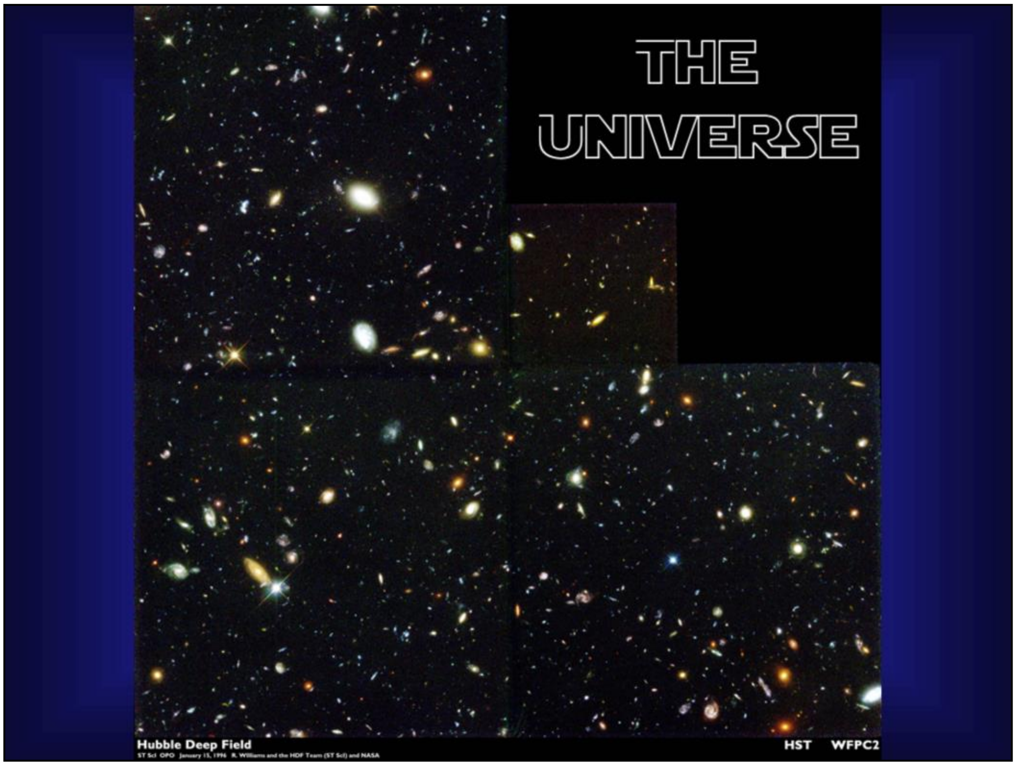
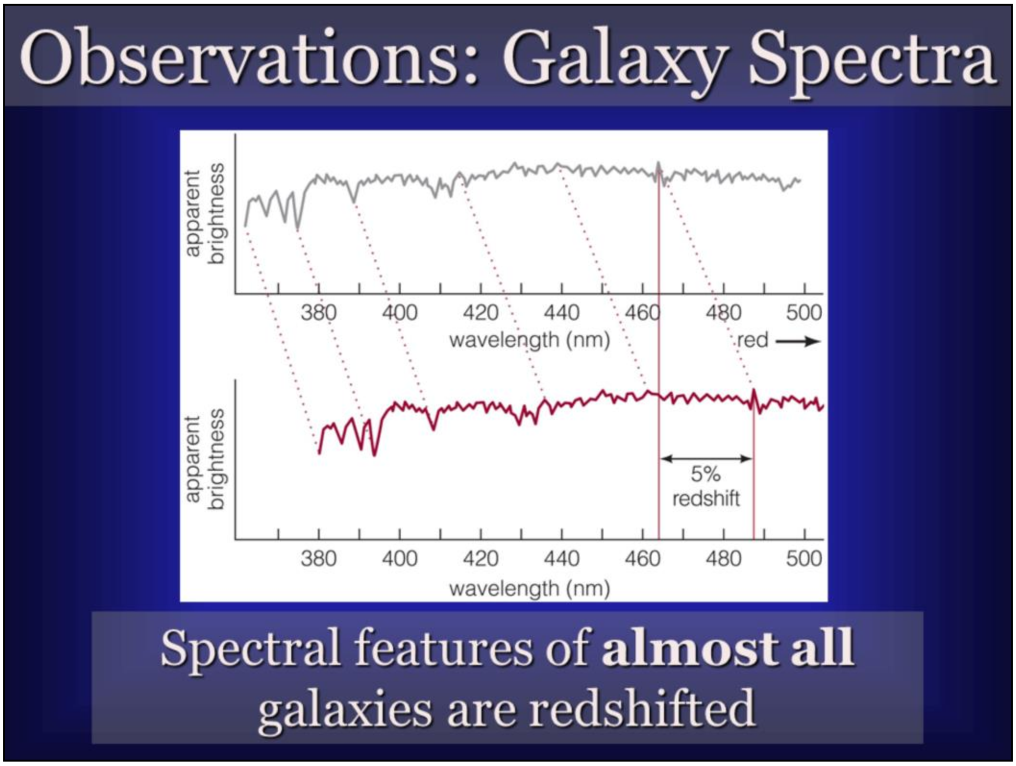
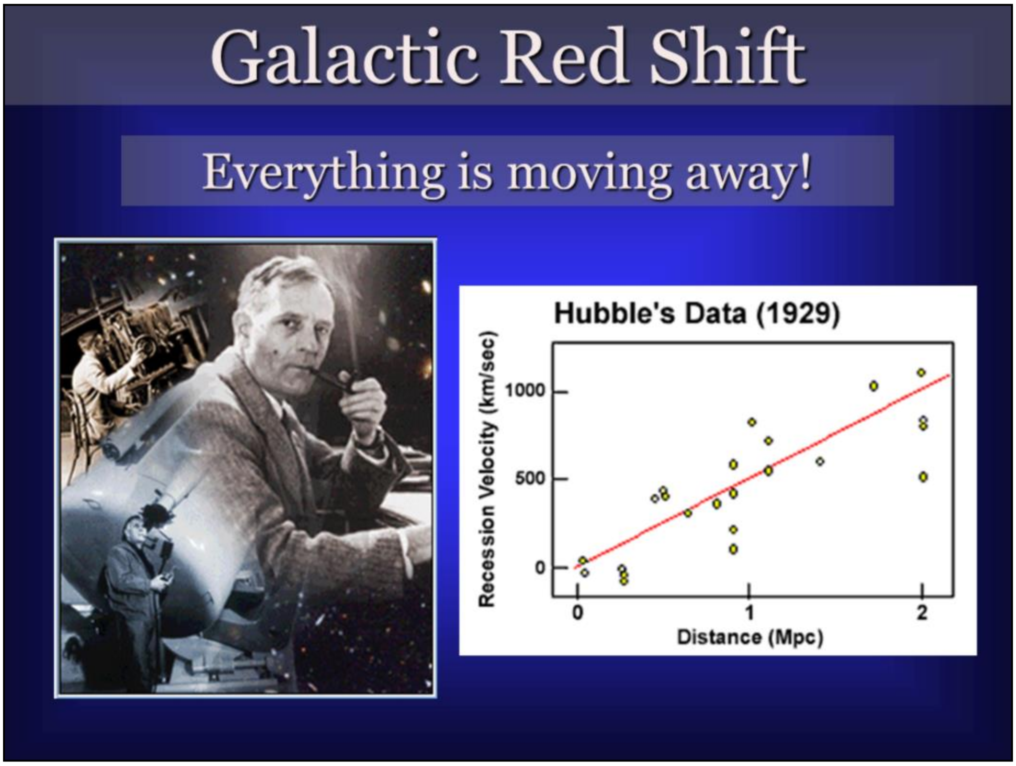

THE UNIVERSE
Hubble Deep Field
ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA
HST WFPC2



The only ones that are not are close enough to be gravitationally bound to us.



After determining that the distance to M31 (Andromeda) is about 3 million light years, Edwin Hubble went on to survey many other galaxies.

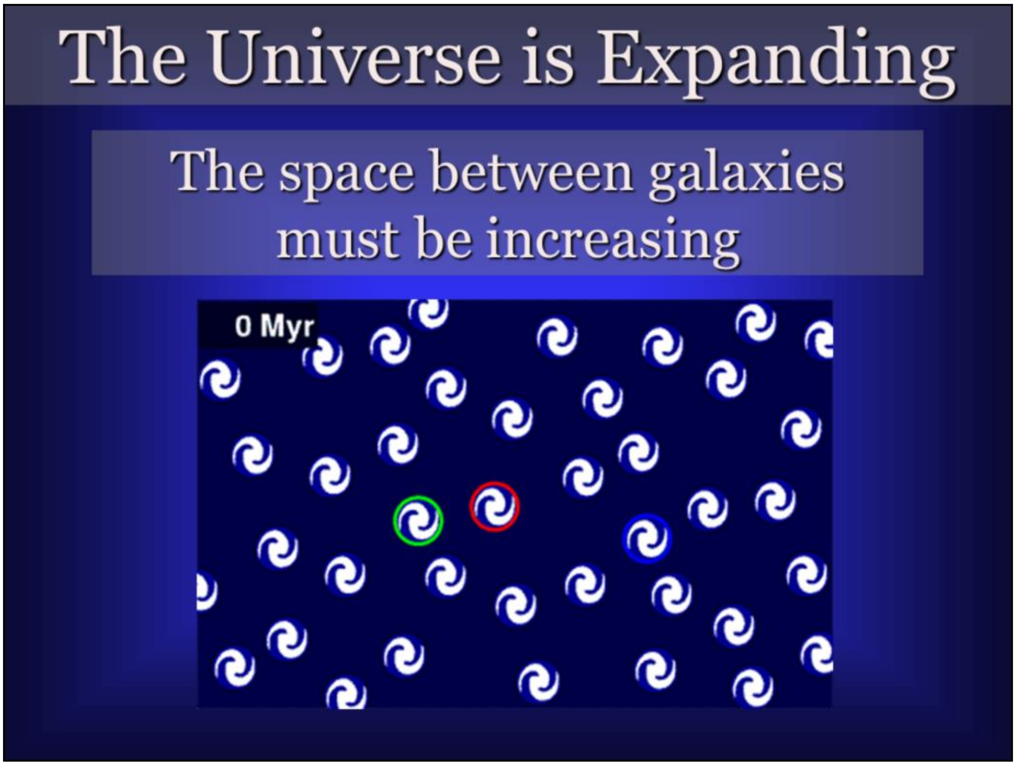
Hubble noticed that all of the galaxies he was measuring were red shifted…

In fact there was a correlation between distance and recessional velocity.

More distant galaxies were moving away FASTER than nearby galaxies.

This relationship is called Hubble's Law.

The slope of the line (H_0) is Hubble's Constant.



ANIMATED GIF WAIT FOR IT TO PLAY

Hubble observed that all galaxies have red shift.

