The Fate of the Universe

The fate of the Universe depends on how much "stuff" (mass and energy) there is in the Universe.

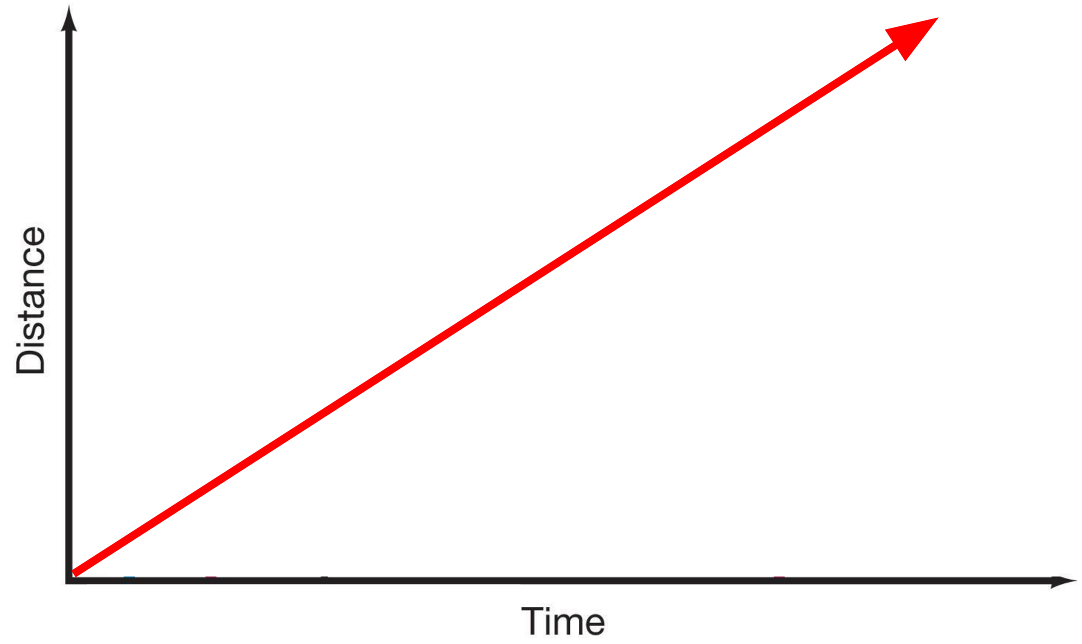
Einstein originally only accounted for gravity, but then added a "**cosmological constant**" to balance gravity so that the Universe would be "static". However, he later called this a mistake.

Yet, it turns out that he was correct to do so (but for the wrong reasons), since there is strong evidence today that the Universe is dominated by what we call **dark energy**. Not only does this balance gravity, but it apparently dominates it.

The Fate of the Universe

Depends on how much mass and energy there is in the Universe.

Ignoring energy and *assuming mass exerts no gravitational pull*, the Universe would expand forever at the same rate that it is today (and was in the past).

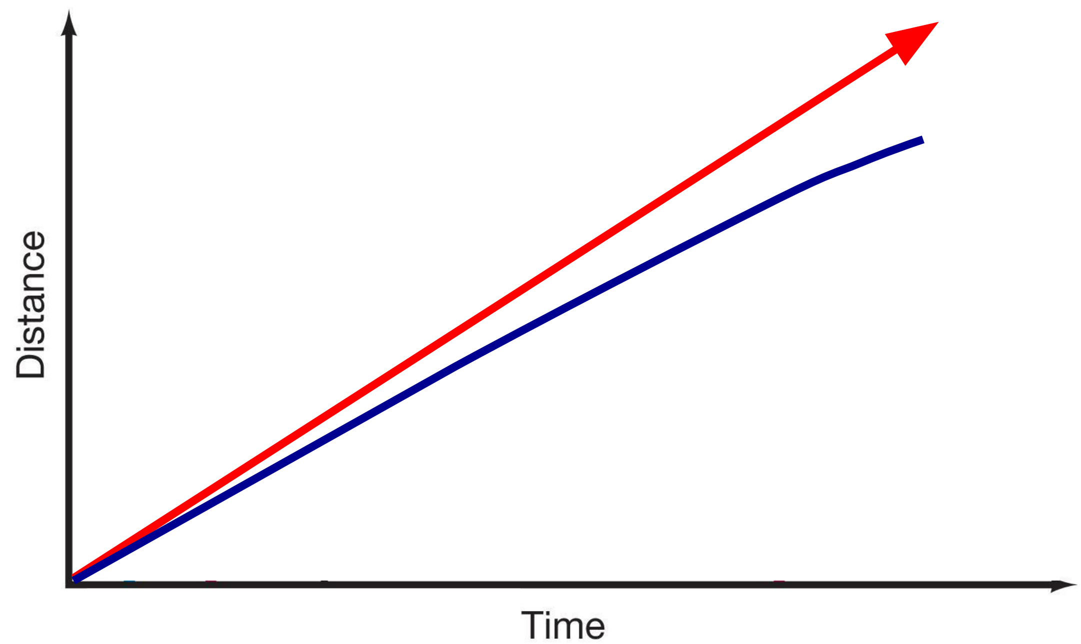


The Fate of the Universe

Depends on how much mass and energy there is in the Universe.

Still ignoring energy but now allowing mass to exert gravitational pull, the Universe would slow down in its expansion (and not get as big).

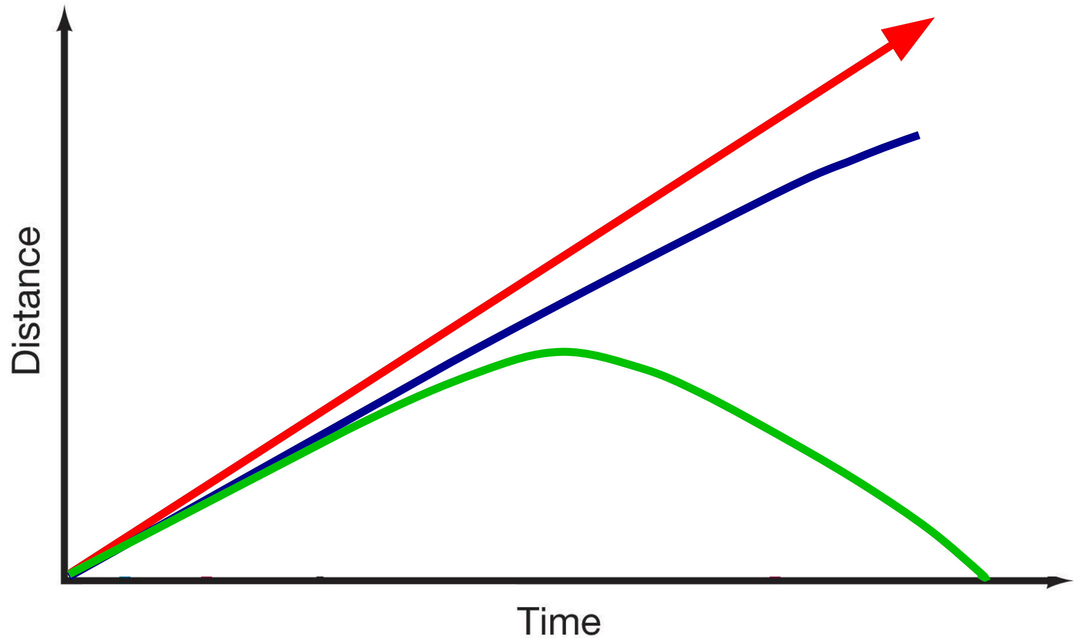
Gravity acts like friction.



