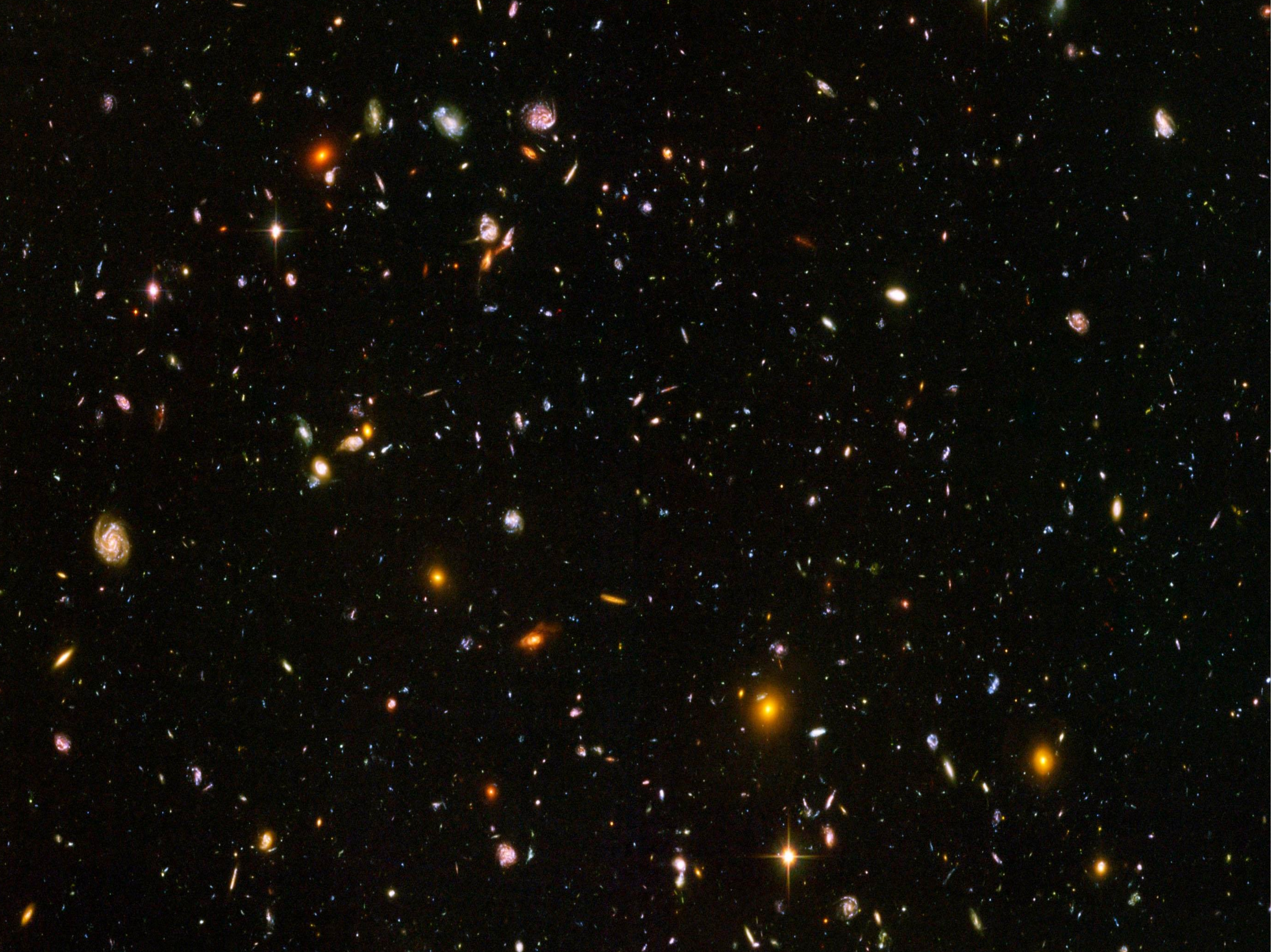
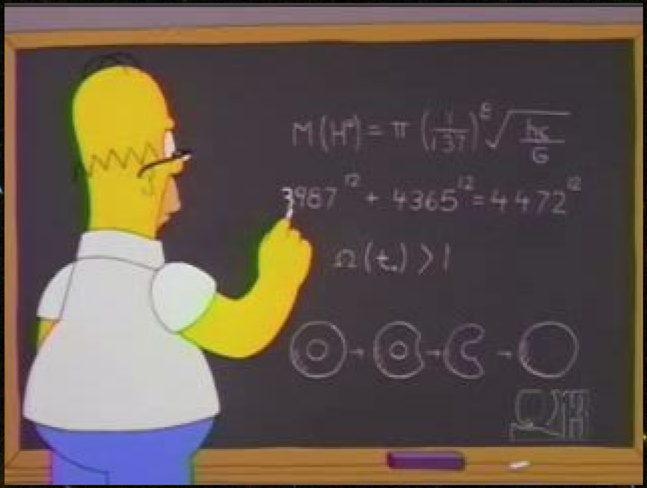


