark matter. This also allows one to extract basic cosmological parameters, as well
measure the properties of the fluid in an expanding universe known to be filled with
2. The response of the fluid to the gravitational potential fluctuations allow one to
the photon-baryon fluid moves in a gravitational potential well before last scattering.
upshearing in the early universe through gravitational instability. This implies that
It is believed that large scale structure in the universe grew out of small per-
smoothed to an effective beam resolution of 10 degrees. It is shown in my
sets, and was made at a higher resolution than the previously released public maps
http://wmap.gsfc.nasa.gov/HEALpix/SYNDAP.html. (See also
make COBE-DMR four-year sky maps in the HEALPix format [6] to re-
volume A.1. Banday, K.M. Gorski, G. Hinshaw, and A. Kogut (in-
Figure 3.1: This figure is a preliminary map of a collaborative effort (in-
Galactice
where \( \mathcal{J} \) is the transfer function for a generic perturbation and is fixed by the current

\[
\{(\gamma x)^2 \phi \phi \} (\gamma \cdot \mathsf{I}) = \{ (* \gamma x) \phi \phi \} (\gamma \cdot \mathsf{I})
\]

padded can be written as

```
All perturbations are specified by \( \phi \phi \phi \) and when Fourier ex-
```

direction as known as the CMB anisotropy. In the number of photons at position \( x \), with momenta \( (\gamma x) \phi \phi \phi \) and density \( \phi \phi \), \( (\gamma x) \phi \phi \phi \) lead to a perturbation in the energy of interest. Leave the portion during inflation and re-enter it after inflation ends. A scale is inside the horizon if \( H t > x \) and outside if \( H t < x \). The distance scale correlated with the expansion, which is specified by its current value, \( \frac{d \theta}{d t} \) defines a physical wavenumber as \( k / a \). The inverse of the physical wavenumber, \( \frac{d t}{d \theta} \) defnes a temporal position, \( \mathbf{x} \). The variable \( \mathbf{x} \) is related to the physical position \( \mathbf{x} \) by the relation \( \mathbf{x} = \mathbf{x} \). Giving the

\[
\mathbf{x} = (\gamma \mathbf{x}) \phi \phi \phi \nabla \mathbf{x} = (\gamma \mathbf{x}) \phi \phi \phi
\]

Quantum fluctuations of the supermultiplet inflation fields, \( \phi \) and \( \phi \phi \), are given by

**3.2 Cosmological perturbations**

CMB anisotropies result from doing with the data available at the present time, the angular power spectrum of

than Fourier space \( \gamma \) where the underlying potential fluctuations exist. When this
function. However, it is often desired to approach unit on large scales.

Thus the photon momentum, or equivalently, the direction of observation, \( \mathbf{e} = - \mathbf{n} \). This

Note that this is independent of \( \mathbf{x} \), because the evolution equations are invariant under rotations.

It can be shown \( \text{cf.} \ [17] \) that to first order in perturbations \( \mathbf{d} \) is a blackbody

\[
(d)f + (d)f = (d)f
\]

and the total is given by

where \( \mathbf{d} f \) is given by a blackbody

\[
\frac{I - \mathbf{d}f_0}{I} = (d)f
\]

Notice that the number of photons per quantum state, or occupation

\( \text{Multipole} \)

\( \phi \)

\[
\psi H = \chi \phi \left( \frac{\psi}{\psi H} \right) = \chi \psi
\]

that is common and is related to the vacuum fluctuations and Hubble parameter by

scalar perturbation of the Friedmann-Robertson-Walker metric in any slicing

still remains well defined even after and decay. It can be shown that the

quantity is the curvature perturbation which is consistent outside the horizon, and

horizon, and after the scalar fields decay these quantities cease to exist. A more useful
describing the evolution of perturbations because they are not consistent outside the

However, \( \dot{H}, \ddot{H}, \dot{x}, \ddot{x}, \phi, \dot{\phi}, \phi \) and the four-velocity for

value of the Hubble parameter, \( H \), and the four-velocity, \( U \).
This is defined as the frame in which the momentum density vanishes.

