INFLATIONARY COSMOLOGY:

IS OUR UNIVERSE A MULTIVERSE? PART OF

PART 1



- Alan Guth -Ħ

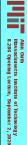
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The Standard Big Bang

- 🖈 Theory that the universe as we know it began 13-14 billion years satellite collaboration, 2018.) ago. (Latest estimate: 13.80 ± 0.02 billion years, from the Planck
- 🖈 Initial state was a hot, dense, uniform soup of particles that filled space uniformly, and was expanding rapidly.

- How the early universe expanded and cooled
- 🖈 How the light chemical elements formed
- 🖈 How the matter congealed to form stars, galaxies, and clusters of galaxies







What it doesn't describe:

- What caused the expansion? (The big bang theory describes only the aftermath of the bang.
- ☆ Where did the matter come from? (The theory assumes that all matter existed from the very beginning.

In other words, it says nothing about what banged, why it banged, or what happened before it banged!

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What is Inflation?

- ☆ Inflation is a "prequel" to the conventional big bang picture.
- \Rightarrow In particular, inflation is a theory about the bang of the big bang propelled the gigantic expansion of the big bang That is, inflation is a possible answer to the question of what
- 🖈 Inflation is also a possible answer to the question of where almost all of the matter came from.
- \Rightarrow Inflation is **NOT** a theory of the origin of the universe, but it can explain how the entire observed universe emerged from a patch only 10^{-28} cm across, with a mass of only a few grams.
- 🖈 Inflation explains the expansion by means of

Gravitational Repulsion.



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Two Miracles of Physics

Definition: A "miracle of physics" which is a feature of the laws of physics

- (a) was never taught to me when I was a student; and
- (b) is so far-reaching in its consequences that it can change our picture of the universe.

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- 🖈 Inflation proposes that a patch of repulsive gravity material existed cm. (Since any such patch is enlarged fantastically by inflation, scale $(\sim 10^{16}$ GeV), the patch needs to be only as large as 10^{-28} in the early universe — for inflation at the grand unified theory the initial density or probability of such patches can be very low.)
- 1 GeV pprox mass energy of a proton.
- ↑ The gravitational repulsion created by this material was the driving force behind the big bang. The repulsion drove it into exponential expansion, doubling in size every 10^{-37} second or so!

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Miracle of Physics # 1: Gravitational Repulsion

- 🖈 Since the advent of general relativity, physicists have known that gravity can act repulsively.
- 🖈 In GR, pressures can create gravitational fields, and negative pressures create repulsive gravitational fields
- 🖈 Einstein used this possibility, in the form of the "cosmological with repulsive gravity preventing its collapse. constant," to build a static mathematical model of the universe,
- \Rightarrow Modern particle physics suggests that at superhigh energies there should be many states with negative pressures, creating repulsive gravity.





- 1 The patch expanded exponentially by a factor of at least 10^{28} size of a marble. destined to become the presently observed universe was about the Inflation lasted maybe 10^{-35} second, and at the end, the region $(\sim 100 \, {
 m doublings})$, but it could have expanded much more.
- ☆ The repulsive-gravity material is unstable, so it decayed like
 a radioactive substance, ending inflation. The decay released a radioactive substance, ending inflation. energy which produced ordinary particles, forming a hot, dense "primordial soup." Standard cosmology began.

Caveat: The decay happens almost everywhere, but not everyorigin of eternal inflation. where — we will come back to this subtlety, which is the



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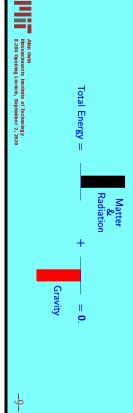
- After the repulsive gravity material decayed, the universe continued to coast and cool from then onward.
- ☆ Key feature: During the exponential expansion, the density of matter and energy did NOT thin out. The density of the repulsive gravity material was not lowered as it expanded!
- Although more and more mass/energy appeared as the repulsive-gravity material expanded, total energy was conserved! HOW?????

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Miracle of Physics #2: Energy is Conserved, But Not Always Positive

- ☆ The energy of a gravitational field is negative (both in Newtonian gravity and in general relativity).
- ☆ The negative energy of gravity canceled the positive energy of matter, so the total energy was constant and possibly zero.
- ☆ The total energy of the universe today is consistent with zero.

 Schematically,



Evidence for Inflation

Large scale uniformity. The cosmic background radiation is uniform in temperature to one part in 100,000. It was released when the universe was about 400,000 years old. In standard cosmology without inflation, a mechanism to establish this uniformity would need to transmit energy and information at about 100 times the speed of light.

Inflationary Solution: In inflationary models, the universe begins so small that uniformity is easily established — just like the air in the lecture hall spreading to fill it uniformly. Then inflation stretches the region to be large enough to include the visible universe.