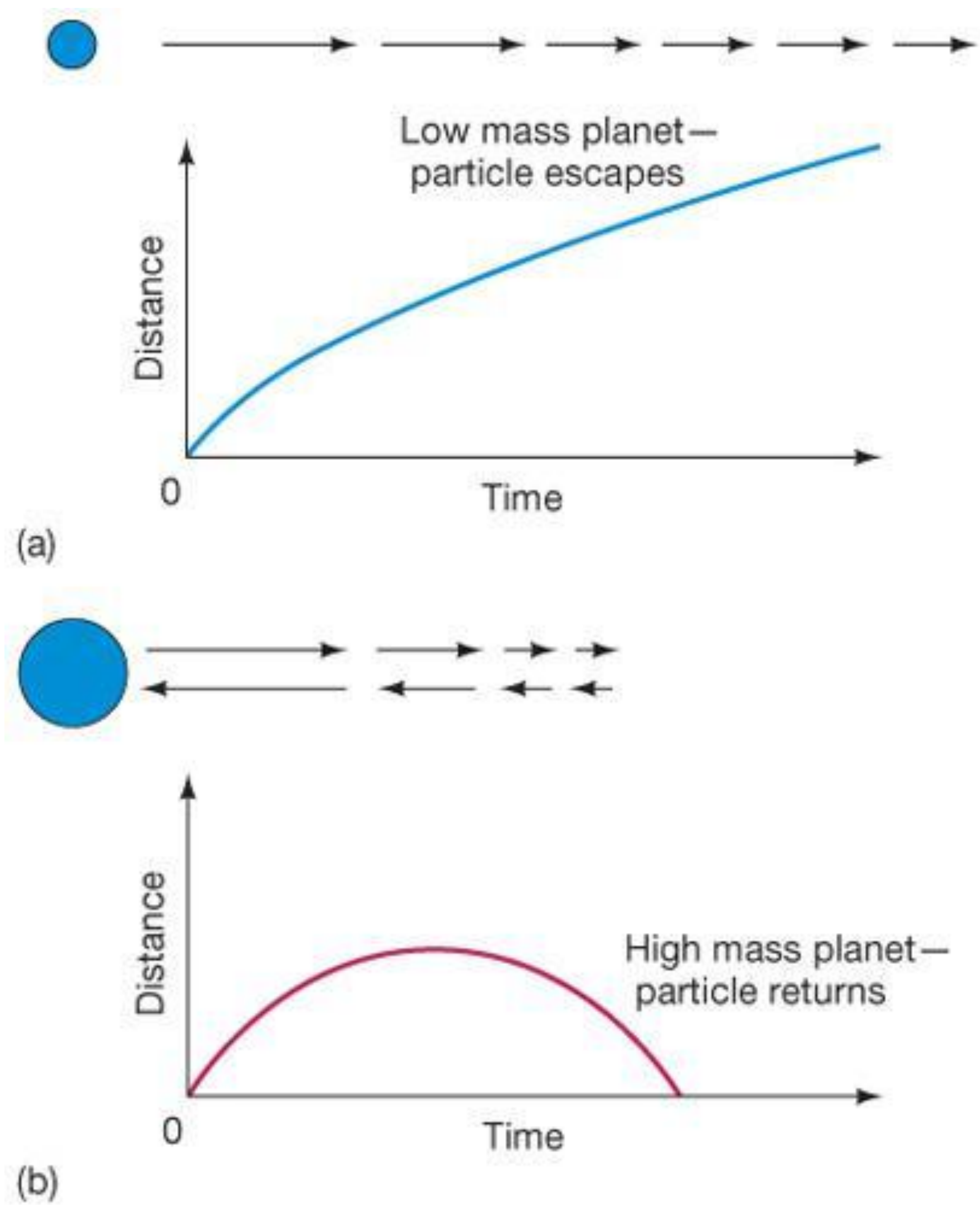
The Fate of the Universe

Depends on how much mass and energy there is in the Universe.

If there is enough mass the Universe will collapse back upon itself.



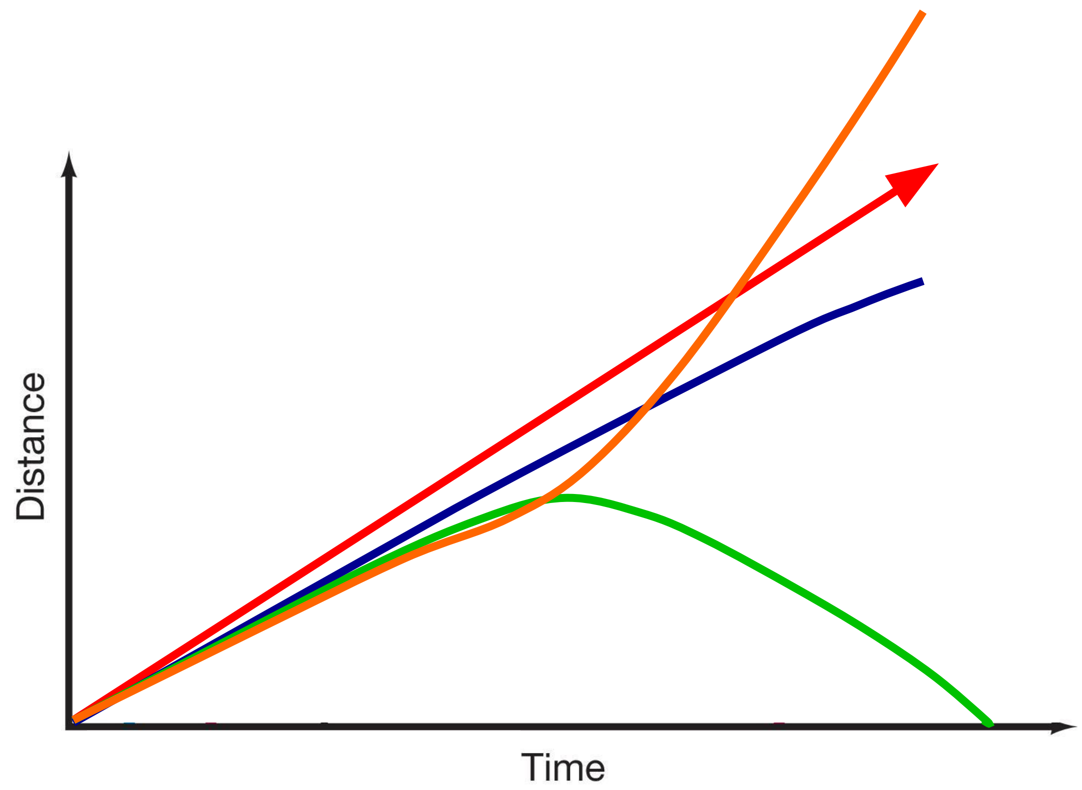
Comparison to Earth's Gravity



The Fate of the Universe

Depends on how much mass and energy there is in the Universe.