\[(\text{I.11})\]
\[
\frac{\phi_d}{\varepsilon} \left( \frac{\phi}{\bar{w}H} \right) = (\gamma)^{\omega_N} d
\]

\[(\text{I.10})\]
\[
\frac{\phi_d}{\varepsilon} \left( \frac{\phi}{\bar{w}H} \right) = (\gamma)^{\omega_N} d
\]

and are given by

\[(\gamma)^{\omega_N} d\]

When the slow-roll approximation is used the primordial curvature spectrum, $\zeta'$, is

\[(3.9)\]
\[
\frac{r}{y^p} \{ (\gamma)^{\omega_N} d + (\gamma)^{\omega_N} d \} (\gamma) \Theta_L \int_0^\infty u F = \langle \zeta^w | \zeta \rangle \mathcal{L} = \zeta
\]

The ensemble mean variance of the CMB multipoles defines the quantity, $\zeta$, the

Invariance of the CMB transfer function, $\Theta_L \equiv \text{CMB}$ transfer function, must be independent of $\omega$ because of this

\[(\text{3.8})\]
\[
\frac{r}{y^p} \{ (\gamma)^{\omega_N} d (\gamma) \Theta_L \int_0^\infty \frac{u F}{\zeta^w} \} = \zeta^w d
\]

Because the equations are linear and invariant under rotations, CMB multipoles

\[(L.3)\]
\[
(\zeta)^{\omega_N} \frac{u F}{\zeta^w} \mathcal{L} = \frac{L}{(\zeta) \mathcal{L}^9}
\]

the fractional temperature perturbation, $\zeta$, is given by
38

(3.13) \[ \frac{\gamma}{\eta p} \left[ \left( \frac{\phi}{\phi_0} \right) + \left( \frac{\phi}{\phi_0} \right) \right] \left( \gamma \right) \frac{\phi_0 L}{L} \int_0^\infty \eta d = \gamma \phi \]

Thus the CMB spectrum under the supernatural inflation model is given by the function

\[ (\gamma_N - \gamma_H) = \gamma_{sup} \]

where \( \gamma \) is the CMB spectrum without the supernatural inflation.

(3.16) \[ \frac{N}{m_L} = \left[ \frac{\phi_0 L}{L} \right] \left( \frac{\phi}{\phi_0} \right) \left( \frac{\phi}{\phi_0} \right) \]}

(3.13) \[ \frac{\gamma}{\eta p} \left[ \left( \frac{\phi}{\phi_0} \right) + \left( \frac{\phi}{\phi_0} \right) \right] \left( \gamma \right) \frac{\phi_0 L}{L} \int_0^\infty \eta d = \gamma \phi \]

Comparing these equations with those of chapter 2 yields:

(4.13) \[ H^v = \frac{H^v}{H^v} \left[ \left( \frac{\phi_0 L}{L} \right) \left( \frac{\phi}{\phi_0} \right) \right] = \left( \gamma \right) \phi \phi \phi \]

(3.13) \[ H^v = \frac{H^v}{H^v} \left[ \left( \frac{\phi_0 L}{L} \right) \left( \frac{\phi}{\phi_0} \right) \right] = \left( \gamma \right) \phi \phi \phi \]

Combining equations gives the spectrum of primordial curvature perturbations.

(3.12) \[ H^v = \frac{H^v}{H^v} \left( \frac{\phi_0 L}{L} \right) = \phi \phi \phi \]

Combining equations gives the spectrum of primordial curvature perturbations.

Assuming that \( \phi \phi \phi \phi \) are practically free fields, slow-roll applies such that they

where \( t \) is the Hubble time after the epoch of horizon exit, given by

\[ \frac{\delta}{\eta} = \frac{m_L}{L} \]
4.1 CMBFAST and modifications

Calculating the cmb transfer functions requires calculation of multipoles $\ell \geq 2$ to represent the intrinsic anisotropy of the microwave background. To do this the Boltzmann hierarchy must be solved to sufficiently high order. While codes have been written to solve these equations ([4],[9],[9]), they are much too slow to permit an exploration of the parameter space. Even in codes where reionization is assumed to be negligible (which is unlikely anyway) solving the Boltzmann hierarchy is still much too slow.

A more efficient approach is to express the temperature transfer function as an integral along the photon past light cone. This is known as the line of sight method and is the one employed in CMBFAST [9]. The temperature transfer function using

...continued from previous page...