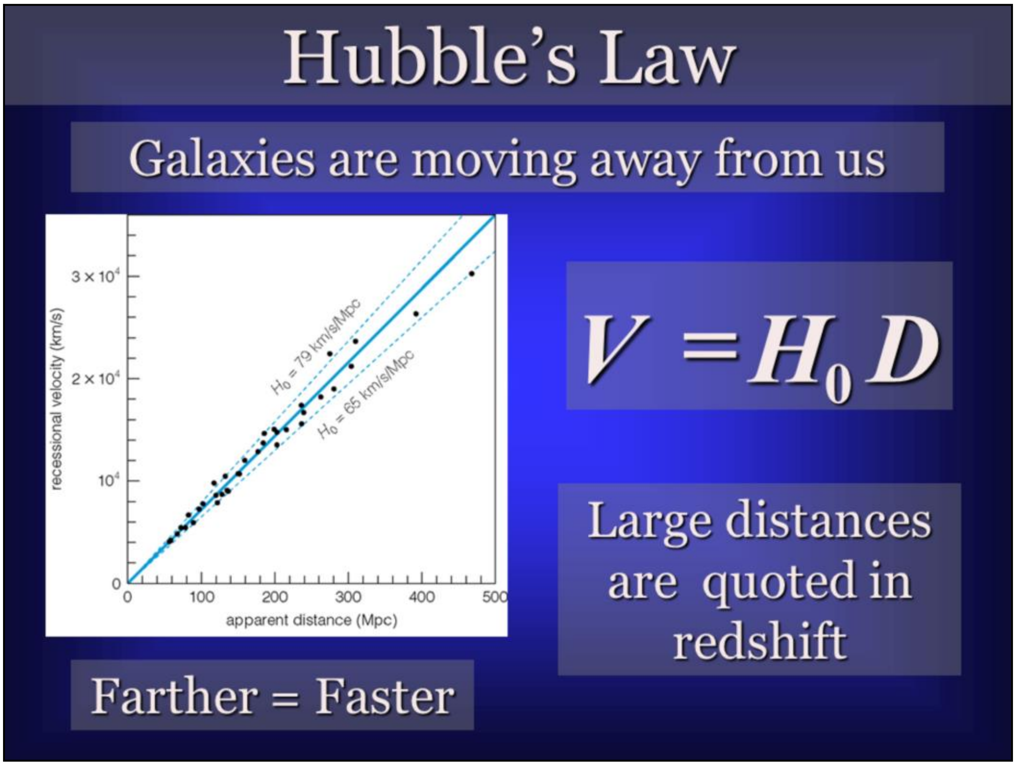
More distant galaxies have larger red shifts.

Like raisins in a cake, the cake stuff expands and the space between raisins gets larger.

Hubble's Law arises naturally from a uniformly expanding universe. (uniform means that the expansion appears to be the *same* everywhere!)

Einstein was very embarrassed when Hubble demonstrated that the universe is expanding.

He called the cosmological constant his greatest folly.



Hubble, after his success with M31, was measuring distances to a whole bunch of galaxies.

He noticed something peculiar. The more distant a galaxy is, the more it is red shifted.

In fact, there is a linear relationship between velocity and distance.

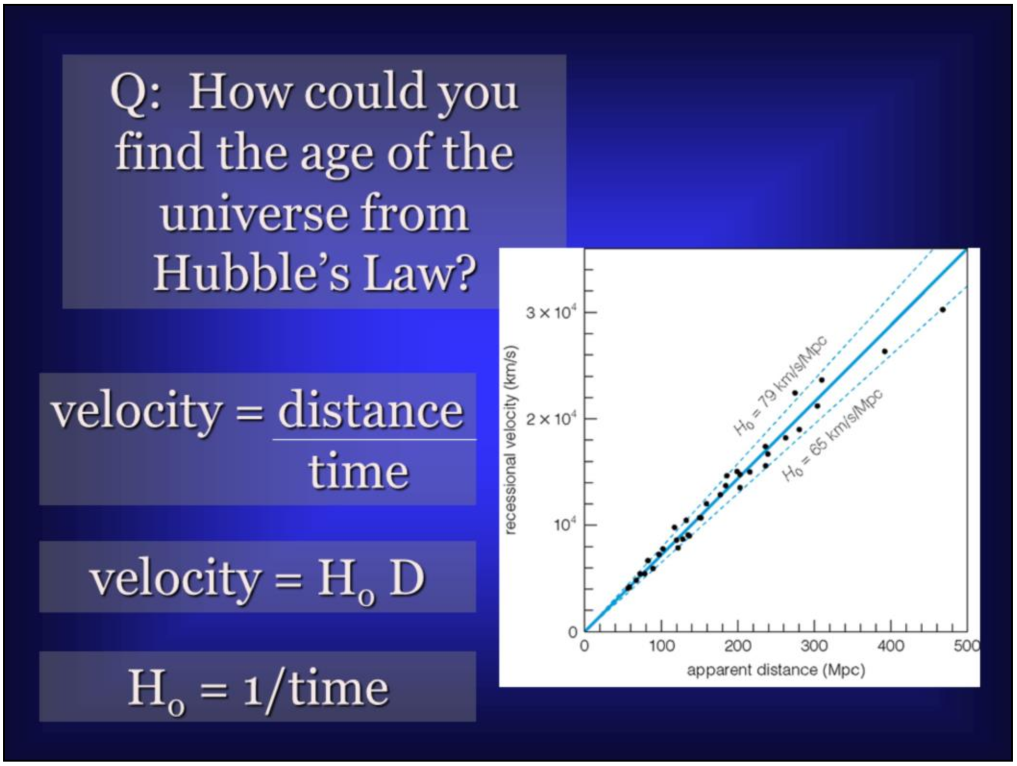
The slope of the line is H_0. H_0

We measure velocity by measuring doppler shift.

Since all distant galaxies appear to be moving away from us, all distant galaxies are red shifted.

More distant objects have a greater redshift, so you will often hear distances quoted as redshifts.

H0 (pronounced H naught) is measured in km per second per Mpc. (kilometers per second per mega parsec) mega = million



Useful lecture tutorials: p. 155 etc.

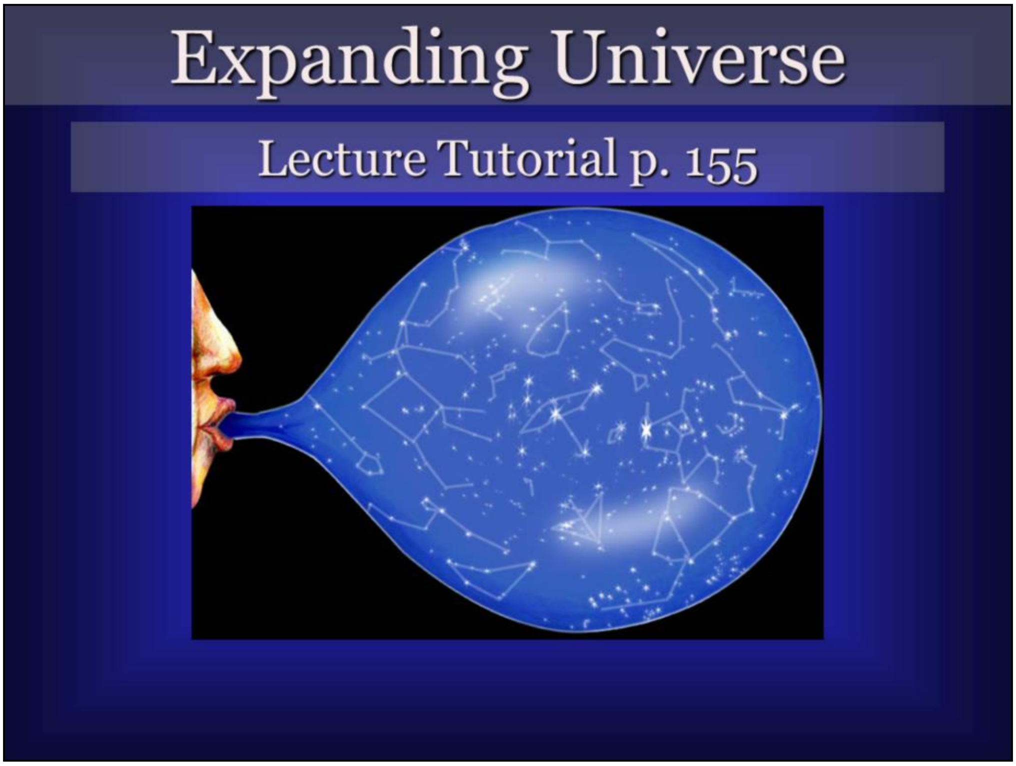
Although everything appears to be moving away from us, and the farther away it is, the faster its moving…

We are NOT at the center.

Everything is moving away from everything else. The space between all galaxies is getting larger.

For nearby galaxies, like those in the local group such as M31, the peculiar velocity dominates.

Hubble flow dominates at large distances. Like halfway across the observable universe.



