

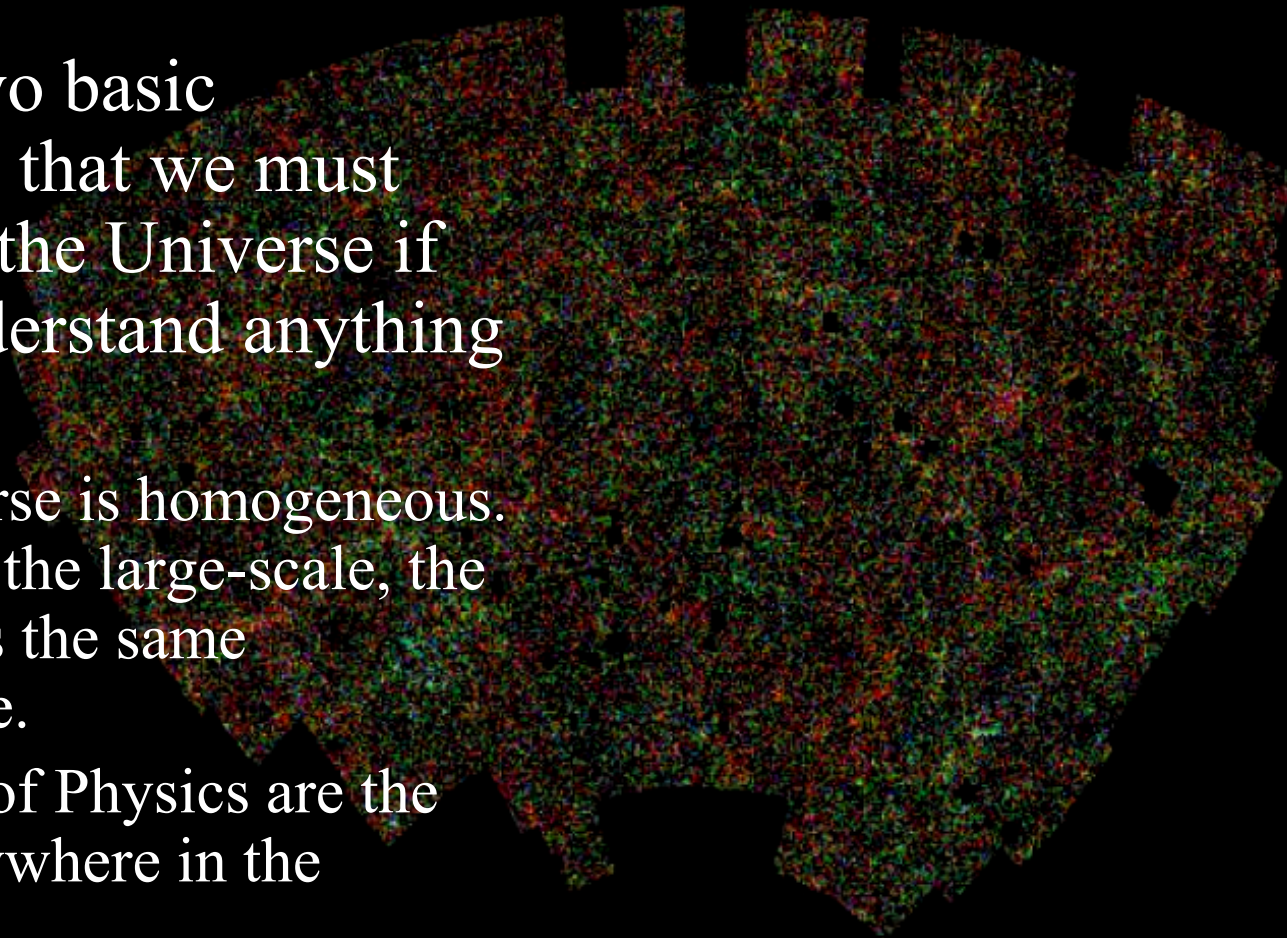


# Cosmology

The History and Structure of our  
Universe.