**Chapter 4**

CMB Temperature spectrum

*“This summer I have discovered something that is totally useless.”*

- Peter Higgs, in a 1964 note to his research student.
This leads to an error of approximately $I^2$. The quantity $\phi$ is taken as an estimate of $N_{1/2}$. If $N_{1/2}$ is calculated using equation (3.3),

$\exists I_{W}$ can be made. The results of these calculations are summarized in the table of 1.2, can be made. The results of these calculations are summarized in the table of 1.2.

Using this quantity (called $\phi$), estimates for the magnitude of $\phi$ are consistent with $\phi$. The ratio of the magnitude of $\phi$ to $\phi$ is then calculated.

To check the magnitude of fluctuations for different values of $\phi$, parameter $\phi$.

4.2 Cheking the magnitude of fluctuations

where (\(\phi\)) represents the power law portion of the spectrum and $\phi = \phi(\phi)$. This is the

\[ (\phi) \psi \phi d + (\phi) \phi = (\phi) \text{powerlaw} d \]

with

models supplemented inflation models, the primordial power spectrum was replaced.

default primordial power spectrum to a pure power law. To accommodate this, the two-field

development. Thus, CMBFAST was designed for single inflation models and sets the

When CMBFAST was first introduced, few two-field inflation models had been

replaced by a velocity and photon moment up to $\phi$.

and only depends on small number of contributions from the gravitational potential.

for subsequent calculations. The source term is the same for all multipole moments

logical model. The geometric term can thus be computed only once and stored

momentum $\phi$ and a geometric term $\phi$, which is independent of the particular cosmic

momentum $\phi$ and a geometric term $\phi$, which is independent of the multipole

The main advantage of the line of sight integration method is that the anisotropy

\[ \int_p (\phi - \phi_0) \psi \phi \phi \phi \Theta \phi_0 \phi = (\phi_0) \phi \phi \phi \phi \]

this method is given by.
Figure 4-1: The magnitude of the spike generated by the field in supernature.

Figure 4-2: The characteristic of COBE data.
Calculating the CMB spectrum

energy scales that the parameter corresponds to in figure (4.3).

small change in parameters would be needed to make \( \nabla = 1 \). Table 4.1 shows the

However, because \( \nabla \) changes very quickly as the parameters are varied, only a very

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CMB Scale</th>
<th>Intermediate Scale</th>
<th>Planck Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.78 &gt; m &gt; 1.2</td>
<td>0.9 &gt; B &gt; 0.96</td>
<td>0.9 &gt; B &gt; 0.96</td>
<td>0.9 &gt; B &gt; 0.96</td>
</tr>
<tr>
<td>2.2 &gt; m &gt; 2.7</td>
<td>2.4 &gt; m &gt; 2.9</td>
<td>2.6 &gt; m &gt; 3.2</td>
<td>3.0 &gt; m &gt; 3.6</td>
</tr>
<tr>
<td>98 &gt; \theta &gt; 95</td>
<td>99 &gt; \theta &gt; 96</td>
<td>100 &gt; \theta &gt; 101</td>
<td>102 &gt; \theta &gt; 103</td>
</tr>
</tbody>
</table>

Table 4.1: Energy Scales of Peak Parameters in Supernatural Inflation
Comparison only.

is the best model fit for the Boomerang 78/150 GHz data [14, 15], and is shown for 
crude mass parameters (h = 0.67, Ωm = 0.27, Ω = 0.31) and is fixed. The solid 
sky should appear in this map, so this is a test for data contamination. The solid 
length map from the difference map (A − B)/2). The green dots show the power 
maps (A and B) were made from the chesky haloes, and the green points show the power 
maps. [A and B] into two parts, corresponding to the first and second halves of the line stream. Two 
the power spectrum of a difference map obtained as follows: the data were divided 
The current I uncertainty in the angular 
The current I uncertainty in the calibration corresponds to an overall re-scaling 
effects of the 10 beam and the 14 beam. They grow at large l due to the signal attenuation caused by the combined 
errors/sampling variance. The errors are dominated by cosmic/sampling variance at 
earth base influence the uncertainty due to noise and 
5/2. Each point is the power averaged over √ l and has negligible correlations 
Boomerang 150 GHz, taken from 

