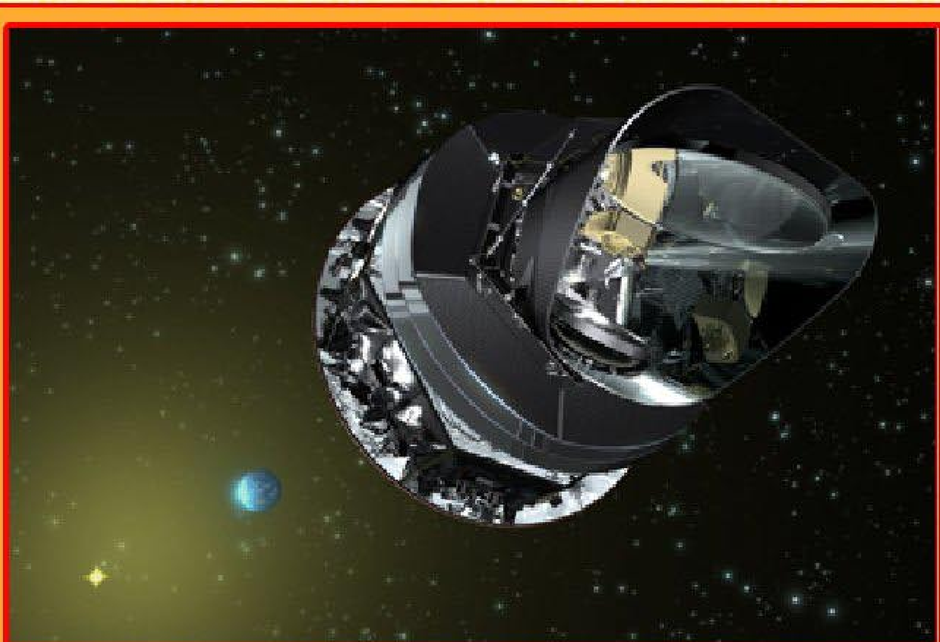
INFLATIONARY COSMOLOGY:

IS OUR UNIVERSE PART OF A MULTIVERSE?

PART 1



— Alan Guth —

Massachusetts Institute of Technology

8.286 Opening Lecture
September 5, 2018

The Standard Big Bang

What it is:

- ☆ Theory that the universe as we know it began 13-14 billion years ago. (Latest estimate: 13.82 ± 0.05 billion years!)
- ☆ Initial state was a hot, dense, uniform soup of particles that filled space uniformly, and was expanding rapidly.

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What it describes:

- 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:

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- ☆ Where did the matter come from? (The theory assumes that **all matter** existed from the very beginning.)

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Gravitational Repulsion.

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(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.

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 constant," to build a static mathematical model of the universe, with repulsive gravity preventing its collapse.
- Modern particle physics suggests that at superhigh energies there should be many states with negative pressures, creating repulsive gravity.

★ Inflation proposes that a patch of repulsive gravity material existed in the early universe — for inflation at the grand unified theory scale ($\sim 10^{16}$ GeV), the patch needs to be only as large as 10^{-28} cm. (Since any such patch is enlarged fantastically by inflation, the initial density or probability of such patches can be very low.)

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- 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!

- The patch expanded exponentially by a factor of at least 10^{28} ($\sim$ 100 doublings), but it could have expanded much more. Inflation lasted maybe 10^{-35} second, and at the end, the region destined to become the presently observed universe was about the size of a marble.

- The repulsive-gravity material is unstable, so it decayed like a radioactive substance, ending inflation. The decay released energy which produced ordinary particles, forming a hot, dense "primordial soup." Standard cosmology began.

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

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- Although more and more mass/energy appeared as the repulsive-gravity material expanded, total energy was conserved! HOW????

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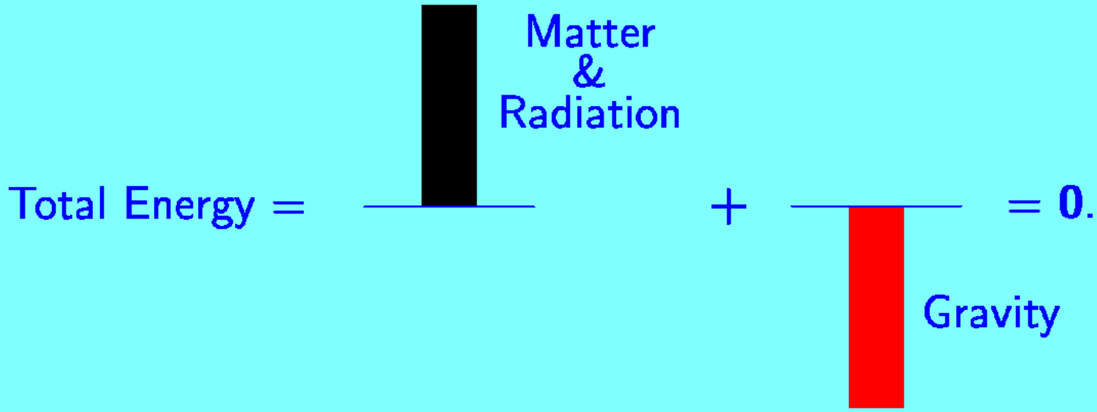
- ☆ The total energy of the universe today is consistent with zero. Schematically,



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Evidence for Inflation

1) **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.

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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.