# The Two Cosmological Principles

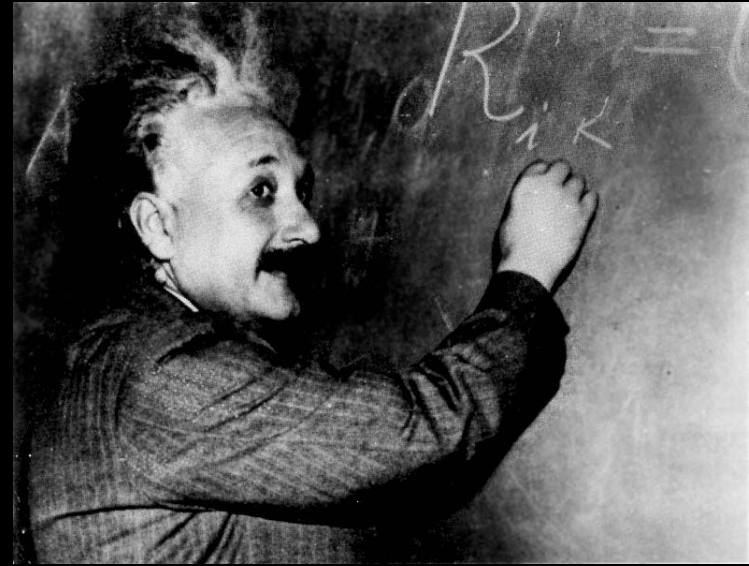
- There are two basic assumptions that we must make about the Universe if we're to understand anything about it.
  - The Universe is homogeneous. That is, on the large-scale, the Universe is the same everywhere.
  - The Laws of Physics are the same everywhere in the Universe.



APM Survey picture of a large part of the sky, about 30 degrees across, showing almost a million galaxies out to a distance of about 2 billion light years.

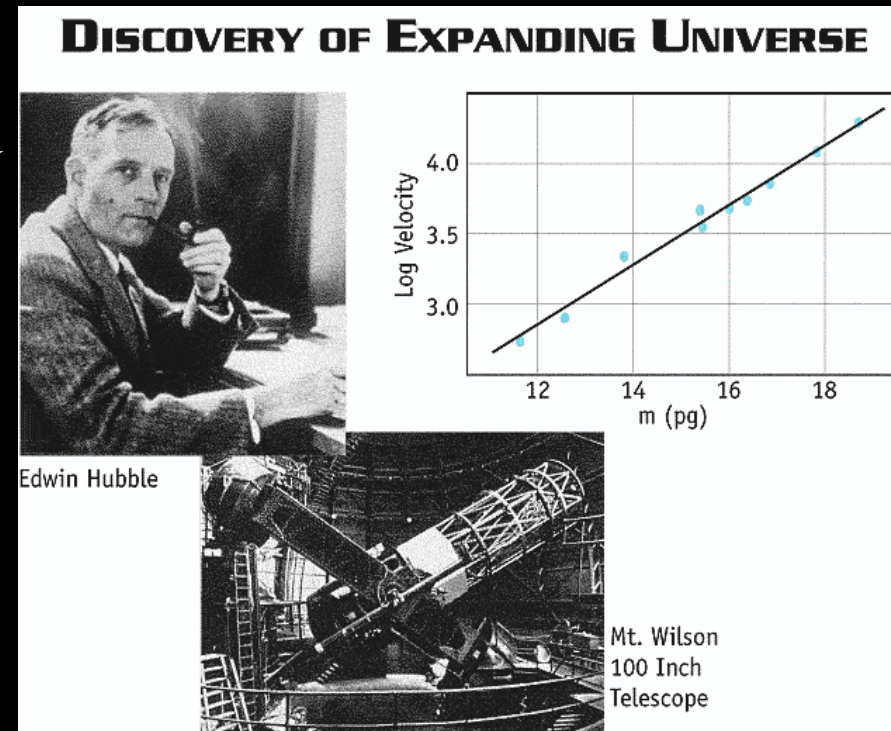
# The Expanding Universe and Einstein

- Einstein's Theory of General Relativity, which is an improved theory of gravity, predicted that the Universe should be expanding.
- Einstein, however, didn't believe his own work, and added an extra term into his field equations to force his model of the Universe to remain fixed in size.

