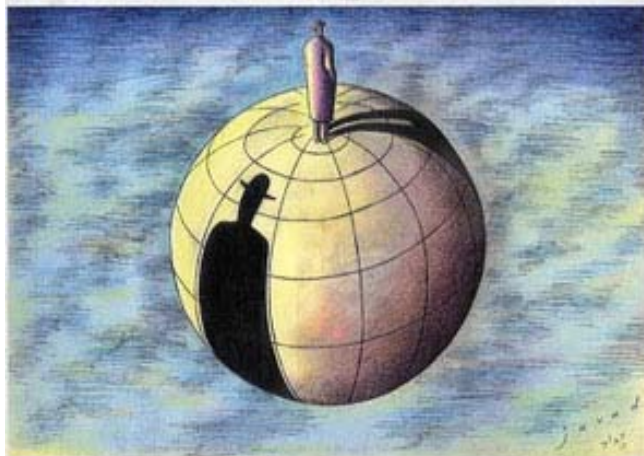
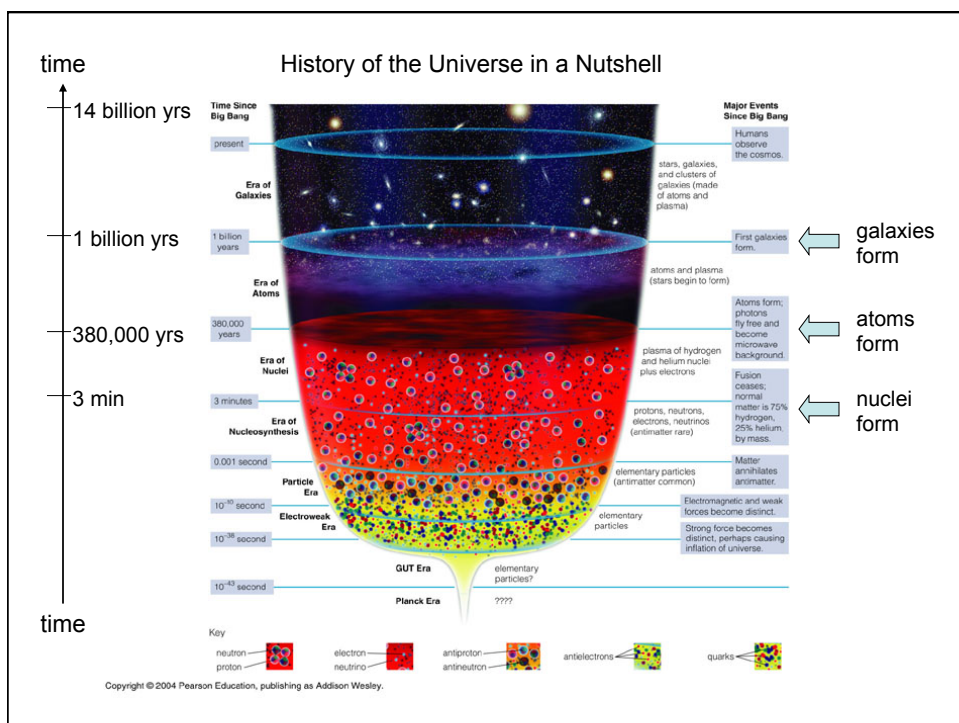


WHAT KIND OF UNIVERSE DO YOU LIVE IN?