Queen Mary University of London
Nuclear Physics and Astrophysics, lecture on

Big Bang: Cosmology and Nucleosynthesis

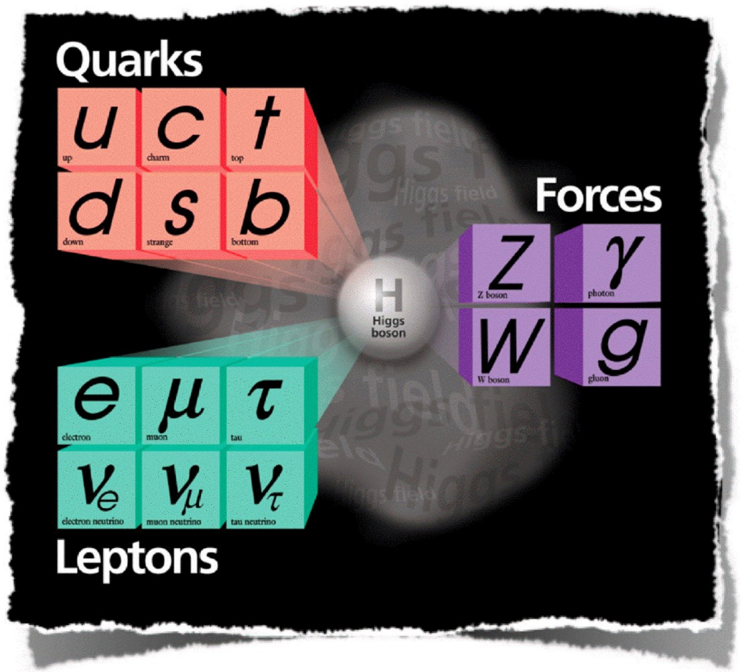