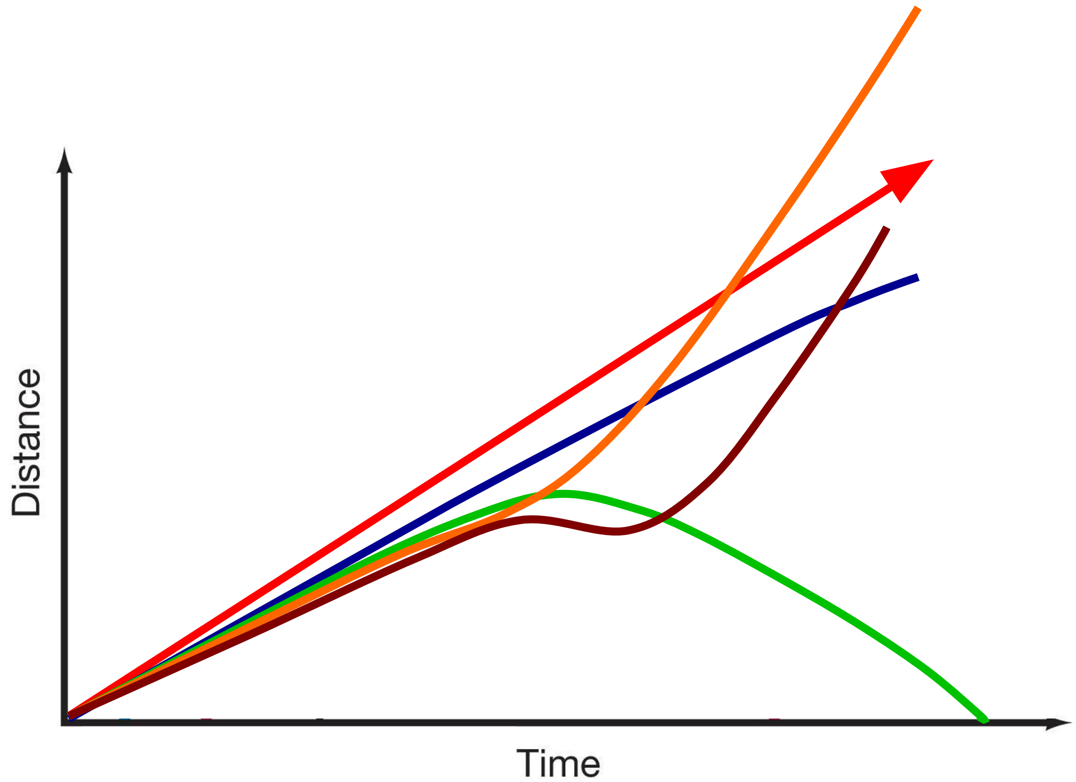
But Dark Energy has a repulsive force that can cause the expansion of the Universe to speed up again.



The Fate of the Universe

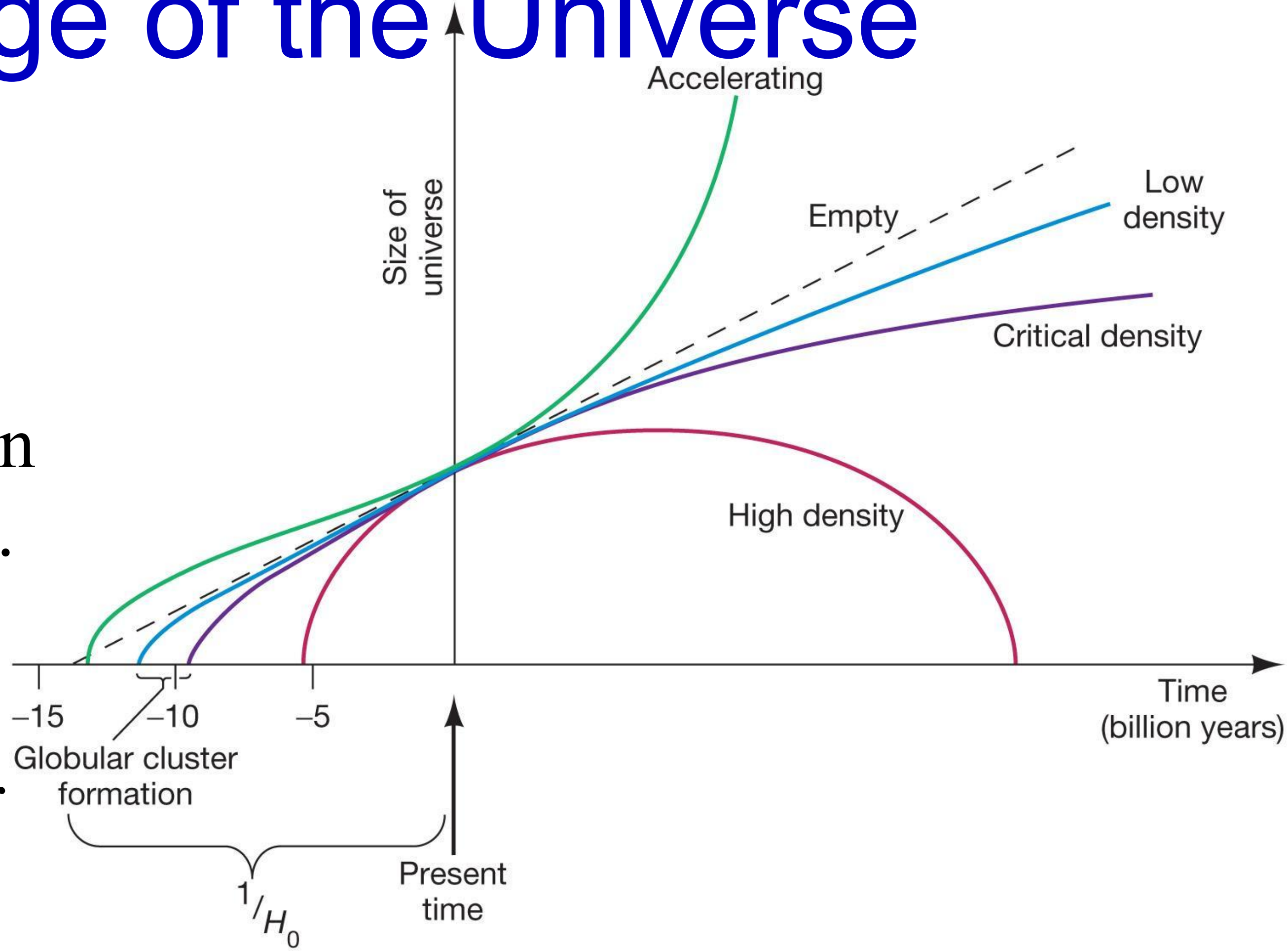
Depends on how much mass and energy there is in the Universe.

More matter (or less Dark Energy) would could the re-expansion to happen later.



Age of the Universe

In reality, the different curves should meet today rather than at the Big Bang. This has important implications for the age of the Universe.

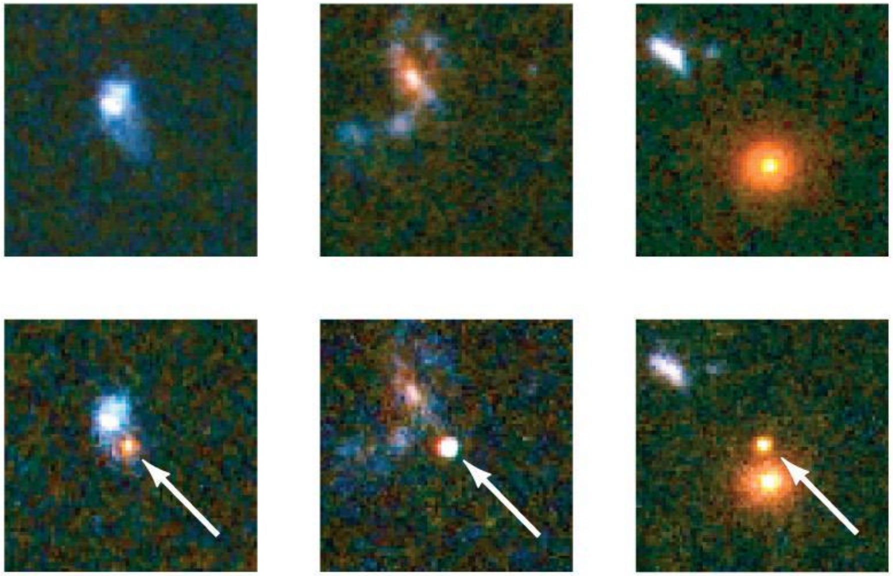


Possible explanation for the acceleration: vacuum pressure (cosmological constant), more generically called dark energy.

An Accelerating Universe?