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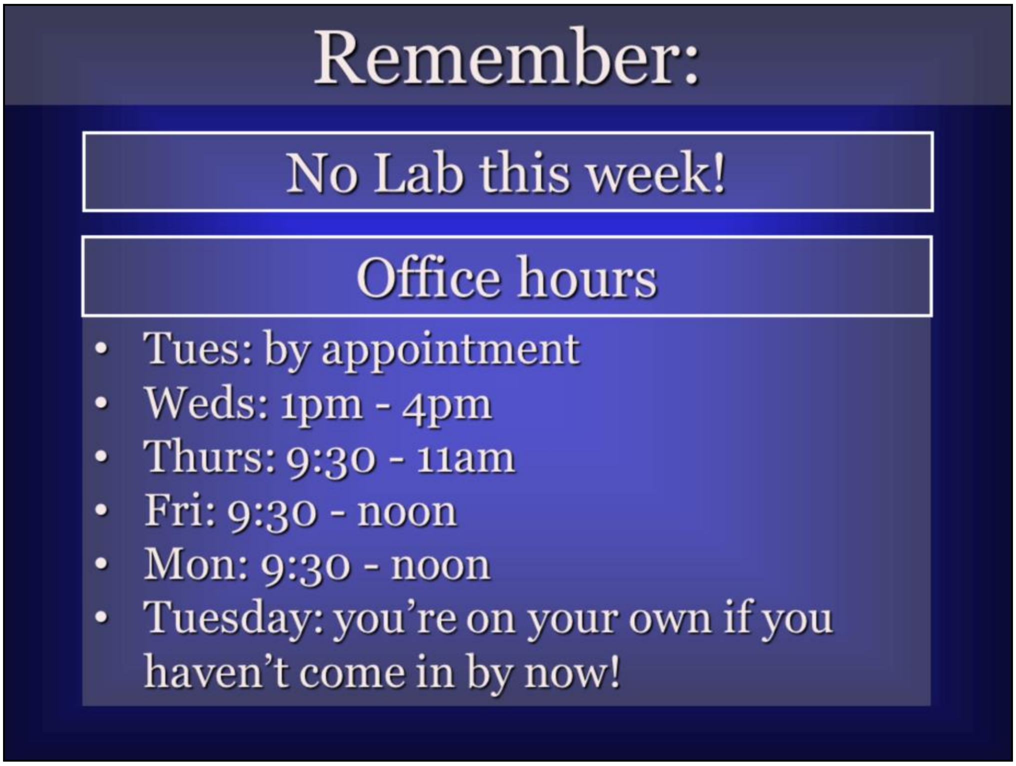
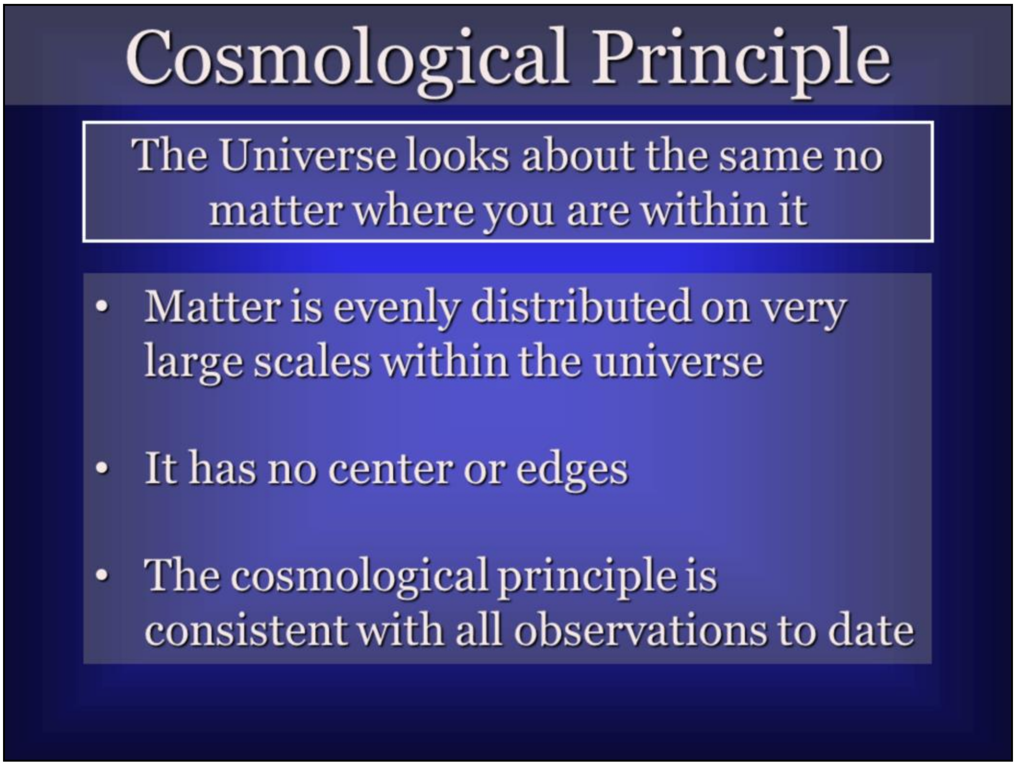


In our modern conception of the universe, time is simply another dimension. Space and time itself came into existence at the Big Bang.

Let your philosophical side run wild.



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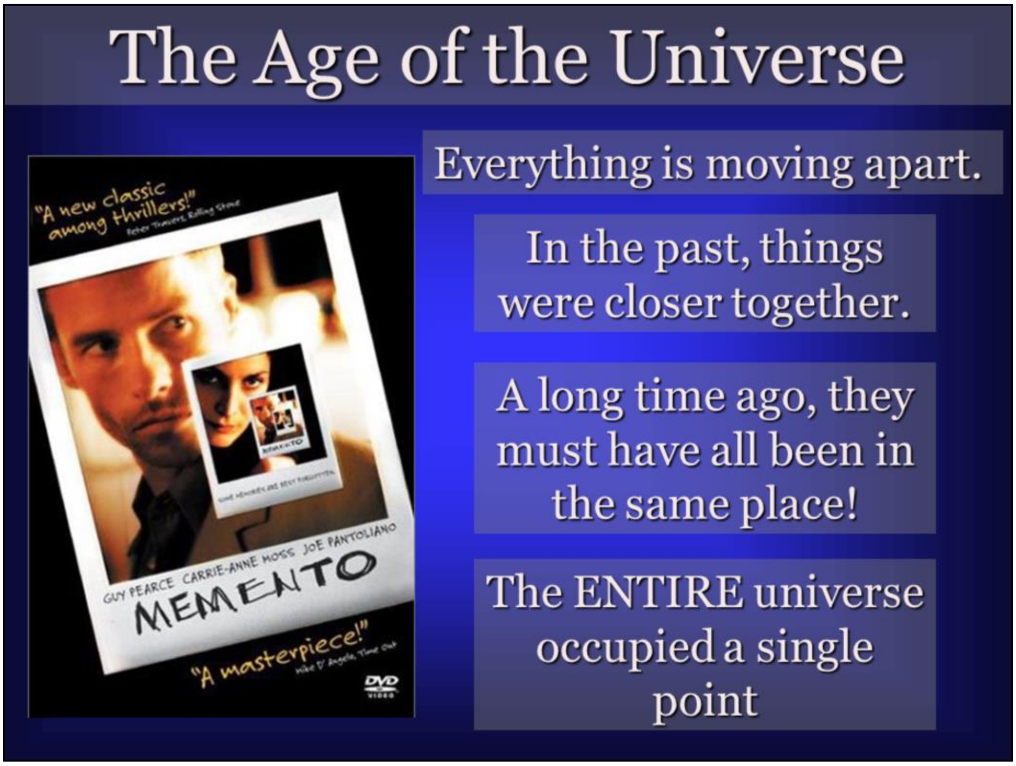
Let your philosophical side run wild.


Let's start at the beginning...
Olli Wilkman



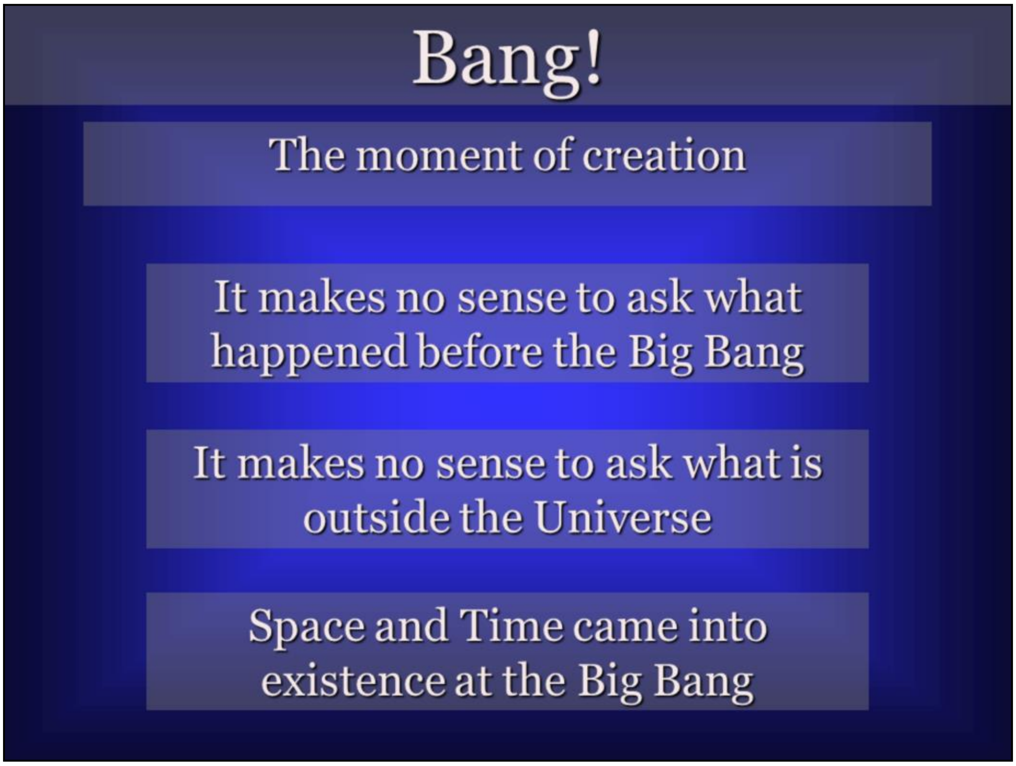
We just have to run the movie backwards to find out what happened at the beginning

It turns out that 1/H0 = the age of the universe…

About 13.7 billion years.

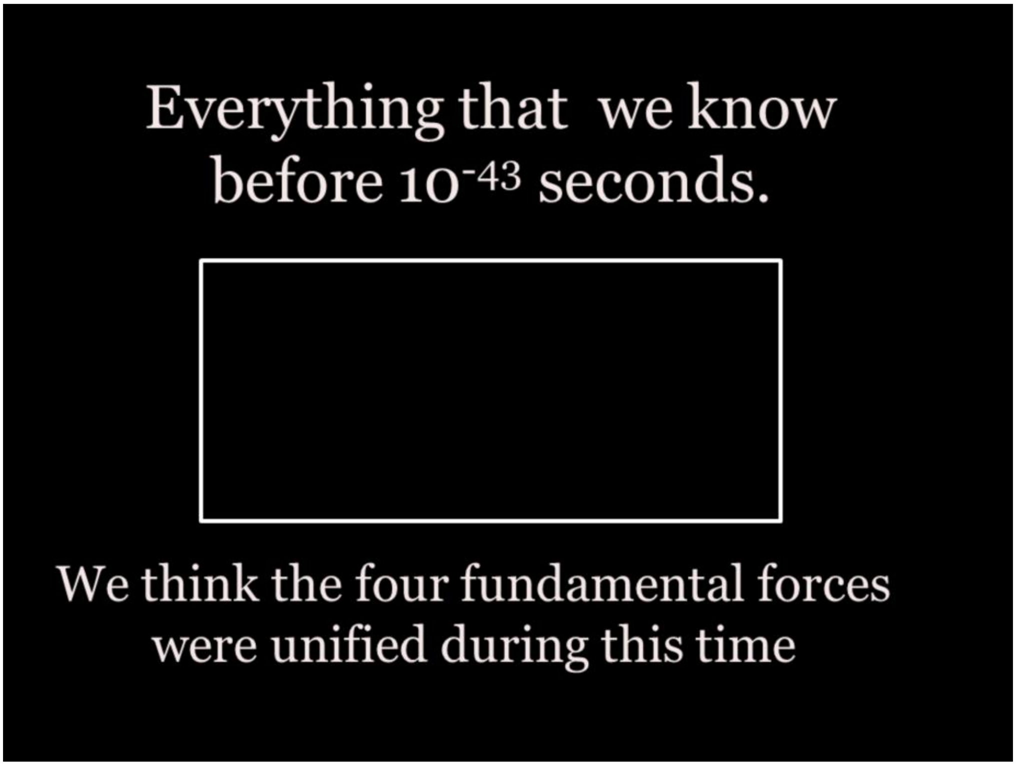
At the beginning, the universe is infinitesimally small.