Figure 4.2: Angular power spectrum measured by Boomerang at 150 GHz, taken from
The results can be compared with the input \( n^* \) calculated using equation (4.1). The results can
be compared with the input \( n^* \) calculated using the default CMBFAST
power-law process of the parameter \( n^* \) was maximum. These were compared against calculations done without
perturbation integral parameters, and in each of figures (2-3), (2-4) and (2-5).
The CMB temperature anisotropy spectrum was calculated for values of the su-
corresponding range of the scalar spectral index to 1.06 to 1.13.
and the parameter space of figure (2-5) to less than half by the above restrictions and the
field decay rate at \( \Lambda \) is unacceptable for \( n^* \) is only \( \Lambda \times 10^4 \) and \( n^* \) is only \( \Lambda \times 10^4 \) and taking \( \Lambda = 1 \) as a strin-
g model, double the \( 10 \) values quoted in table (4-1), and taking \( \Lambda = 1 \) as the next
is calculated from figure (2-6). It is difficult to derive much more from unity and is given by,
when \( n^* \) is calculated using the range of \( n^* \) is calculated using the range of \( n^* \) is calculated using the range of \( n^* \).
For \( \Lambda \) at the Planck or CHF scales, \( k^* \) does not deviate from unity when cal-
and is very close to \( 1 \) both the Planck and CHF scales. This differs from the usual
where, according to [17], \( n^* - \frac{\Lambda}{\Lambda^2} \) is always greater than \( 1 \).

<table>
<thead>
<tr>
<th>( n^* )</th>
<th>( \Lambda = 1 )</th>
<th>CMB Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.0001</td>
<td>0.00001</td>
</tr>
<tr>
<td>0.02</td>
<td>0.0002</td>
<td>0.00002</td>
</tr>
<tr>
<td>0.03</td>
<td>0.0003</td>
<td>0.00003</td>
</tr>
</tbody>
</table>

Table 4.2: This table is a sample of some results of parameter estimation using the

Results when the CMB prior is applied.

Table 4.2: This table is a sample of some results of parameter estimation using the

should not be interpreted as CMB-determined constraints; exceptions are the \( \Omega_\Lambda^2 \) and
and columns 6-10 (2) to (7) are influenced by the structure of the parameter space and
columns 6-10 (2) to (7) are influenced by the structure of the parameter space and
columns 6-10 (2) to (7) are influenced by the structure of the parameter space and
columns 6-10 (2) to (7) are influenced by the structure of the parameter space and

amplitude is generated at such small scales that it is negligible for CMB observations.

Although the peak generated by the field in supernatural inflation has a very large

**Discussion**

The effect of the spike in the primordial perturbation spectrum on the CMB

Figure (4.3) illustrates that when the inflation field decays at a very large rate,

be found in figure (4.3).

The bottom curve is a reproduction of the Lane' et al. [11] curve. The same

same way for supernatural inflation at the CNP, the middle curve was calculated in the

middle curve was calculated in the

natural inflation at the intermediate scale using either the CMBFAST default $(\mu = 1.3)$. The top curve is the CMB temperature anisotropy spectrum for super-

terms were used: $(\mu = 1, \nu = 0, 0.4, 0.26, 0.04, 0.025, 0.7228)$. 

Figure 4.2: In all the curves which appear above, the following cosmological param-

Supernatural Inflation CMB Temperature Anisotropy Spectrum
Noam Chomsky, personal correspondence.

...and can only think of

Likely the parameter space of supernatural inflation at the intermediate scale even more

CMB experiments will establish a value for n_s to the 0.1 level, which will constraint

parameteric models, it is the most likely constrained by current data, and future

information at the intermediate scale is favored by Randall, et al in the context of su-

decay rate L'. When accommodated by a modest change in \( \Delta a \). Although supernatural

suggest that \( N^\prime \) for the same parameters is generally about 5 larger using the smaller

a nonperturbable superpotential; assuming the larger decay rate. Randall, et al

important to note that the above statements only hold for supernatural inflation with

CMB temperature anisotropies are unobservable at the scale of 1/Mpc. However, it is

volumes. In addition, although this peak is very wide in \( \ell \) space, its effects on the
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