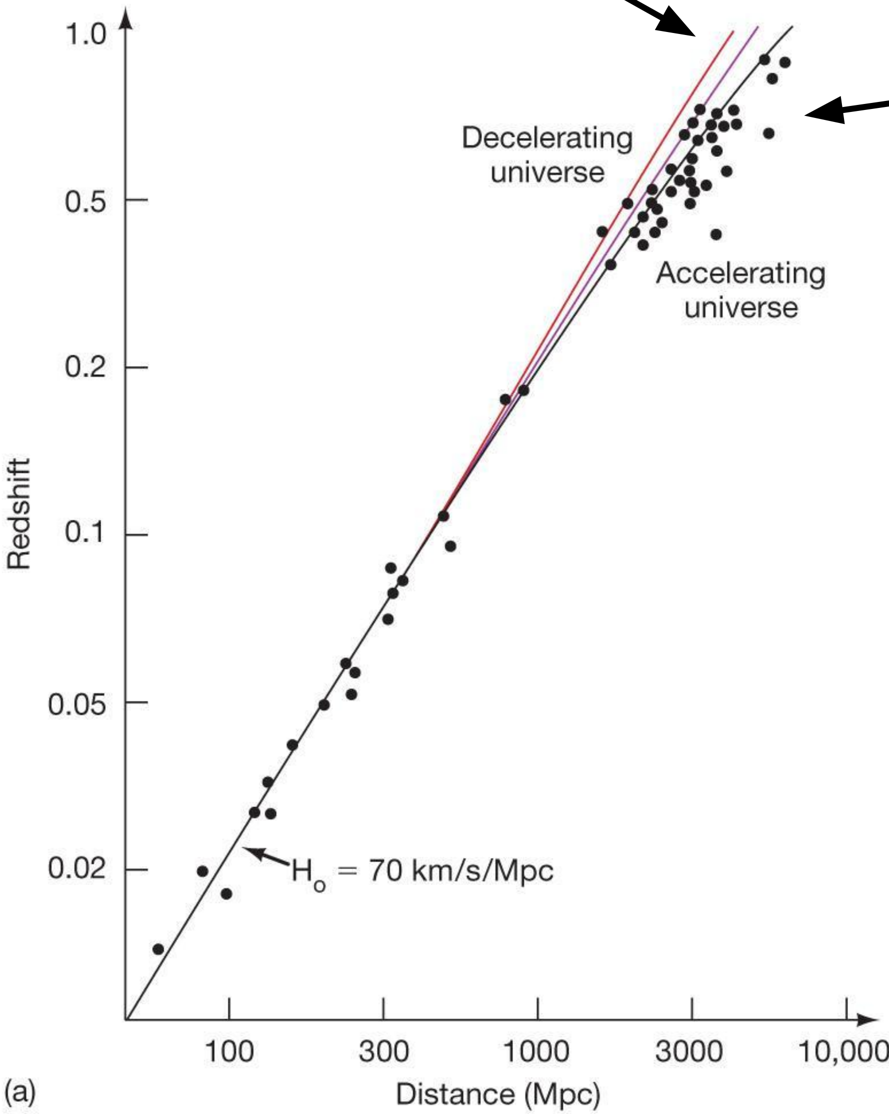
Type I supernovae can be used to measure the behavior of distant galaxies.

In a **decelerating** Universe, we *expect* to see more distant galaxies receeding relatively faster than nearby galaxies.



Where we expected the data to be

Where it really is.



However, when we look at the data, we see that it corresponds not to a **decelerating** universe, but to an **accelerating** one.

That is, the Universe is dominated by **dark energy**.

The Critical Density

The amount of mass needed to just barely make the Universe closed is called the **critical density (ρ_c)** (ignoring the effects of dark energy).

Astronomers like to talk about the density of the Universe in terms of the ratio of the real density to the critical density (Ω).

$$\Omega = \frac{\rho}{\rho_c}$$

Density and the Fate of the Universe

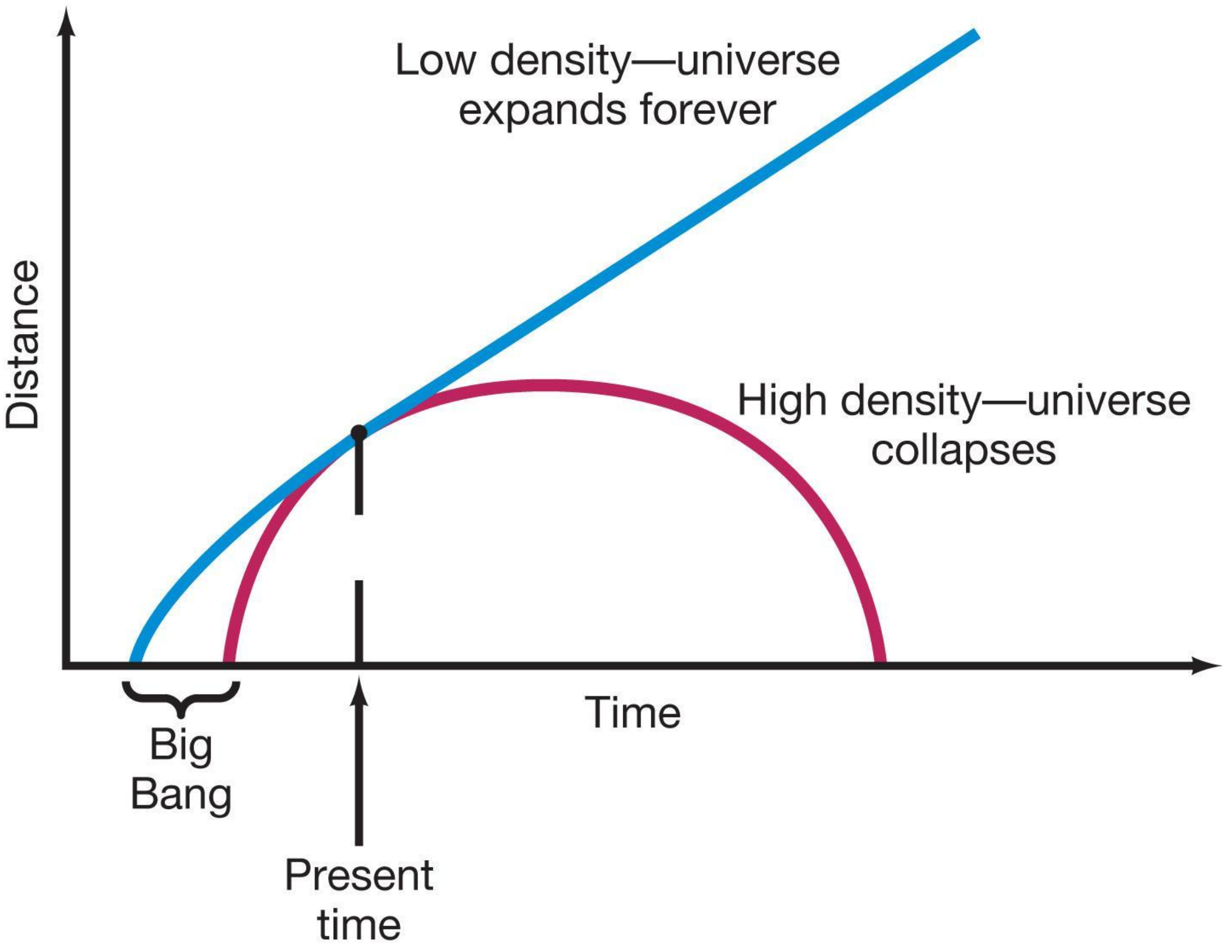
If $\Omega > 1$, the Universe will eventually collapse.

If $\Omega < 1$, the Universe will expand forever.

If $\Omega = 1$, the Universe just barely manages to expand forever.

Density

If the density is **low**, the universe will **expand** forever.



If it is **high**, the universe will ultimately **collapse**.