It is a singularity, like a black hole.

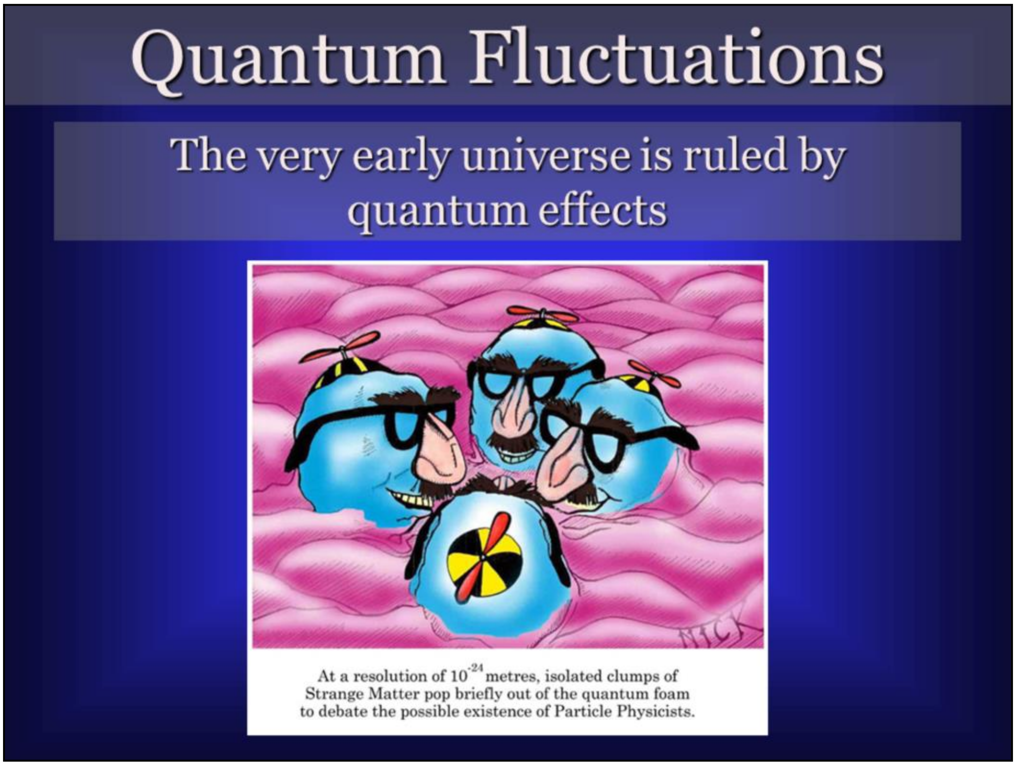


In our modern conception of the universe, time is simply another dimension.
Space and time itself came into existence at the Big Bang.
The universe has been expanding ever since.

Let your philosophical side run wild.



Before 10^{-43} seconds, our current theories of physics fail.
We need to merge together Quantum Mechanics and General Relativity.



Gravity splits from the 4 forces.

Quantum mechanics is not deterministic- You can't always predict future events based on current conditions.

It's probabilistic- You CAN predict the probability of a particular outcome.

When the universe was 10^{-43} seconds old, the indeterminate effects of quantum mechanics ruled.

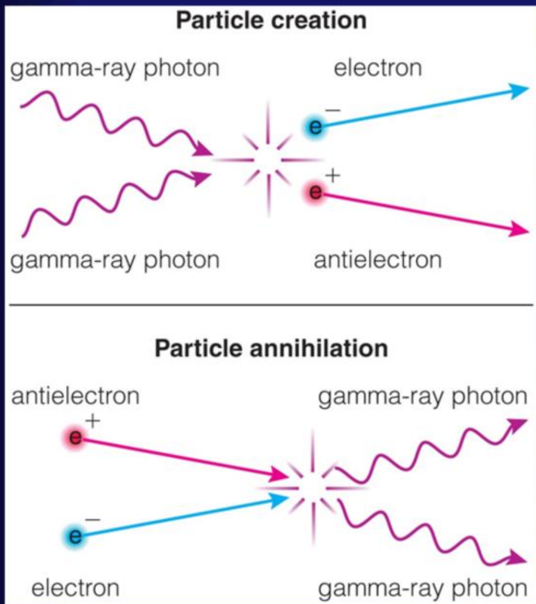
There were large random energy fluctuations.

Particles were literally popping into and out of existence.

BUT! The energy density of the universe is VERY large. As soon a particle is created, it is destroyed by the energy field.

So- there are really no particles in this universe.

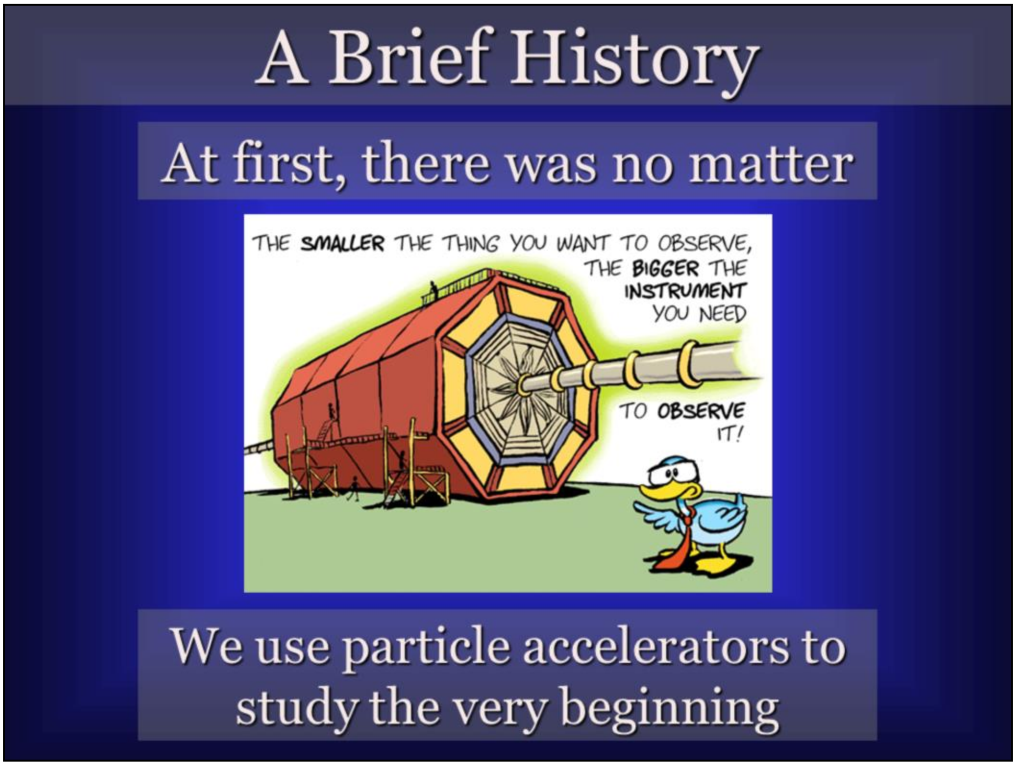
These initial quantum fluctuations become important again later.



Photons converted into particle–antiparticle pairs and vice versa.

$E = mc^2$

The early universe was full of particles and radiation because of its high temperature.



Particle accelerators don't throw bits of stuff together and watch the parts fly out

They annihilate matter and antimatter and get out a blob of pure energy.

From the blob of pure energy, elementary particles are created.

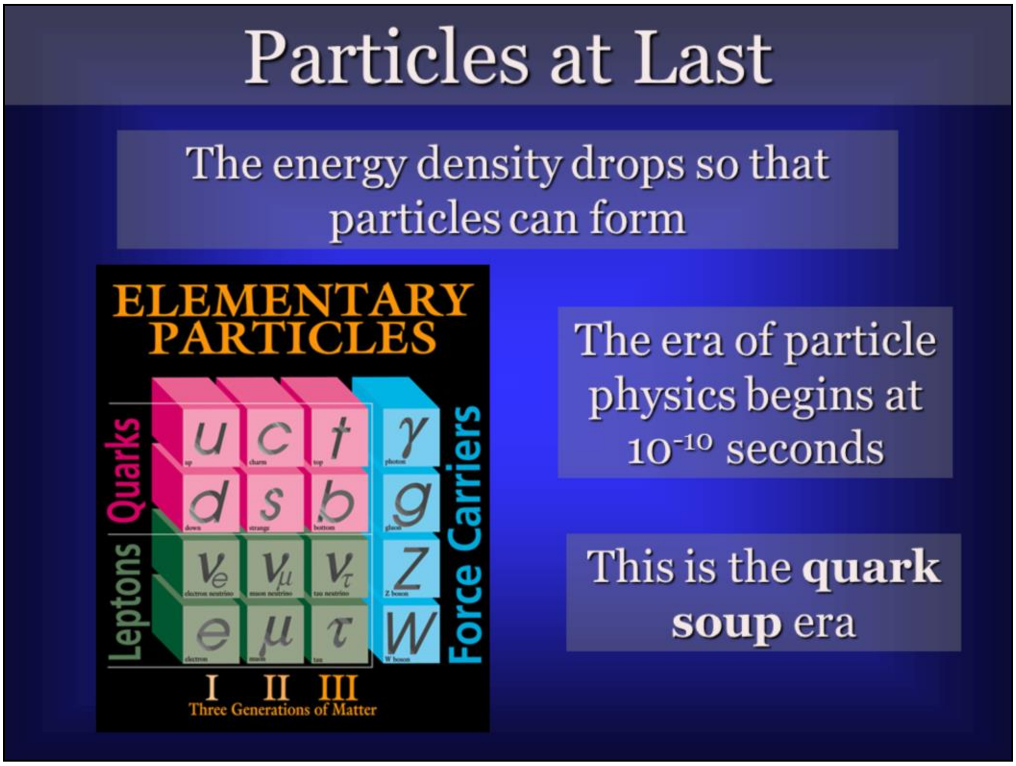
Just like at the beginning of the big bang.

The more kinetic energy we put into the accelerator, the closer we get to the conditions at the Big Bang.

Modern accelerators create conditions similar to 10^{-43} seconds after the big bang.