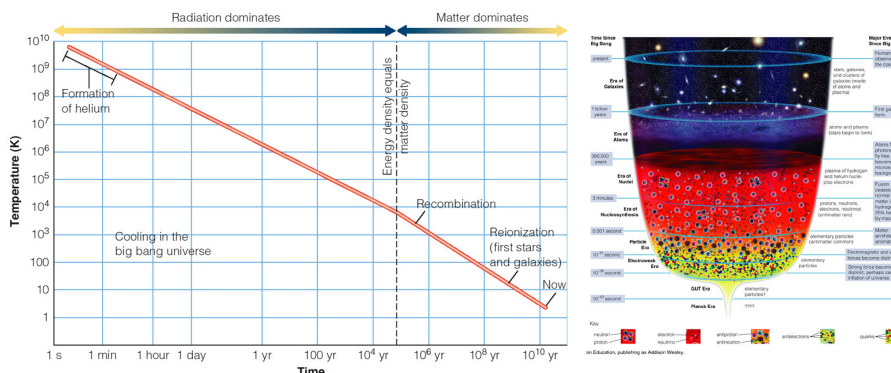


What is the fate of the Universe?



As the universe expanded it cooled and its density decreased

This is what drove all the physics: *temperature* and *density*



Today the universe is 2.73 degrees Kelvin (absolute)

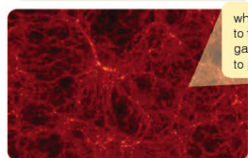
Growth of Structure in the Universe



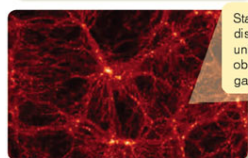
Soon after the big bang, radiation and hot gas are almost uniformly spread through the universe.



Cold dark matter, immune to the influence of light, can contract to form clouds...



which pull in normal gas to form superclusters of galaxies. Gravity continues to pull clusters together.



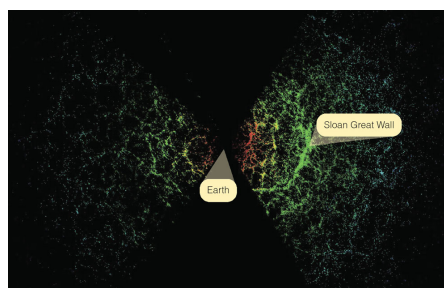
Statistical tests show the distribution in this model universe resembles the observed distribution of galaxies.

Structure Formation (Galaxies)

Driven by gravity...

Dark matter is immune to temperature of normal matter (doesn't interact with light).

Dark matter has always been "cold" and so contracted under gravity and thus provided gravity seeds for overall structure growth.



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Compare real (above) to model (left)

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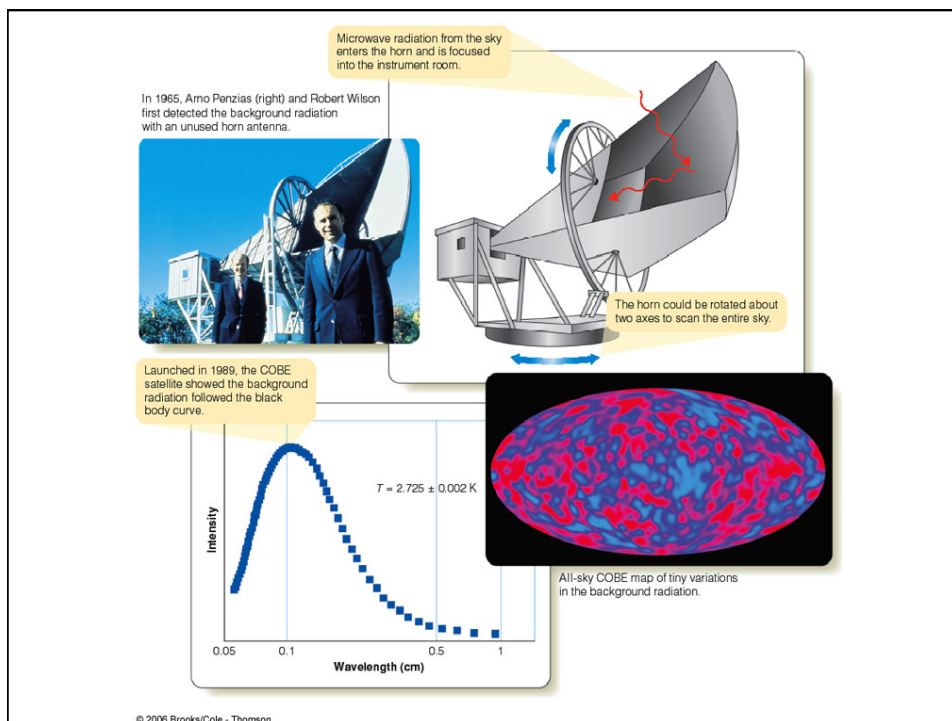
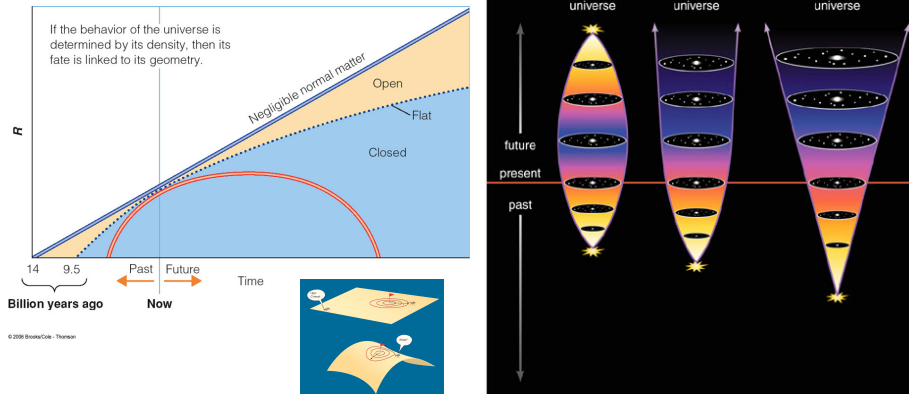
We used to teach 3 possible fates:

OPEN----- density < “critical”; forever expanding

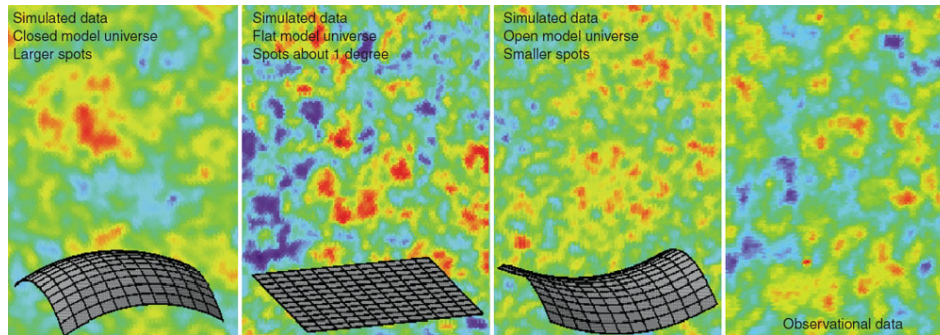
FLAT----- density = “critical”; expanding, but forever slowing

CLOSED - density > “critical”; expanding, then contracting and collapse

All we had to do was determine what the density of the universe is compared to the critical density!

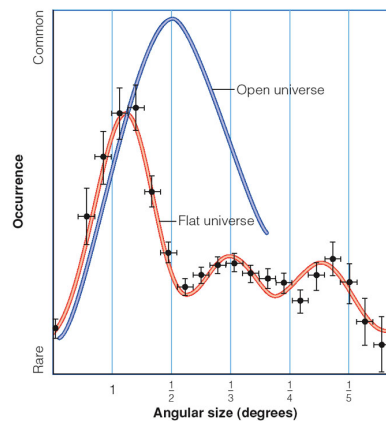


Angular variations in the temperature of the cosmic microwave background provide clues to geometry of the universe.