Fate of the Cosmos

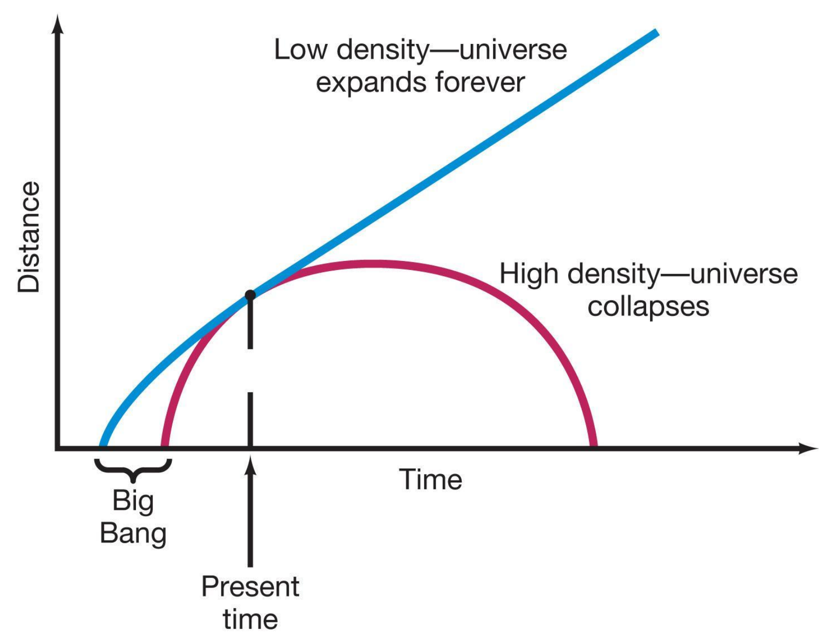
The answer to this question lies in the actual density of the Universe.

Measurements of luminous matter suggest that the actual density is only a **few percent** of the critical density.

But – we know there must be large amounts of **dark matter**.

However, the best estimates for the amount of dark matter needed to bind galaxies in clusters, **still** only bring the observed density up to about 0.3 times the critical density, and it seems very unlikely that there could be enough dark matter to make the density critical.

We can test this by measuring the distances and redshifts of objects.

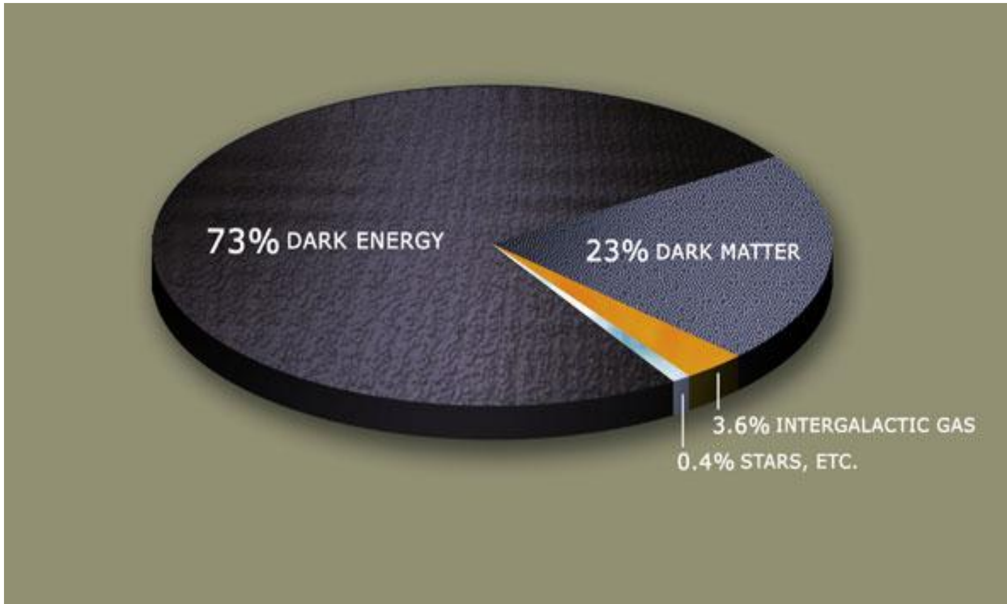


Dark Energy and The Cosmological Constant

Curiously, Einstein had introduced this idea decades before in order to balance gravity and make the Universe “static”.

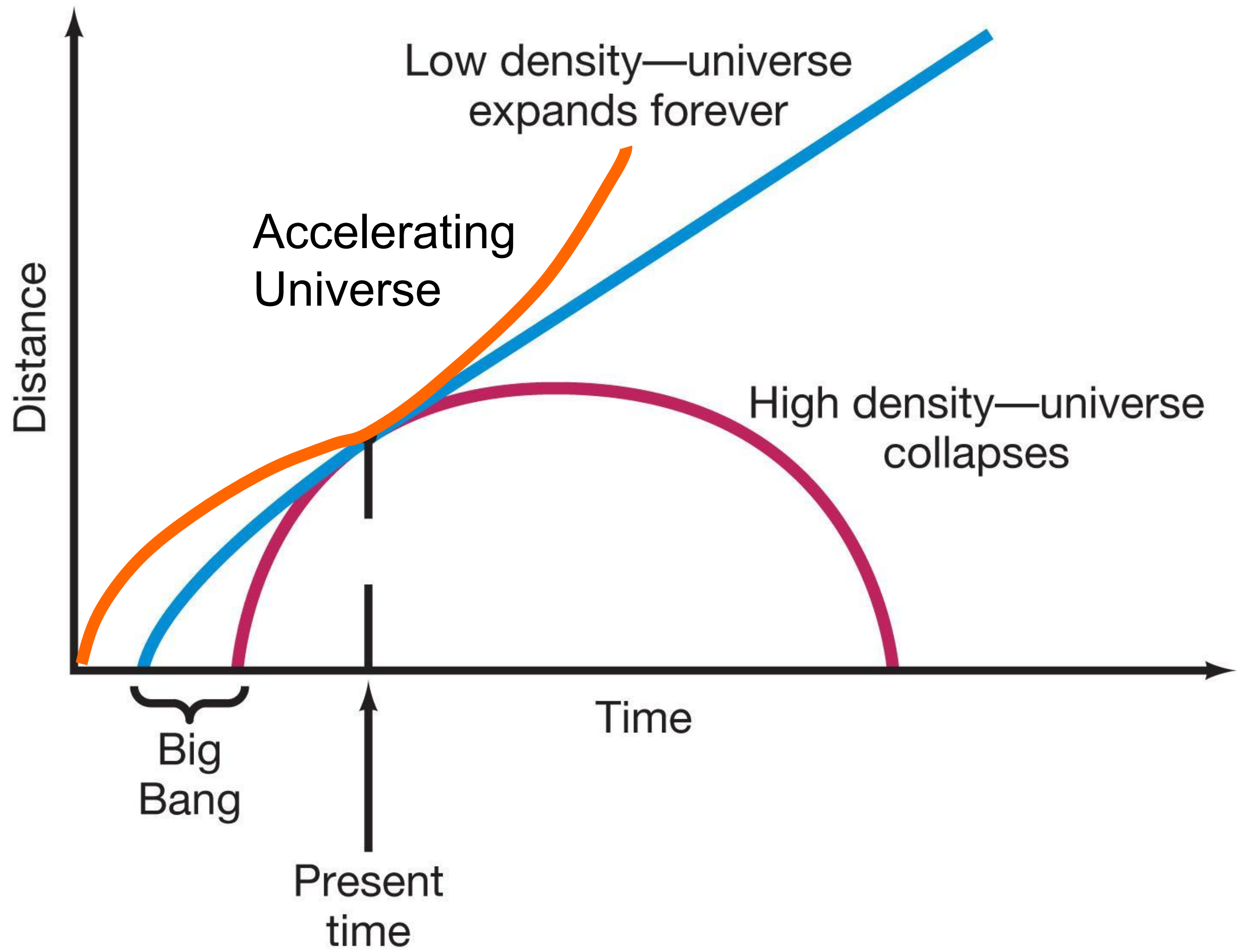
He later called it the biggest blunder of his career.

Turns out he was right.