Inflationary Period

- The GUT (grand unified theory) force splits into the strong and electroweak forces. Now there are 3 forces.
- This split releases LOTS of energy causing the universe to expand RAPIDLY



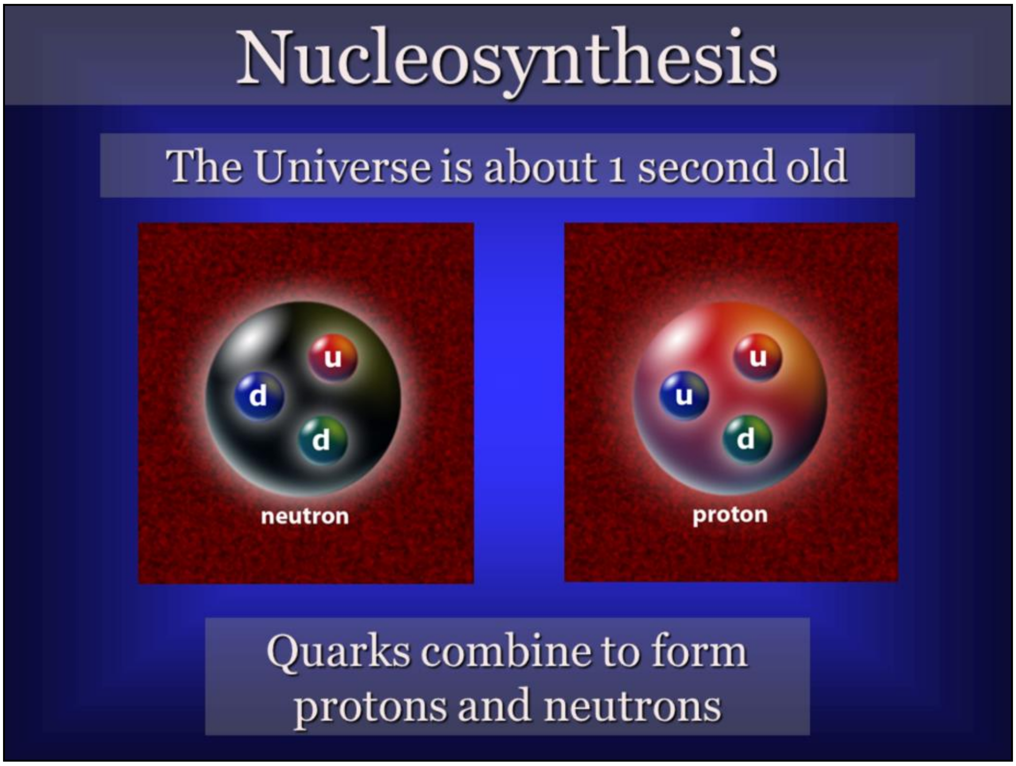
The electroweak force splits into electromagnetic and weak forces

It is finally cool enough for particles to form.

Electrons, neutrinos, and quarks exist at this time.

The energies are still too high for protons and neutrons (which are made up of quarks) to exist.

If a proton or neutron forms, it is still quickly torn apart.



Conditions are right for fusion to occur, but the energies are still so high that helium nuclei are quickly torn apart again.

Shortly thereafter, for a short time, about 3 minutes, fusion occurs without tearing the helium apart.

After about 3 minutes, things cool down enough and the density drops enough that fusion stops and the nuclei ‘freeze out’.

We end up with about 75% hydrogen and 25% helium. (and a bit of lithium)

The universe is a dense mix of protons, neutrons, electrons, AND photons.

An observer in the universe at this time wouldn't be able to see very far.

It would be much like being in a very thick fog. Photons just scatter all over the place and/or get absorbed.

Looking back…

We cannot directly observe this far back in time because after nucleosynthesis:

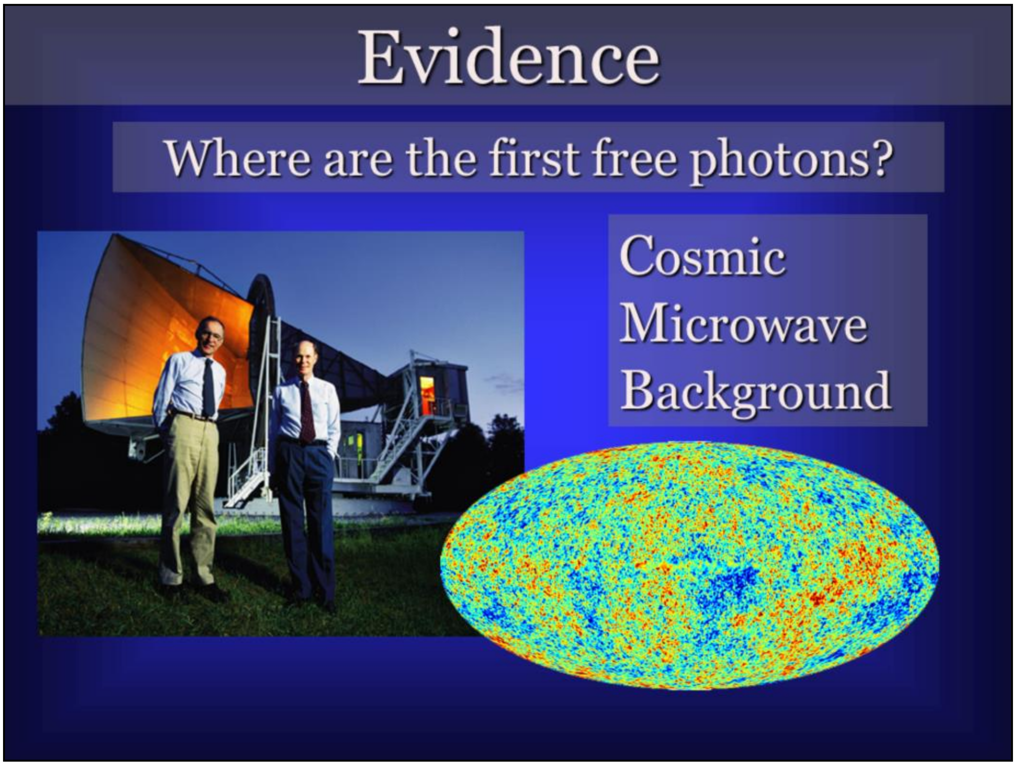
A) Fusion stopped so no light was being produced

B) The universe was too dense to produce light

C) There was plenty of light, it just couldn’t get very far

Eventually… the density drops enough that the electrons are able to hook up with a hydrogen or helium nucleus.

Photons are at last released and allowed to stream free.



In 1965 Arno Penzias and Robert Wilson had some noise in their new antenna that they couldn't figure out.

David Wilkinson and Robert Dicke were building their own instrument at the time to detect the CMB.

Penzias and Wilson scooped them.

The photons from when the fog lifted for the first time should travel mostly unhindered to us from the edge of the universe

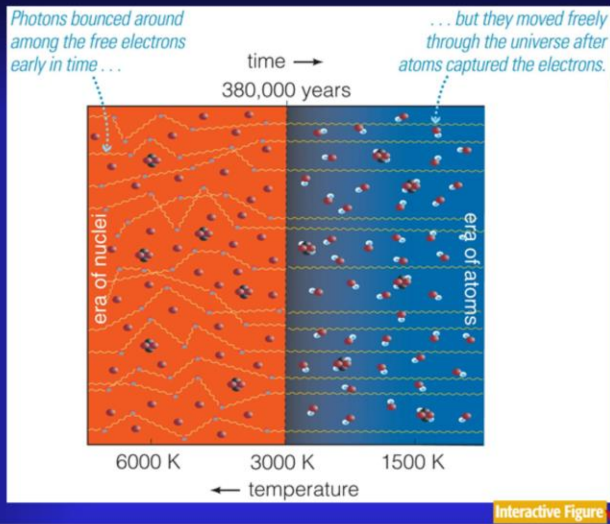
They will be severely red shifted, but we should be able to see them (and we do).

The other evidence is the overall composition of the universe.

Models predict 75% H and 25% He. That is what we see.

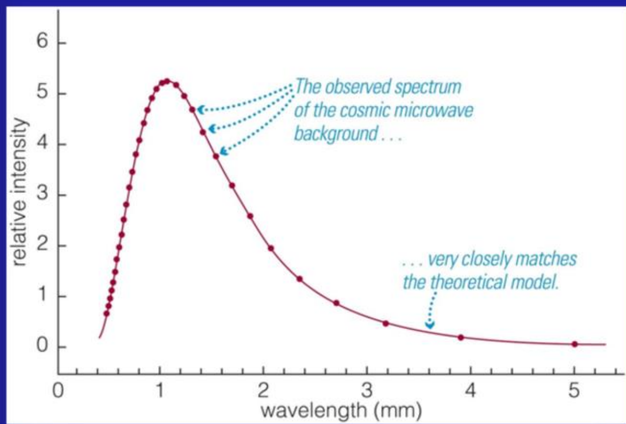
Stars have not contributed a large amount of helium to the Universe at large.

The universe is really, really uniform. The small variations you see in the picture above are *really really* small. But, we had a period of rapid inflation (the universe expanded really super fast) and that made all the small variations much larger. These small variations were the seeds that eventually formed into galaxies and clusters of galaxies.

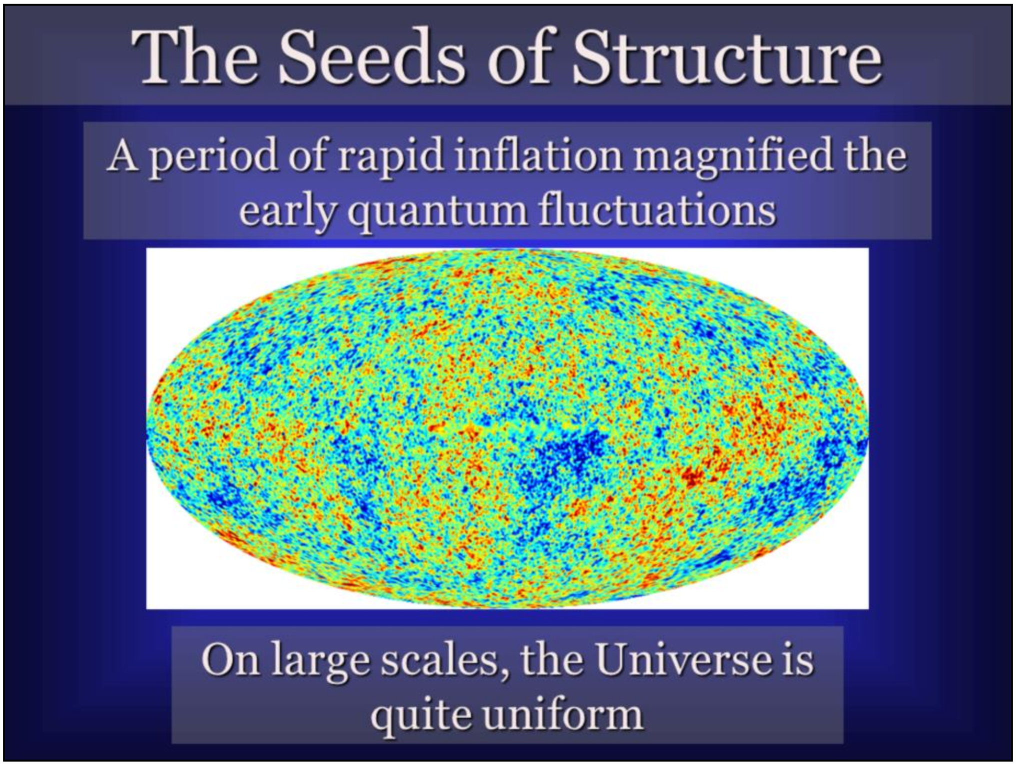


Background radiation from Big Bang has been freely streaming across universe since atoms formed at temperature ~ 3000 K: *visible/IR*.