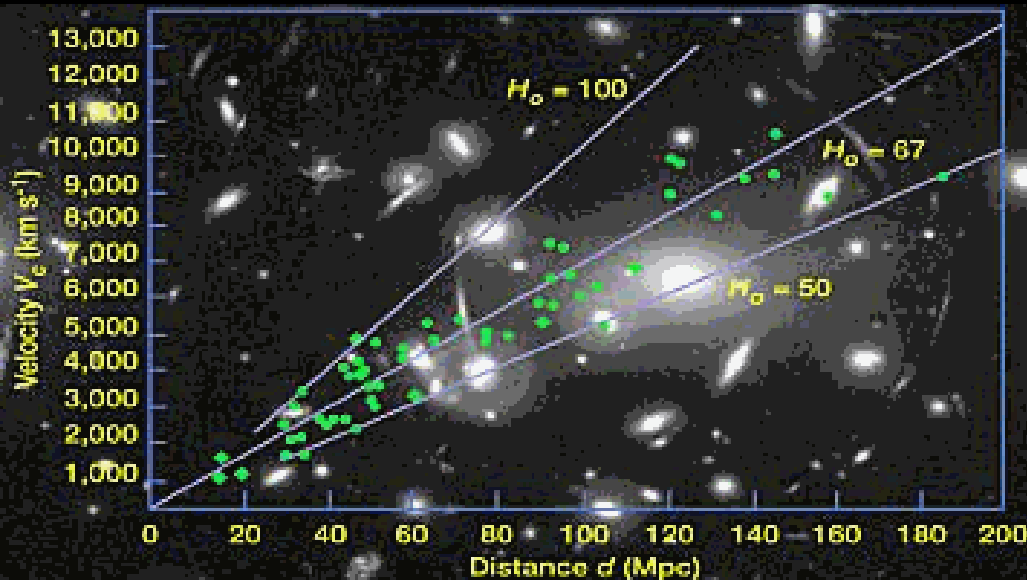


# The Expanding Universe and Hubble

- Edwin Hubble, in 1929, showed that the Universe was expanding.
- Galaxies that were farther away had spectra that were more red-shifted, and therefore, moving away from us faster, than nearby galaxies.
- This led to Einstein admitting his mistake and correcting his theory.
- Einstein later called his first modification the “biggest blunder of [his] career.”



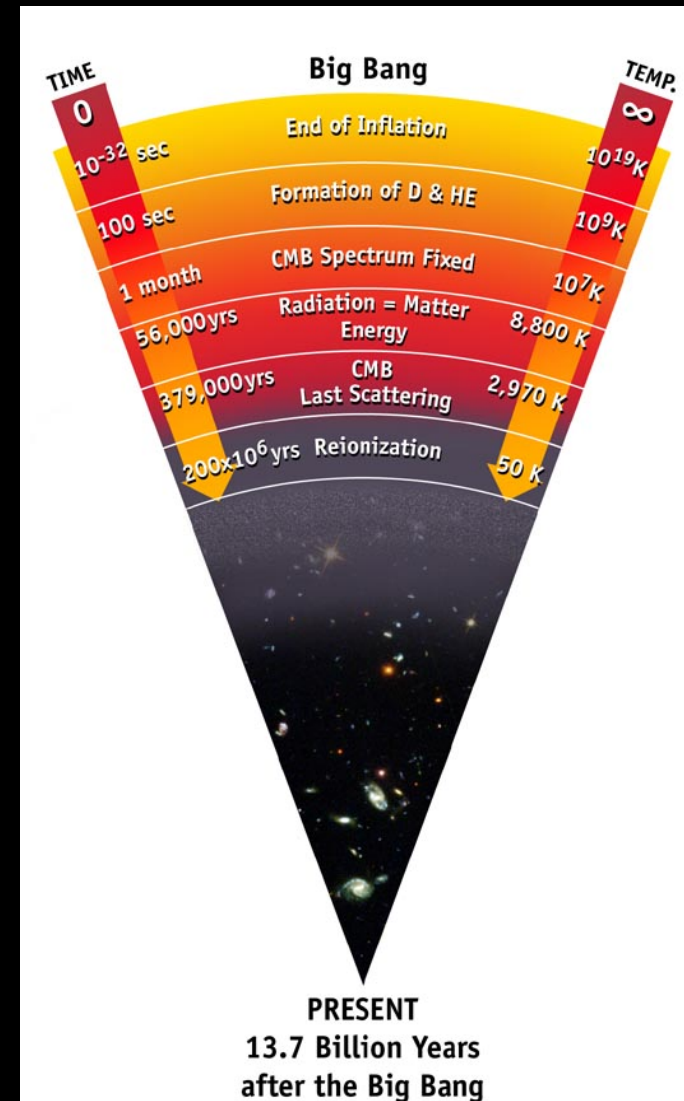
# Hubble's Law



- Hubble's Law states that the velocity at which a galaxy is receding away from us is directly proportional to its distance from us,  $v = H_0 d$ .
- $H_0$  is called Hubble's Constant and has a value of 71 km/s/Mpc (+/- 4 km/s/Mpc).