Age of the Universe

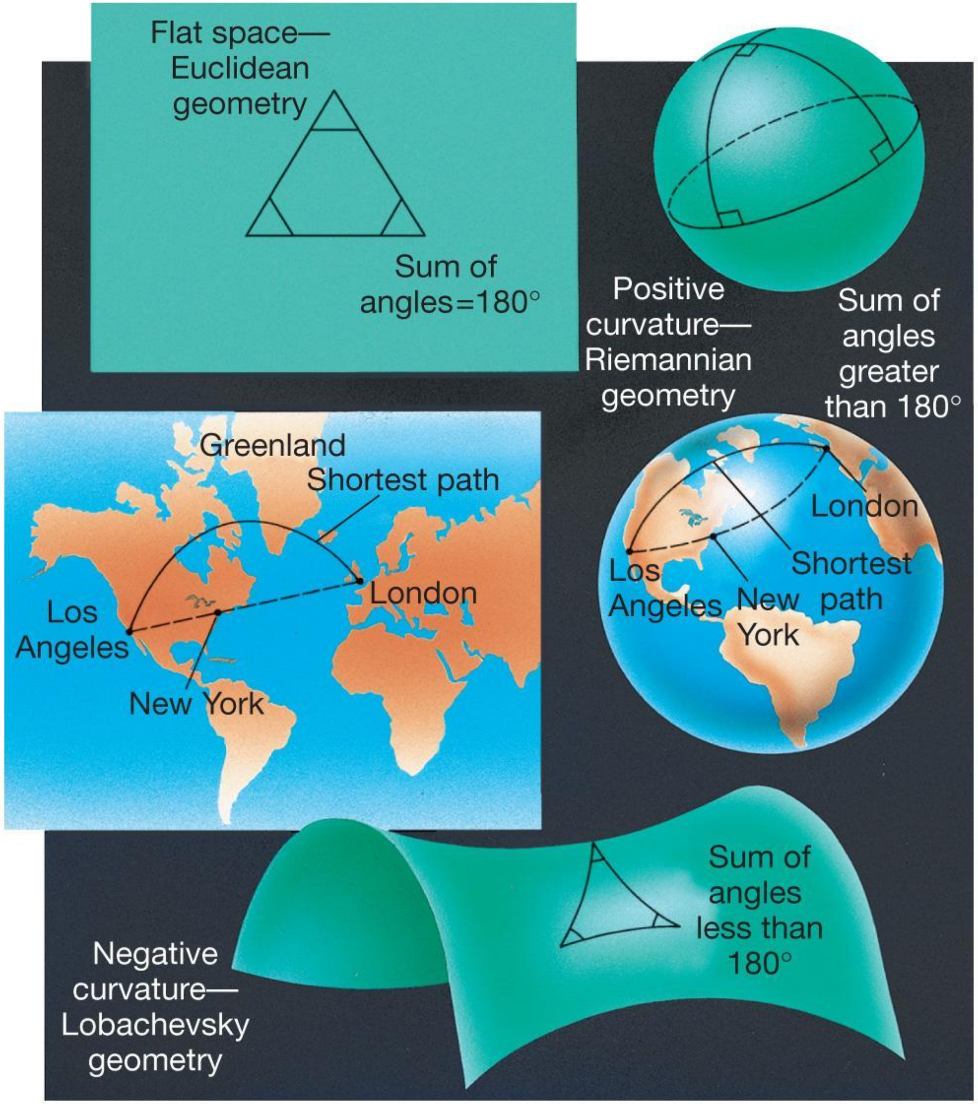
I have drawn these curves starting from the Big Bang, but we should really draw them as being equal today (as that is all that we really know for sure). This has implications for the age of the Universe.



If space is **homogenous**, there are three possibilities for its overall geometry:

1. **Closed** – this is the geometry that leads to ultimate collapse
2. **Flat** – this corresponds to the critical density
3. **Open** – expands forever

The Geometry of Space



These three possibilities are illustrated here. The **closed** geometry is like the surface of a **sphere**; the **flat** one is **flat**; and the **open** geometry is like a **saddle**.

Summary of the Possible Geometries

Density	Universe
$\Omega = 1$	Flat, Open, Infinite
$\Omega < 1$	Negative curvature, Open, Infinite
$\Omega > 1$	Positive curvature, Closed, Finite

Refining the Big Bang Model II: The Flatness Problem

We don't yet know the geometry of the Universe, but it appears to be extremely flat.

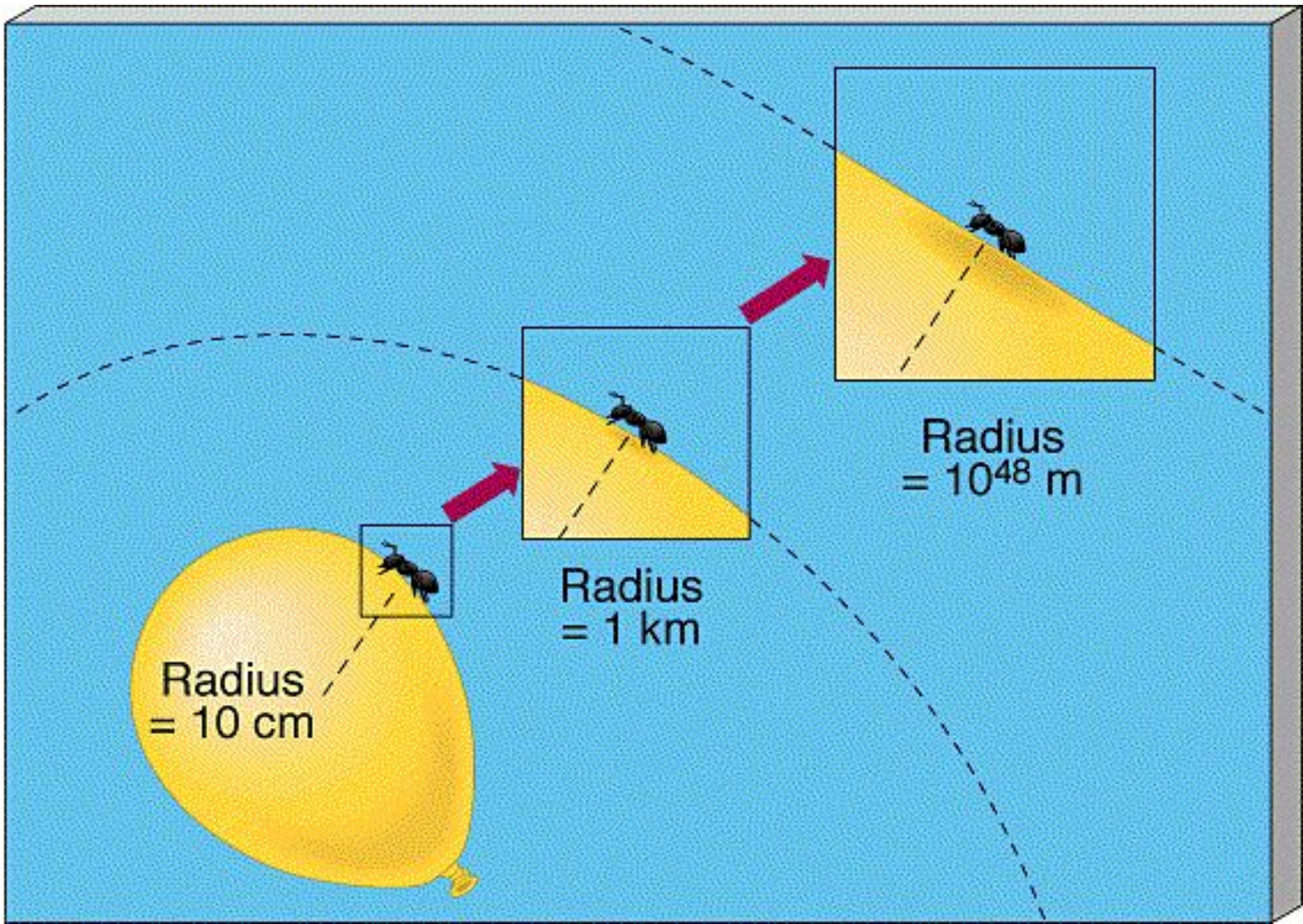
However, theory says that unless is Ω exactly 1 after the Big Bang, it should be either much smaller or much larger today.