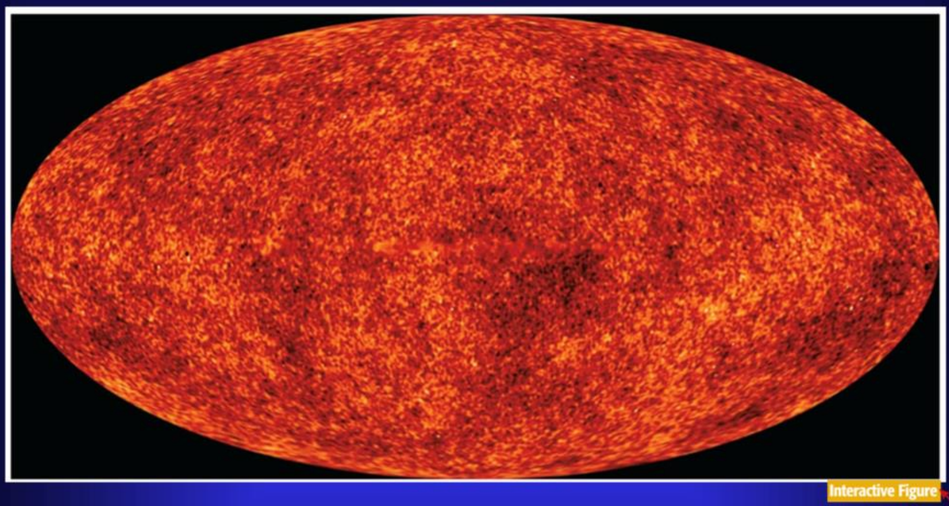
The background has perfect thermal radiation spectrum at temperature 2.73 K



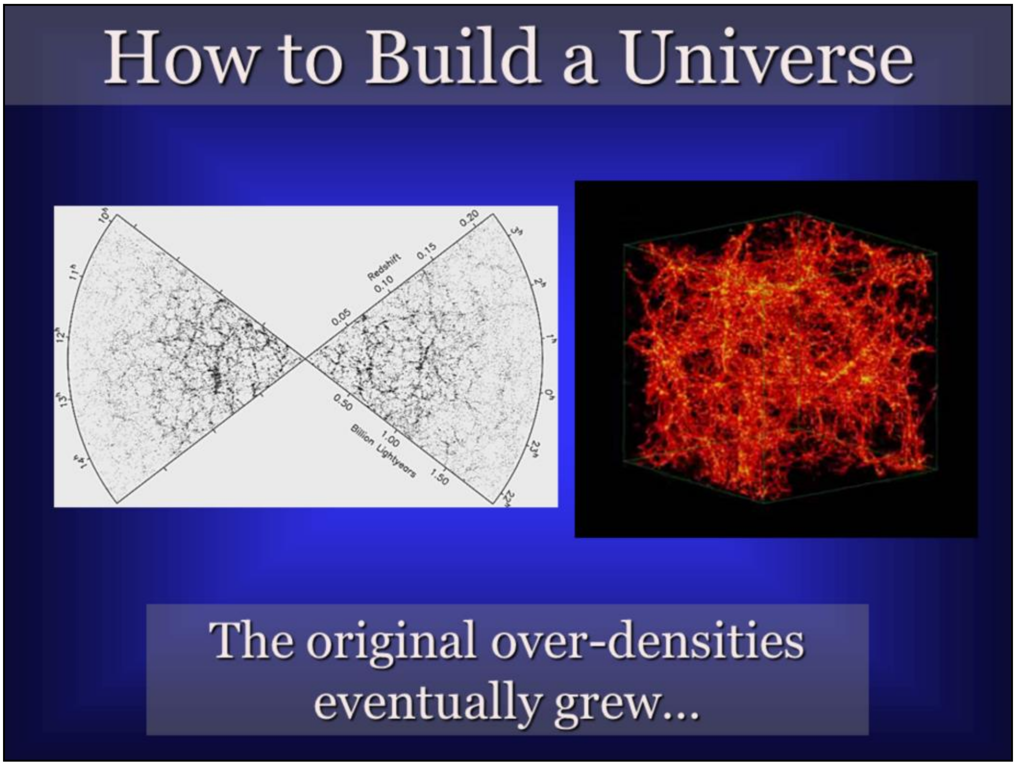
Expansion of universe has redshifted this radiation to ~1000 times longer wavelength: *microwaves*.



Before inflation, the universe was uniform except for the quantum fluctuations. After inflation, the small scale fluctuations were frozen in.



WMAP gives us detailed baby pictures of structure in the universe.



When we start counting galaxies and plotting them in 3-D on the sky, we see that they tend to fall in filaments and cluster together. The spaces between the filaments where few galaxies are located are called voids. These voids aren't completely empty; there are a few faint galaxies in them. However most galaxies lie along the filamentary structure.

So how does this all form?

The original Small over densities caused by the quantum fluctuations grew through self gravity

Gravitational collapse must overcome the expansion.

Small clumps draw material in and become larger clumps.

The matter in the universe eventually organized itself into filaments with voids in between them.

Where filaments meet we find galaxy clusters.

We can see the distribution of mass by looking at light from galaxies.

The picture on the left is actual data from many many galaxies.

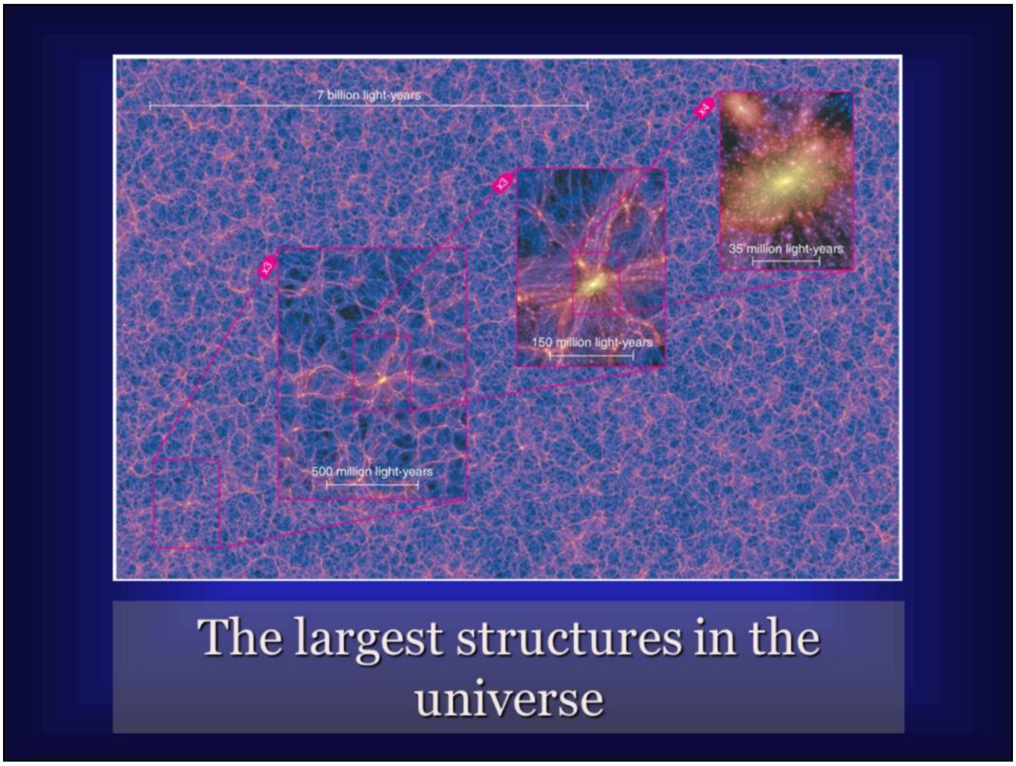
The picture on the right is a computer simulation showing the growth of structure.

These simulations include, and indeed would not work, without a key ingredient… Dark Matter.

To make these simulations work, we use Cold Dark Matter (WIMPS)

WIMPS, although they are weird, are the best current explanation.

