Flat Geometry

- 2-dimensional curved surfaces
- 2-dimensional curved spaces
- 3-dimensional curved surfaces
- 3-dimensional curved spaces

- Curved 2-dimensional spaces are not Euclidean.
- Curved 3-dimensional spaces are not Euclidean.

What is meant by "flat"? Why was the early universe so flat?

"Flatness Problem"?

100,000°C (cosmic microwave background (CMB) uniform to 1 part in 1 part in 10,000,000)

Summary P. 2: Evidence for Inflation

1. Inflation can explain the large-scale uniformity of the universe.

PART 2

Inflatonary Cosmology: Is Our Universe a Multiverse?

PART OF

Is Our Universe a Multiverse? 8.286 Lecture 2

September 10, 2018

- Alan Guth -

Summary of Last Lecture

Matter: energy of the cosmic gravitational field canceling the energy of space. The energy would be very small or maybe zero, with the negative energy of the gravitational field

Cosmic Inflation: The膨胀, describes how the global

in an expanding space

The Standard Big Bang: Really describes only the attempt of a

Beginning with a hot dense uniform soup of particlesfilling

7:286 Lecture 2, September 10, 2018, p. 1
NEW MODEL: Dark Energy. In 1998 it was discovered that the
expansion of the universe has been accelerating for about the last
5 billion years. The “Dark Energy” is the energy causing this to
happen:

\[ \Omega = 66.3 \pm 0.4 \text{(95\% confidence)} \]

astronomical observations:

- Latest observation by Perlmutter (combined with other
- Last 1998 observation pointed to \( \Omega \approx 0.7 \pm 0.3 \).
- Today the universe should have a critical density
even the early universe must always accelerate. It predicts that even
- Since the mechanism by which information explains the finiteness of
- The evolution of \( \Omega \) changes, too. As the universe
- These numbers are extremely high. Perhaps in a limited number
- If the universe were slightly above 1, it would simply fall to zero — and no galaxies would form.
- If \( \Omega \) is less than 1, the universe would never reheat, and no galaxies would form.
- If \( \Omega \) is equal to 1, the universe would be balanced on its
- A universe at the critical density is also a pencil balancing on its

\[ \Omega = \frac{\text{critical mass density}}{\text{actual mass density}} \]

According to General Relativity, the flaxness of the universe is related to its mass density:

- A universe is flat, anisotropic, cold, and deterministic.
- In the event of \( \Omega > 1 \), the universe may have more than one
- To be as close to critical density as we measure today, one
- The universe would expand, and no galaxies would form.
- It would simply fall to zero — and no galaxies would form.
- It would rapidly fall to zero — and no galaxies would form.
- It would rapidly fall to zero — and no galaxies would form.
**The Cosmological Constant Problem**

- The universe is larger by 120 orders of magnitude.
- But it is much larger than the observed value.
- So a nonzero energy density is expected.
- This is dubbed “Dark Energy.”
- According to GR, the presence of Dark Energy is the only way to explain the expansion of the universe, which has been accelerating for the past 5 billion years.
- In 1998, two groups of astronomers discovered that the expansion of the universe is speeding up.

**Information Suggests a Multiverse**

- The models are not found, that is not evidence against inflation: for instance, a 1% of models predict a 50% chance that a model much smaller than 1% of models are not found, that is not evidence against inflation.
- If D-models are not found, that is not evidence against inflation: many models are created with the demand of inflation.
- The search for D-models is still on, if they are found, they will improve the demand of inflation.

**Gravitational Waves: Come and Went**

- In 1974, the first gravitational wave was detected by the Pulsar Doublet, which was a very strong signal of gravitational waves.
- In 2014, the first gravitational wave was detected by the BICEP experiment, which was a very weak signal of gravitational waves.
- However, the detection of gravitational waves has been challenging due to the small signal-to-noise ratio.
- The detection of gravitational waves has been a major breakthrough in the study of the early universe.
- However, the detection of gravitational waves has been controversial due to the lack of independent confirmation.
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**Inflation Region Breathing off and ProducingPocket Universes**

- Once started, the inflation goes on for ever, with pieces of the inflation region breathing off and producing pocket universes.
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**We Would Be Living in One of the Many of Pocket Universes**

- In the inflation region breathing off and producing pocket universes, the universe is expanding, and as it expands, the universe becomes denser, and as it becomes denser, the universe becomes less dense.
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Do Physicists Take the Multiverse Seriously?

Summary

The Inflationary Paradigm Is in Great Shape

The Multiverse and the Cosmological Constant Problem

Almost all inflationary models are eternal into the future. Once

Observational selection effect.

1. It is therefore plausible that the only forms in those pocket universes would observe a small vacuum energy.

2. The multiverse offers a possible (although controversial) solution.

3. There are 10^{50} different types of vacuum (as in string theory).

4. If the vacuum energy were too large and the universe immeasurably small, the multiverse could (expected) not scale.

5. The multiverse arises a possible (although controversial) solution.

6. There will be many different points of origin (as in string theory).

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Lubie and Martin Rees's "I have just enough confidence about the multiverse to bet the lives of both Andre

Steven Weinberg (1979 Nobel Prize in Physics)".

Another Linde (Stanford University, major role in developing inflation).

Why has said that he is so confident that he would bet his own

prize the 2012 Fundamental Physics Prize and the 2014 Kavli

Any cosmologist should in the 2002 Dirac Prize, the 2004 Cumber

Scientific University major role in developing inflation.