# Timeline for the Universe

- The consequence of Hubble's Law is that if the Universe is expanding, in the past it would have been smaller.
- Taking this idea to the logical limit would mean that at some time in the past, the entire Universe would have been enclosed in a single geometric point.
- A smaller Universe would be hotter and more dense than it is today, and that means that different conditions would exist in the past than exist today.



# The Early Universe

- There's only so far back into the history of the Universe that we can view with a regular telescope.
- The history of the Universe before about 300,000 yrs after the 'big bang' has to be inferred by looking at the high-energy reactions in particle accelerators.
- This still gives cosmologists a good idea of what the early, dense, Universe was like, and is sufficient for understanding the Universe back to an age of only a fraction of a second,  $10^{-35}$ s, from the beginning.

# THE BIG BANG THEORY

TIME BEGINS

ONE SECOND

PRESENT DAY

Time	$10^{-43}$ sec.	$10^{-32}$ sec.	$10^{-6}$ sec.	3 min.	300,000 yrs.	1 billion yrs.	15 billion yrs.
Temperature		$10^{27}$ °C	$10^{13}$ °C	$10^8$ °C	10,000°°C	-200°°C	-270°°C

**1** The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second

**2** Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

**3** A rapidly cooling cosmos permits quarks to clump into protons and neutrons

**4** Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog

**5** Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine

**6** Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

**7** As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

Quarks

Neutron

Hydrogen nucleus

Hydrogen atom

Protogalaxy

Electron

Proton

Helium nucleus

Helium atom

Galaxy

# Dark Matter

- As we saw when we looked at our own galaxy, there's more to the Universe than the ordinary matter that we can see.
- Dark matter is material that is not visible, either because it's cold and dark such as a large asteroid or comet fragment, or because it does not interact well with light such as a neutrino.
  - MACHOs: Massive Compact Halo Objects, ordinary matter that is just too cold to emit much light. Normally found in the halos of galaxies.
  - WIMPs: Weakly Interacting Massive Particles, exotic subatomic particles that do not emit, reflect, or absorb light, but have mass and can exert a gravitational force.

# Dark Matter and Lumpiness

- The amount of dark matter in the Universe will affect how ‘lumpy’ the Universe is.
- The more dark matter there is, the stronger the tendency for galaxies to cluster tightly together is.
- By mapping out the position of the millions of known galaxies, cosmologists can get an understanding what the total density of dark matter is in the Universe.

# Possible Geometries

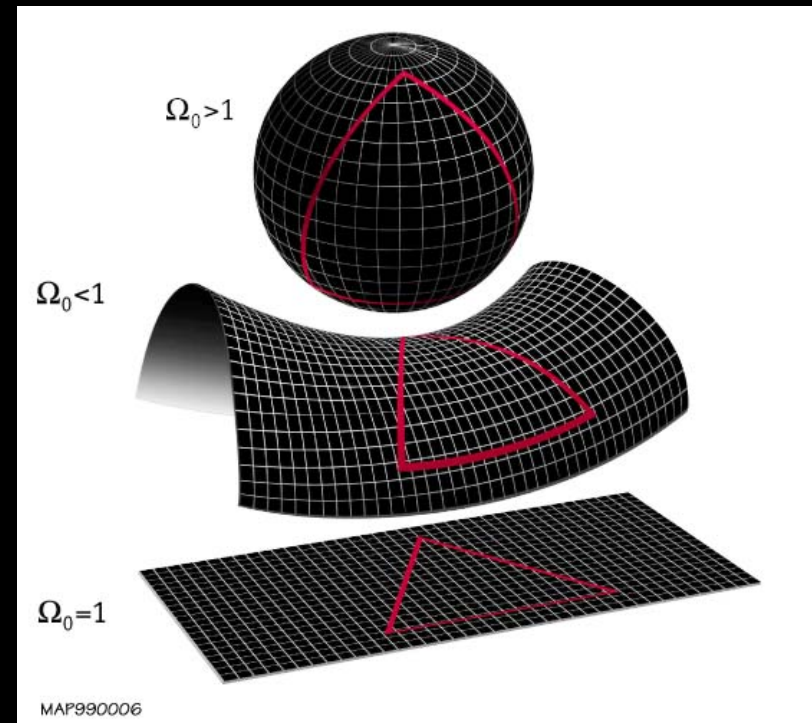
- The amount of matter in the Universe will affect the overall geometry of the Universe.
- The more matter there is, the more the Universe will be positively curved.
- The three possibilities are...
  - An open universe: too little matter, negative curvature like a Pringle chip.
  - A flat universe: no curvature, normal everyday geometry.
  - A closed universe: too much matter, positive curvature like a sphere.