It is unlikely that Ω would have been exactly 1 after the Big Bang.

So, how come the Universe looks so flat today?

Inflation can also solve the **flatness problem**.

A heavily curved region of space can be made to look flat if the radius increases.

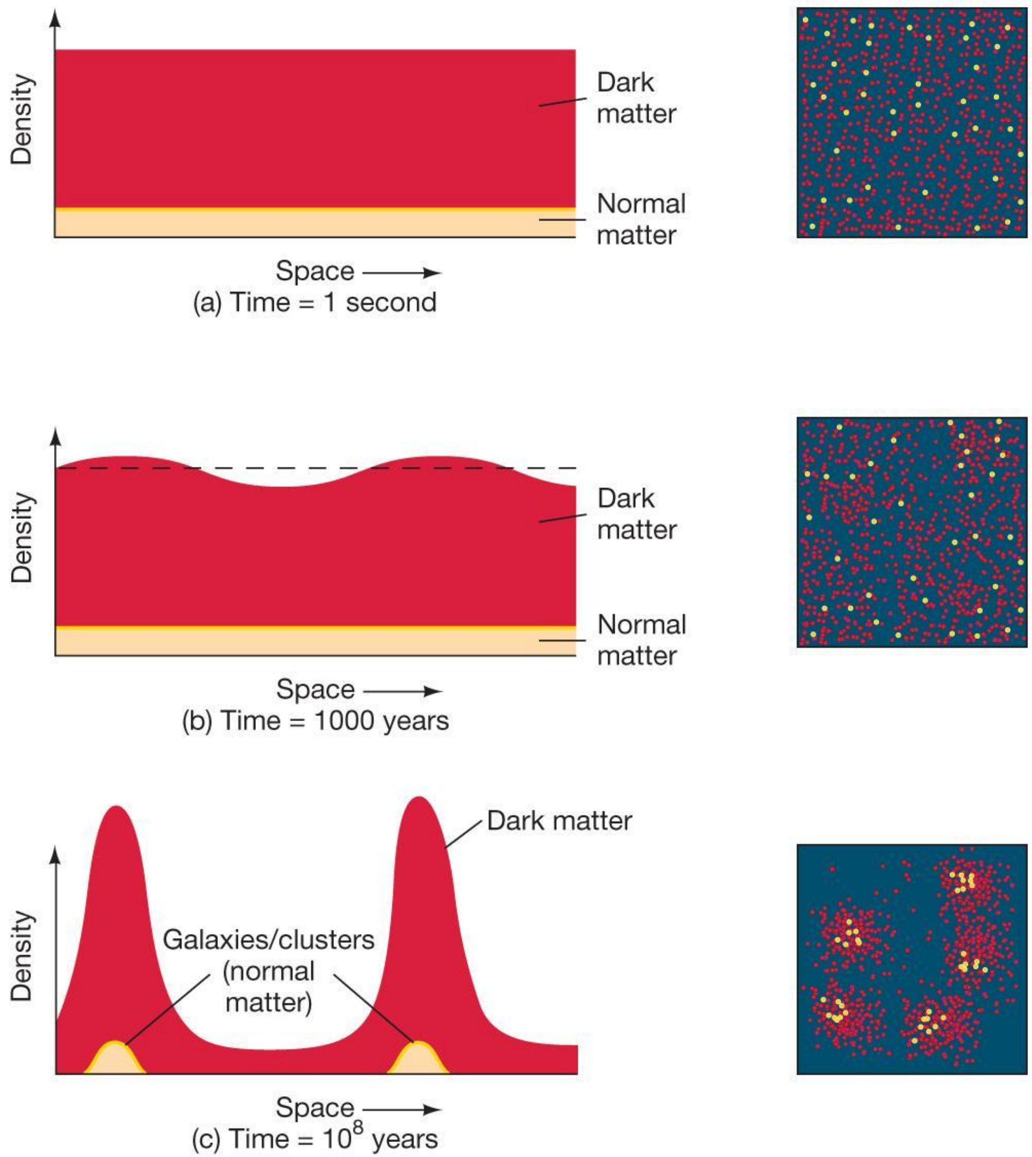


Where Did the Galaxies Come From?

Cosmologists realized that galaxies could not have formed just from instabilities in normal matter.

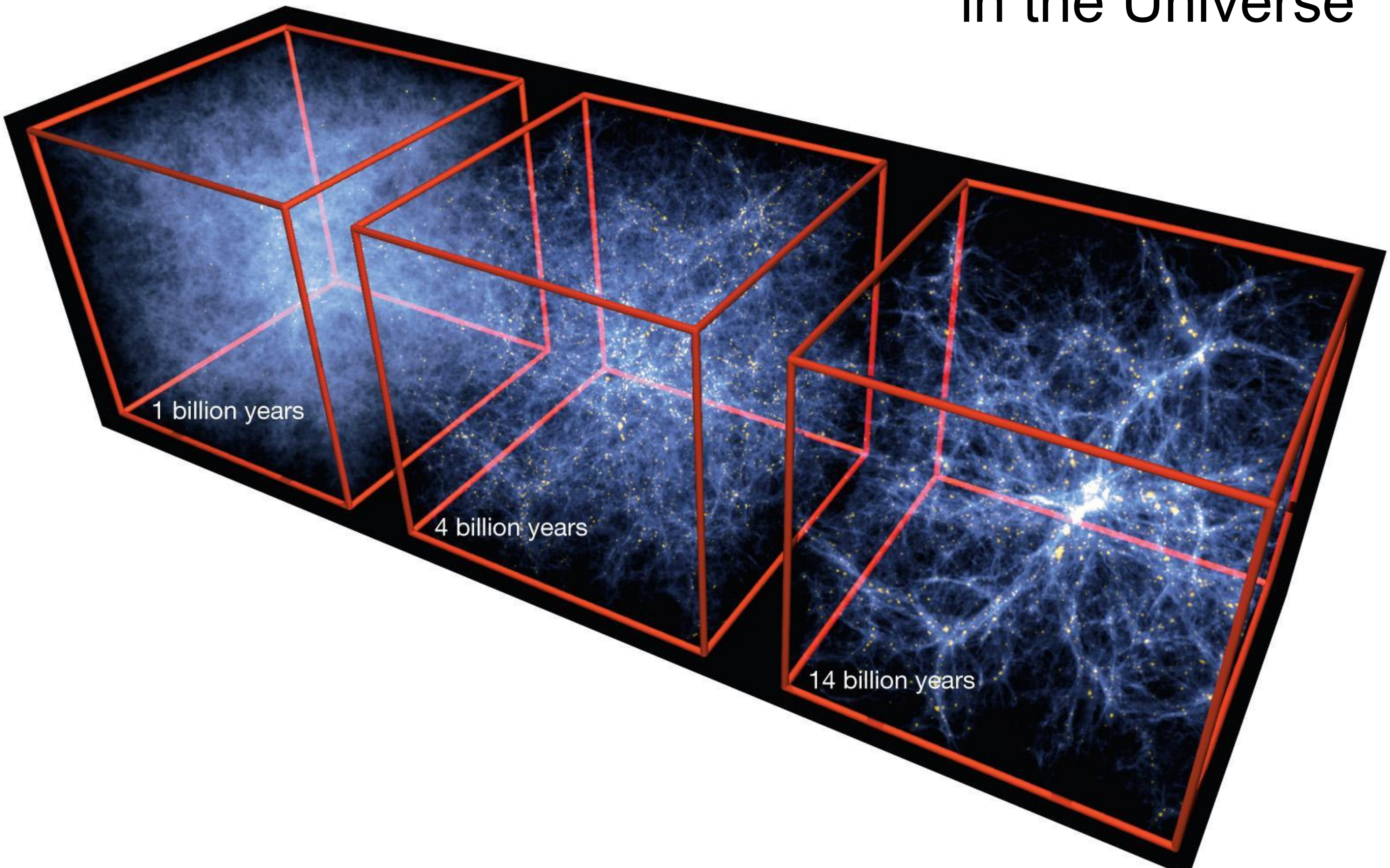
The hot radiation from the Big Bang would have kept normal matter from clumping.