Show APOD: http://apod.nasa.gov/apod/ap120813.html



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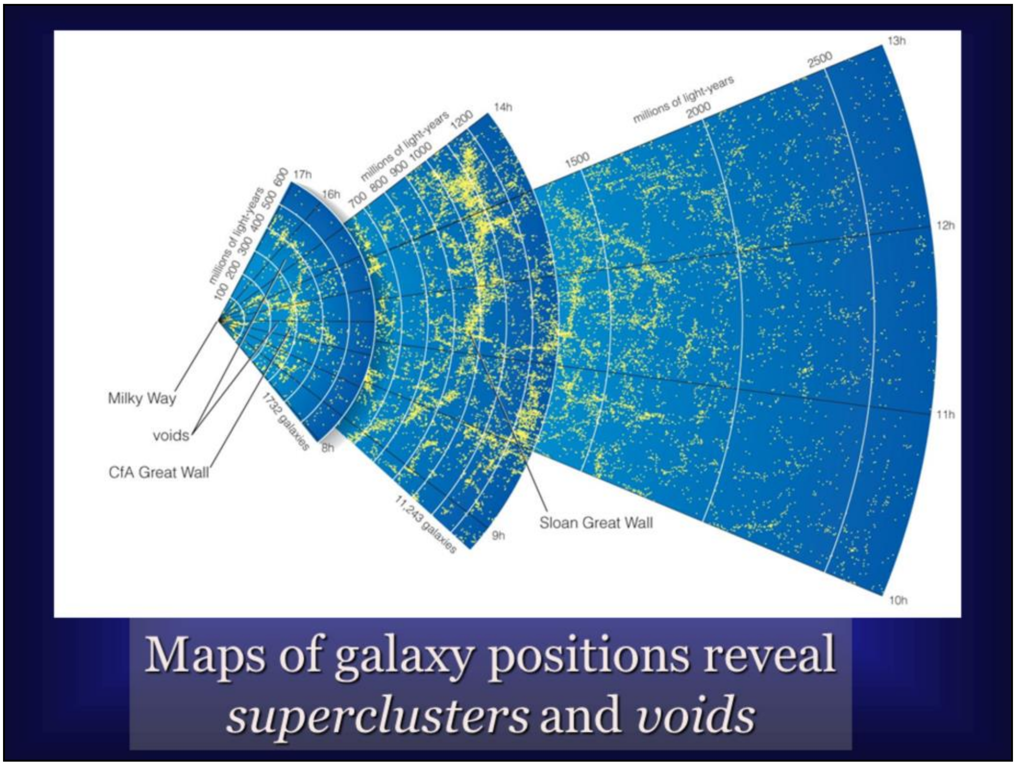
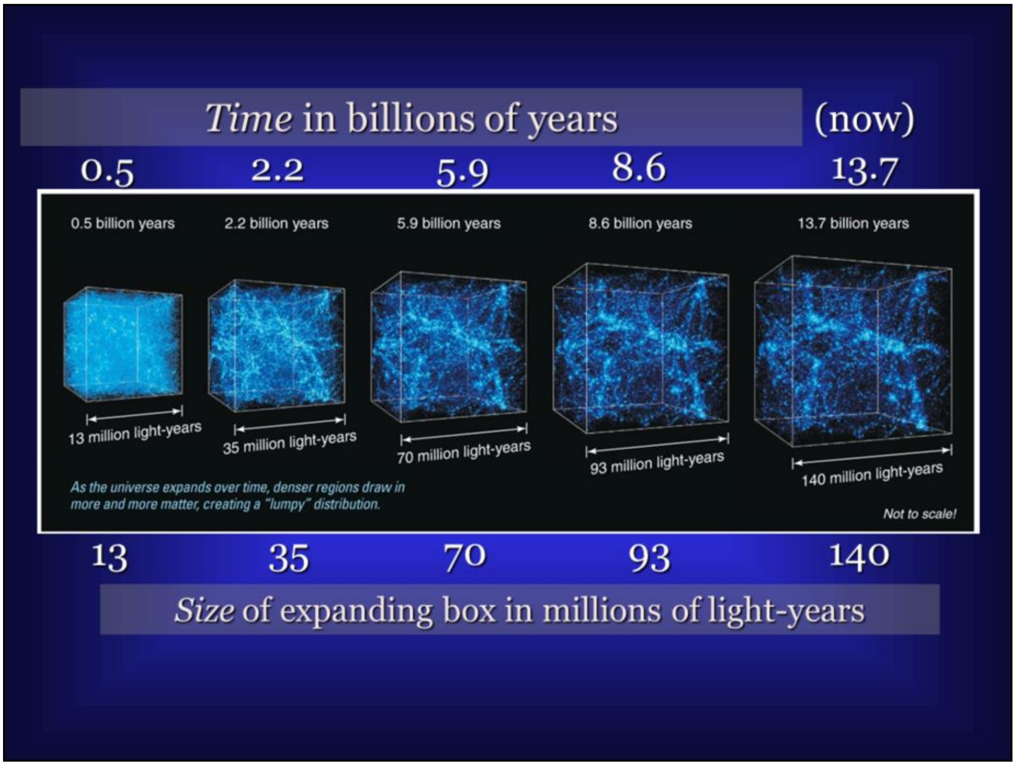
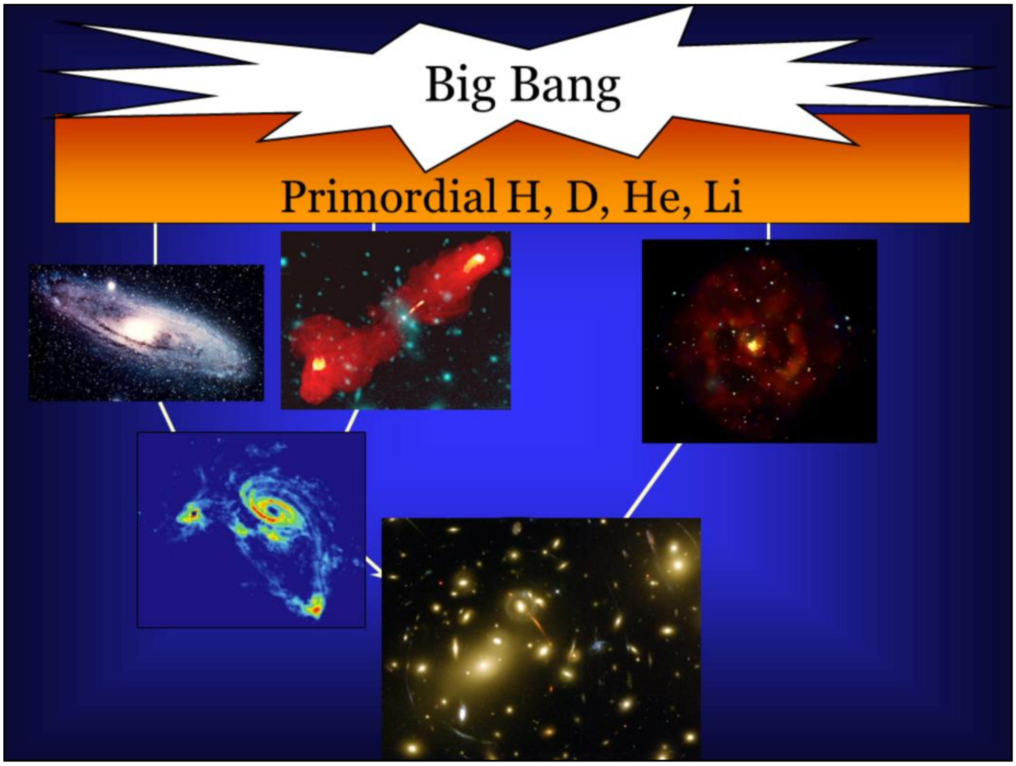


The voids are not completely empty but there isn't much there.



Our best models for galaxy formation assume:

Matter originally filled all of space *almost* uniformly. Gravity of denser regions pulled in surrounding matter.

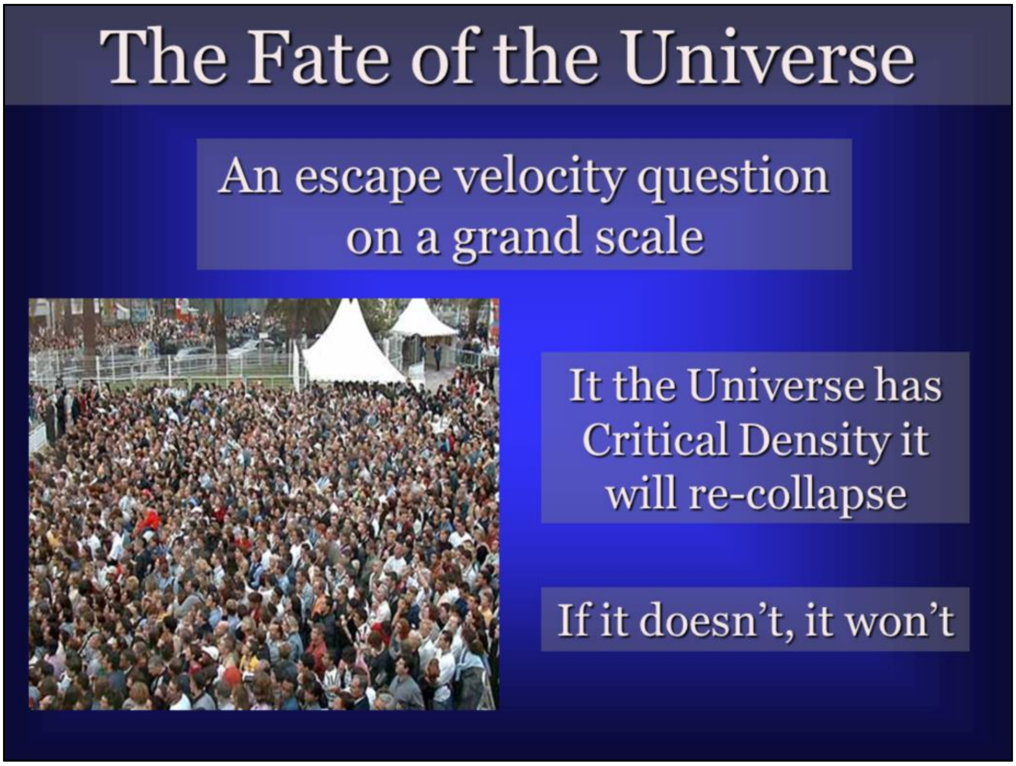


"Bottom up" model for cluster formation: we call this "hierarchical cluster formation"

Dark matter halos are over-dense regions in the primordial soup after the big bang. The Dark Matter is most of the mass – and we'll talk about that more later in the next lecture. But each place which is a little more dense starts to gather up the stuff around it (through gravity) and collapses down into galaxies, quasars, etc. Each over-dense region gathers more stuff to it, eventually becoming groups and then clusters of galaxies.

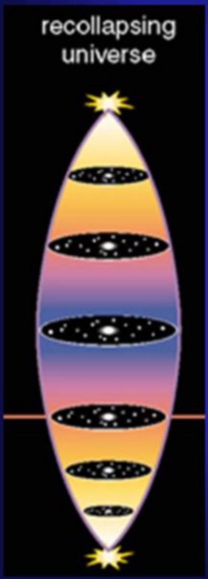
Groups and clusters continue to gather together even today – clusters are still in the process of forming.

Groups even form today, now from the areas that were less dense originally, as matter moves together along "filaments" due to gravitational attraction.