# Density Parameter

- The measure of how much matter is in the universe is done by evaluating the density of a small part of the Universe, and assuming the Universe is homogeneous.
- The Density Parameter,  $\Omega_0$ , is the ratio between the actual density of the Universe and the critical density.
- The critical density is the density the Universe must have in order to have a flat geometry.

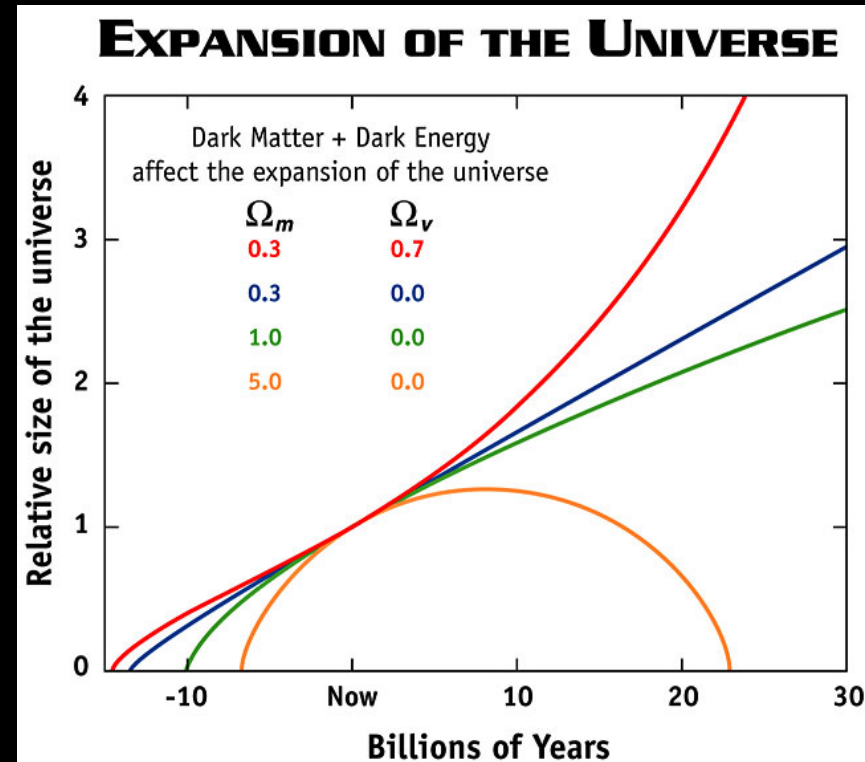
# Density and Geometry

- The amount of matter in the Universe determines the overall geometry.
  - $\Omega_0 > 1$ : A closed universe
    - Sum of interior angles of a triangle  $> 180$  deg.
    - Lines initially parallel will converge.
  - $\Omega_0 = 1$ : A flat universe
    - Sum of interior angles of a triangle  $= 180$  deg.
    - Parallel lines stay parallel
  - $\Omega_0 < 1$ : An open universe
    - Sum of interior angles of a triangle  $< 180$  deg.
    - Lines initially parallel will diverge.