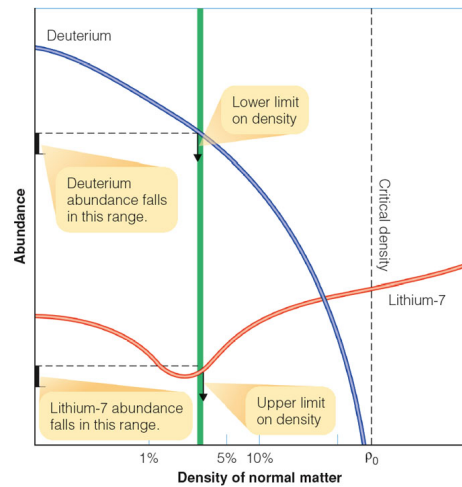
Most angular variations are about 1 degree apart. They indicate that the universe has a flat geometry...

The Universe is Flat!



If the universe is flat, then it has 100% of the critical density!
We would expect that normal matter comprises all the density, right?

Measurements of the abundance of deuterium and lithium (relative to hydrogen) indicate that normal matter comprises only 4% of the critical density!



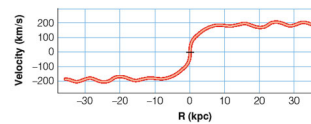
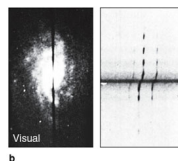
How can this be?

The universe has critical density, but matter is only 4%

What is the remaining 96% of the density of the universe?

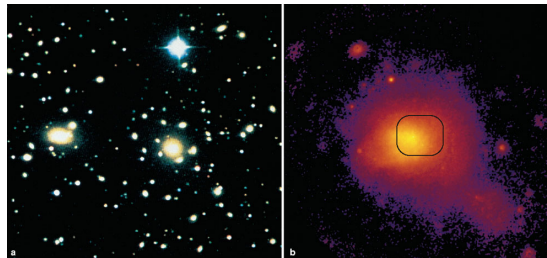
But, 90% of matter is actually dark matter!

In galaxies, the rotation speeds indicate that 90% of the matter is invisible, i.e. dark.



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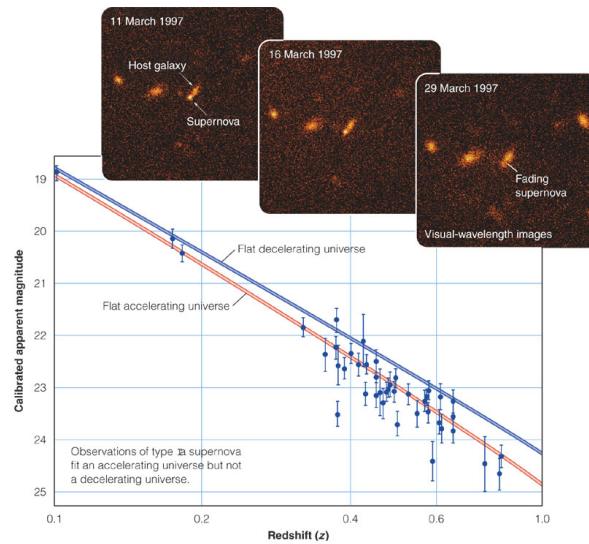
In galaxy clusters, the confined hot X-ray gas also indicates that 90% of the matter is invisible, i.e. dark.



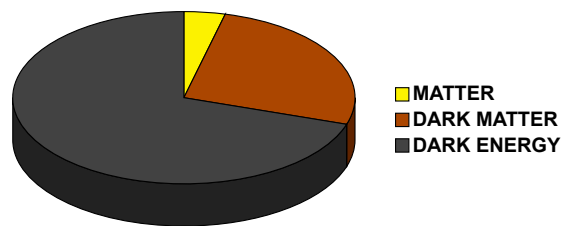
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Hmmm, that still accounts for only about 30% of the critical density!!!
Where is the additional 70% that is required for a flat "critical" universe?

And then... all hell broke loose.



Precision Cosmology?



MATTER + DARK MATTER + DARK ENERGY = TOTAL

4% + 33% + 67% = 100%

We know that the total matter/energy density is 100% of the critical value (the universe is flat)... But, we know only what 4% of the total matter/energy density is!!!!