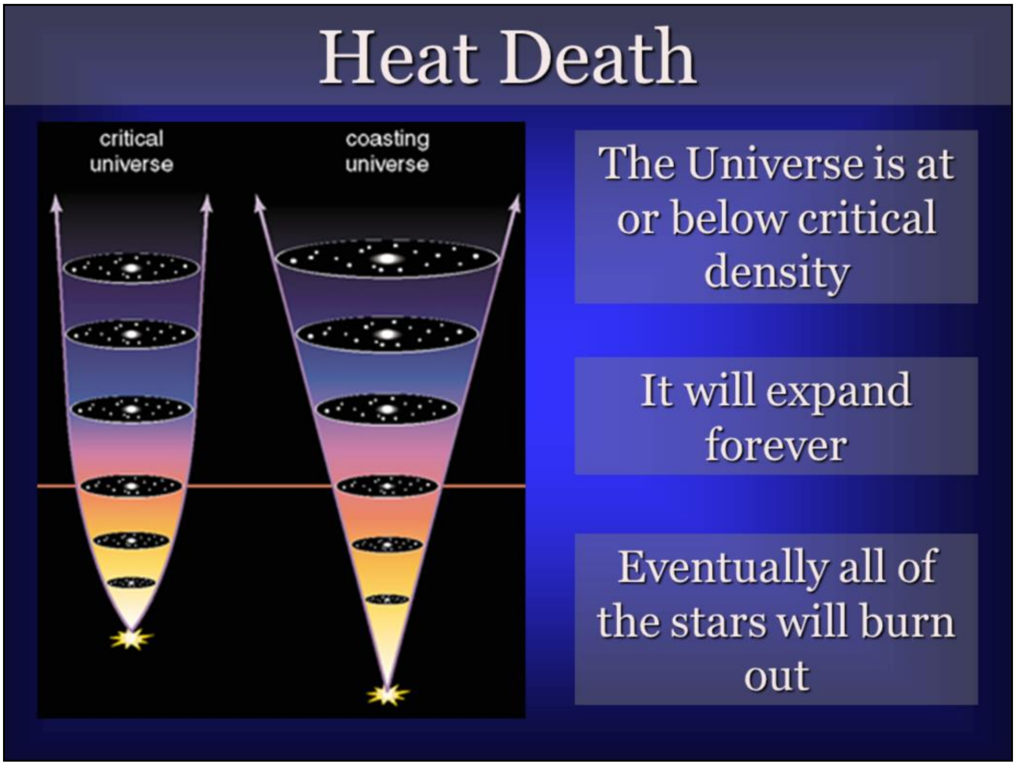
Critical density refers to the energy balance question.
Is there enough mass to eventually halt the expansion.
The amount of mass required is called the critical density.

The Big Crunch



The Universe is above critical density and re-collapses

Perhaps there is another Big Bang and the whole thing just keeps happening over and over



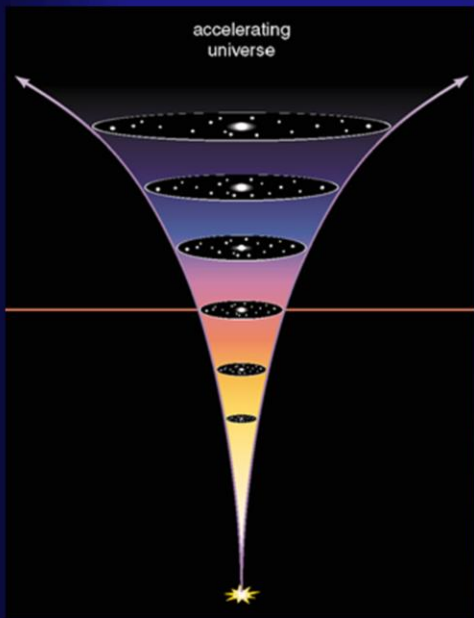
At critical density, the expansion will continue to slow down but the deceleration will become less and less never quite reaching zero

Like Zeno's paradox. Walk half way towards a tree. Now walk halfway again. Again. Again. You never reach the tree.

Less than critical density and the universe just coasts.

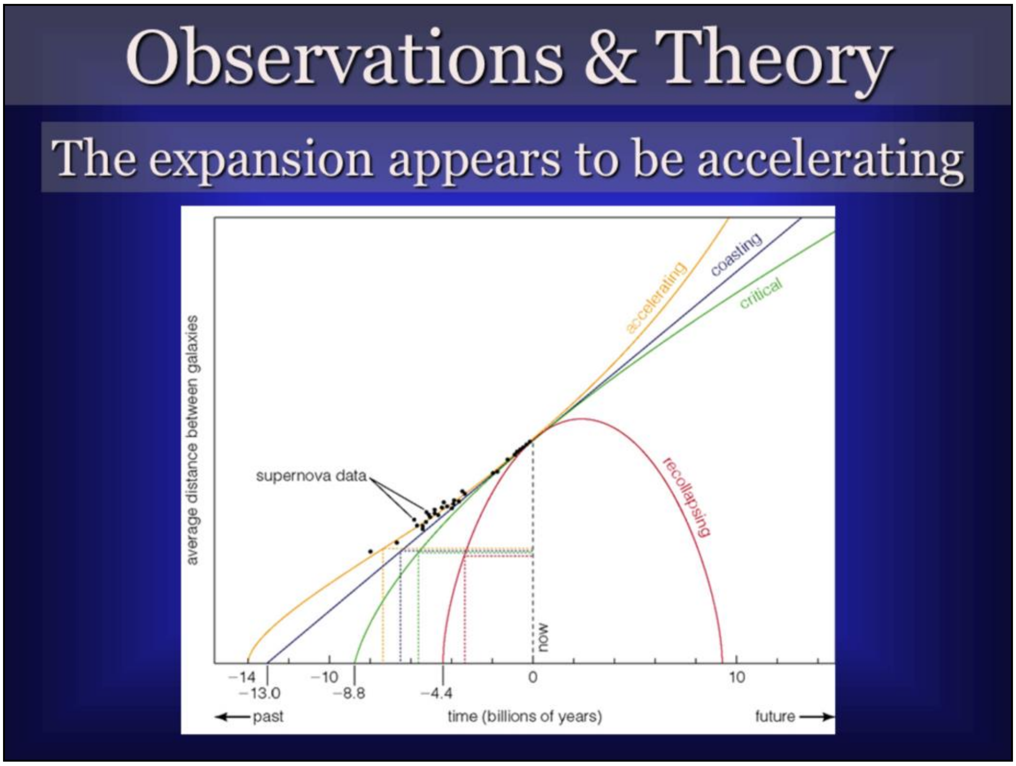
At any rate, it eventually becomes a cold lifeless place. How sad.

The Big Rip



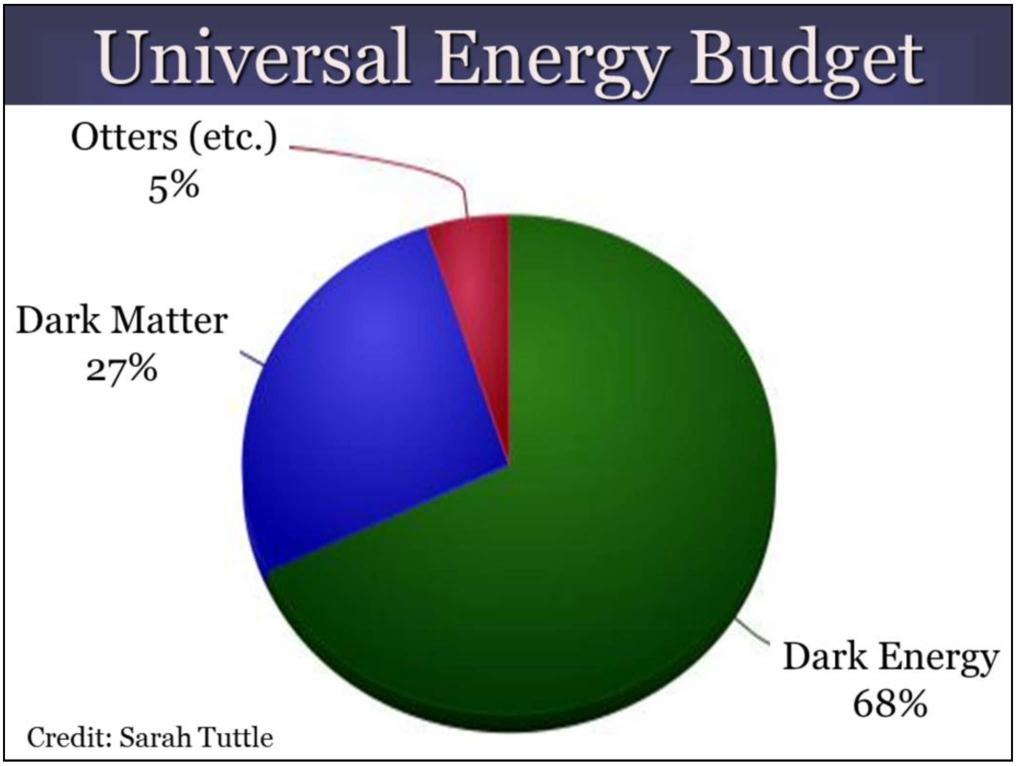
Eventually the expansion will be so fast that gravity won't hold it together

Eventually NOTHING will hold it together!

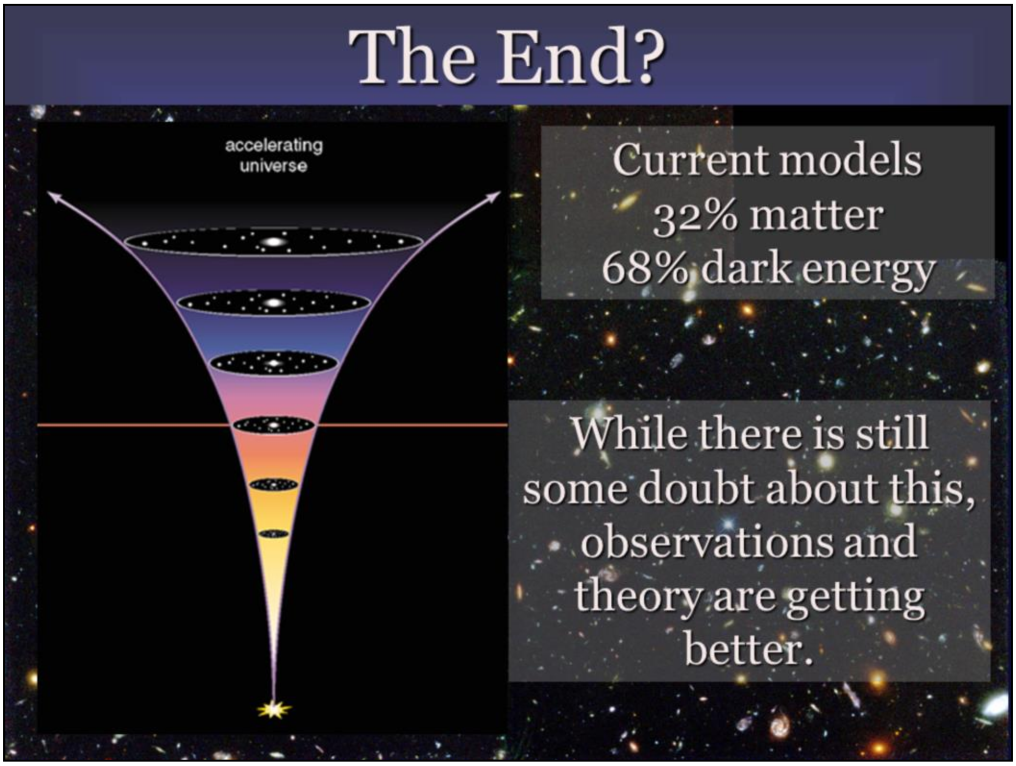


Einstein’s repulsive force is back!

We call the carrier of the repulsive force “Dark Energy”… Spooky.



Otters and other normal matter…. ;)



So long, and thanks for all the fish!


"That's all Folks!"