But, Dark Matter, being unaffected by radiation, could have started clumping long before normal matter.



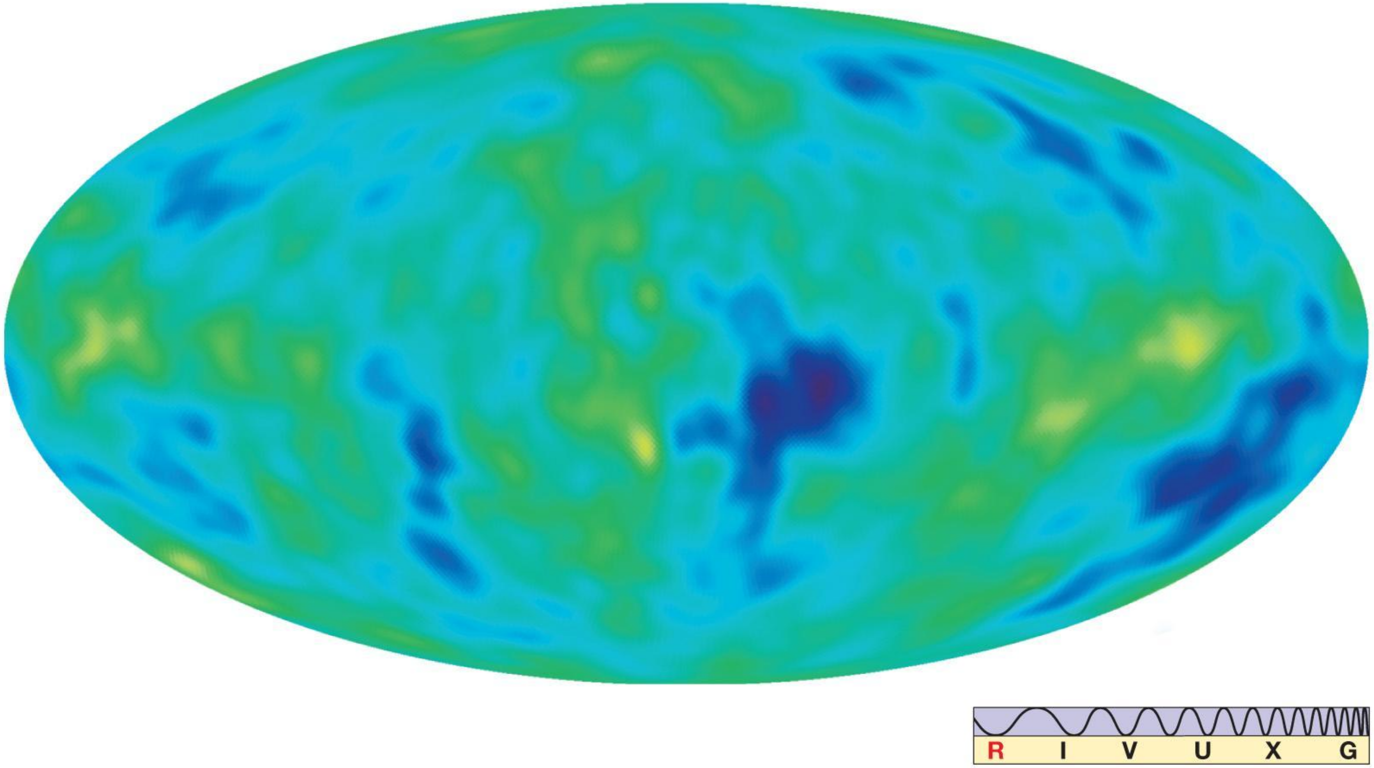
Galaxies could then form around the dark-matter clumps, resulting in the Universe we see.

A simulation of structure formation in the Universe



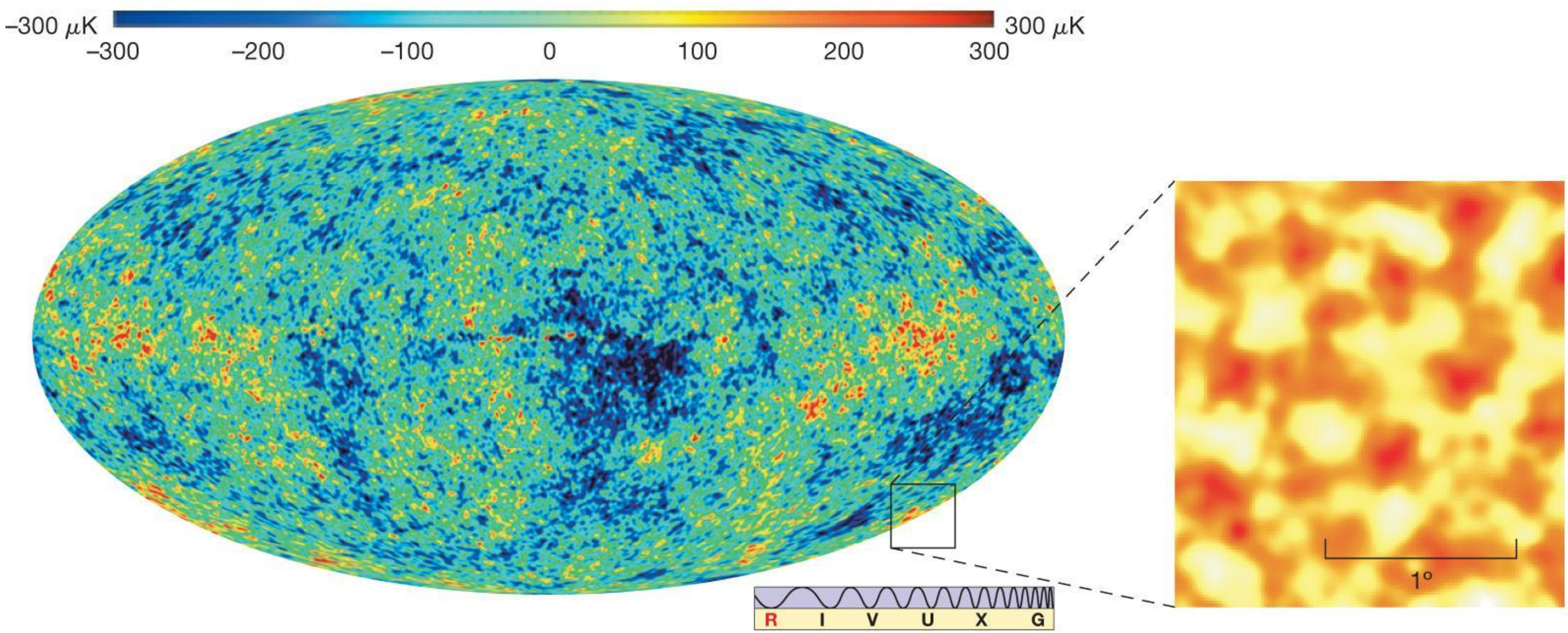
Clumping of matter in the early Universe would lead to tiny “ripples” in the cosmic background radiation.

These ripples have now been observed



This is a much **higher-precision** map of the cosmic background radiation.

It will likely lead to another Nobel Prize in the near future.



Cosmology: Our Best Guess

H_o = 71 km/s/Mpc, so that the Universe is about 153.7 billion years old.

Λ=0.72, which means that q is not $\Omega/2$ and q_o can be < 0.

q_o < 0, so the Universe is actually accelerating in its expansion.

Ω=1, so the Universe is “flat”.