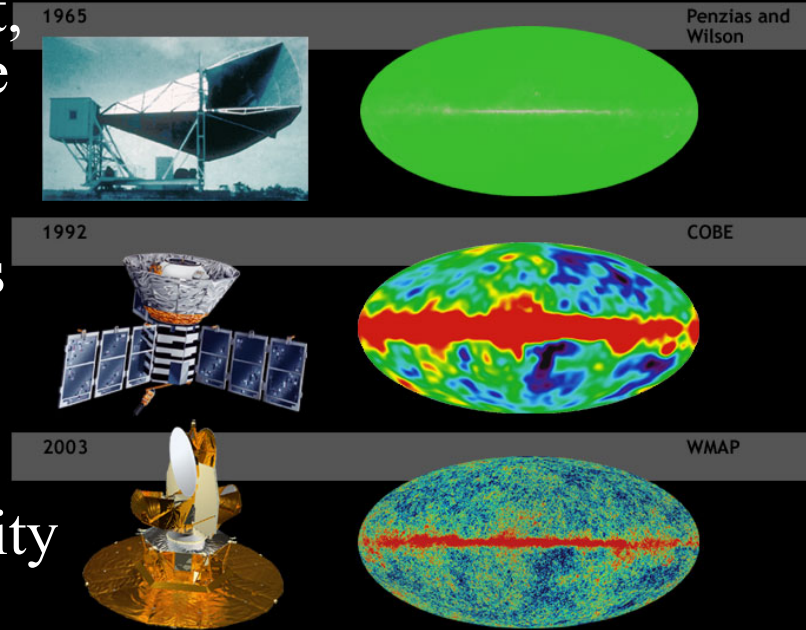
# Density, Geometry, and Age

- The density parameter, and therefore the geometry, of the Universe is also a measure of the age of the Universe.
  - Yellow line = closed universe
  - Blue line = flat universe
  - Red line = open universe
- Our universe is very nearly flat.

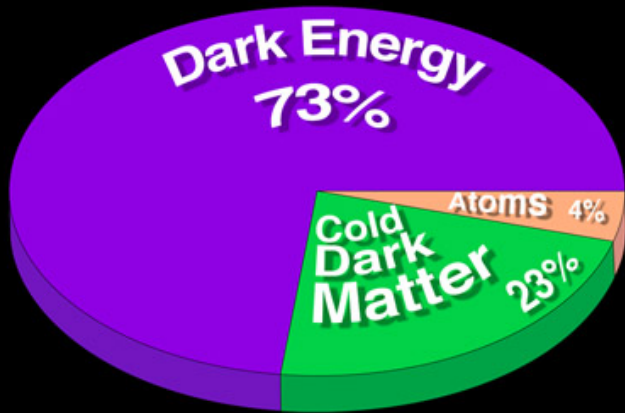


# Cosmic Microwave Background Radiation (CMBR)

- Nearly all of the cosmological parameters such as the density parameter, the age, Hubble's constant, and the amount of dark matter, can be determined by looking at the CMBR.
- The CMBR is very nearly uniform. Remember the Universe as a whole is very isotropic (meaning it looks the same in every direction).
- Cosmologists study the very small variations (anisotropies) in the intensity of the CMBR. The size of these anisotropies are determined by the amount of matter present, and therefore by the density of the universe.



# Our Universe



- $\Omega_0=1$ . This gives us much information about the shape and age of our Universe.
  - The Universe is flat and will continue to expand forever.
  - The Universe is around 13.5 billion years old.
- There is an accelerating force on our Universe. The nature of this force is not yet clear, but its called “Dark Energy”.
- Dark Energy and Dark Matter make up the vast majority of our Universe. Normal matter is only a small percentage of all that exists.

# Outstanding Problems

- The Flatness Problem
  - Out of the infinite number of possible densities our universe could have, why is it exactly 1?
  - Current physics has all densities being equally probable, but obviously an  $\Omega_0=1$  is favored.
- The Horizon Problem
  - The extremes of the universe we can observe appear identical (remember the universe is homogeneous).
  - Things that are the homogeneous now must have been able to interact in the past, but the light has not had a chance to travel from one extreme edge to the other yet.
- Superluminal Expansion
  - A critical part of Inflation Theory is that the universe in the first few fractions of a second expanded in size by about 50 orders of magnitude.
  - This means that the universe was expanding faster than the speed of light which is not possible according to Einstein's Theory of Special Relativity.

# The Ekpyrotic Model

- There's a new idea about the beginning of the Universe. Instead of a Big Bang, there might have been a big 'slap'.
  - Two 4 dimensional sheets in a 5+ dimensional space collide and stick together.
  - Matter is created from the energy of the collision.
- This model is based upon a new form of fundamental physics called String Theory.
  - The Ekpyrotic Model solves the three problems mentioned previously about Inflation Theory.
  - We're as of yet unable to verify String Theory. It sounds solid, but physicists are not yet able to generate the energies needed to test the theory rigorously.