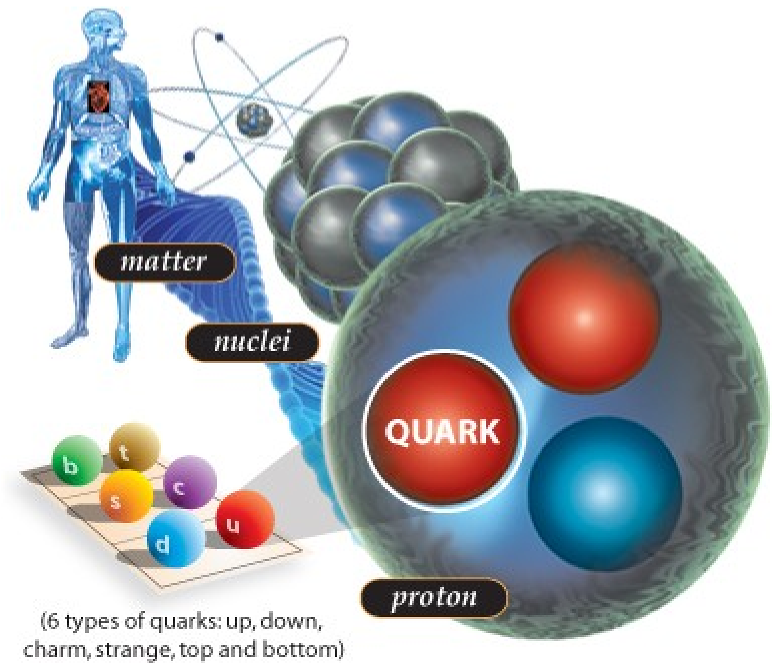
Gianluca Inguglia
29/11/2012

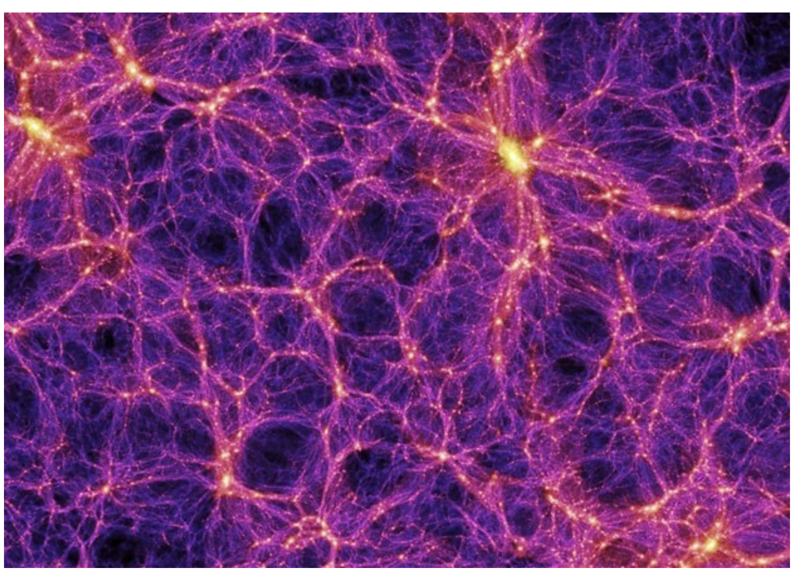
Outline of This Lecture

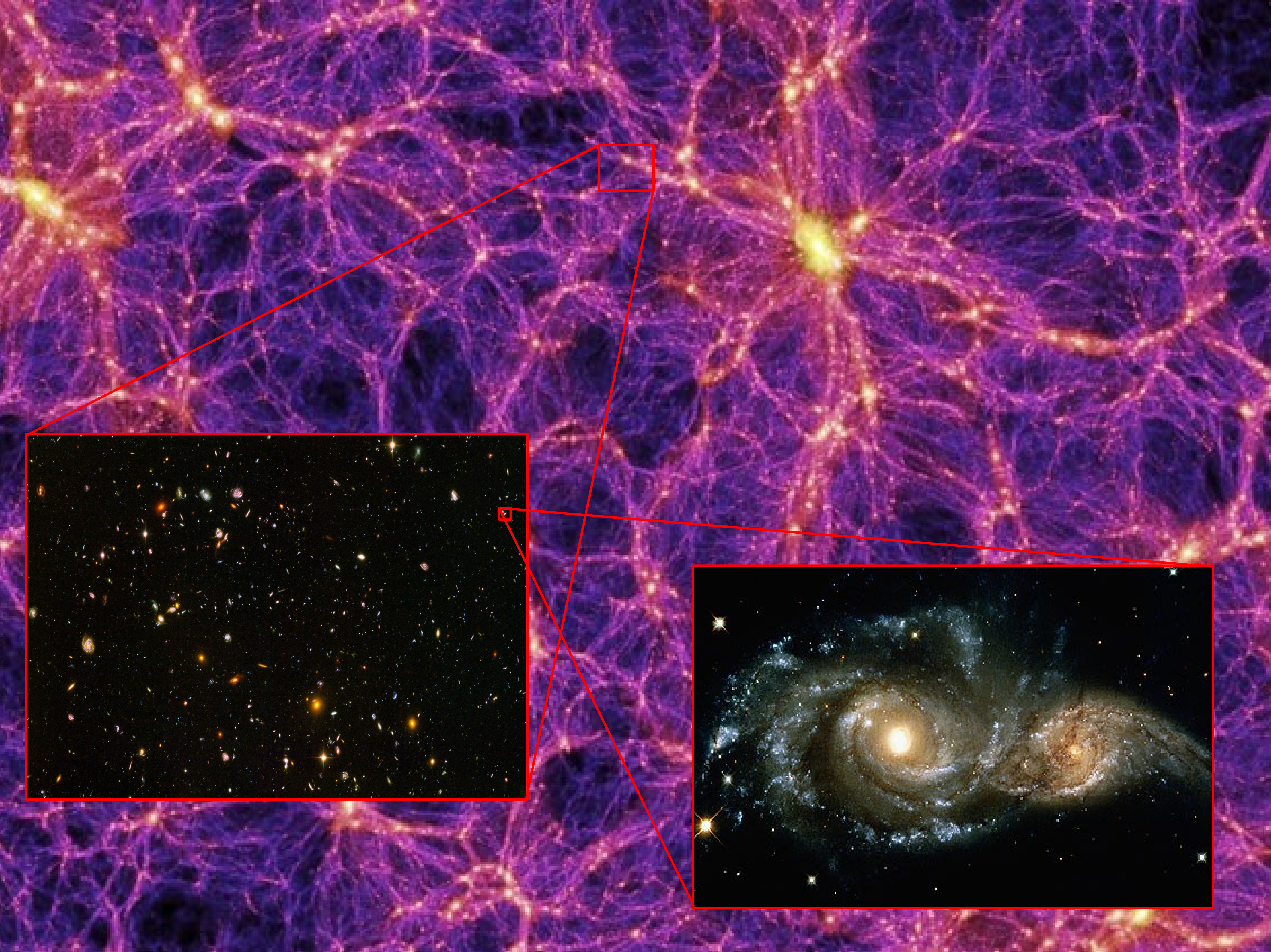
- The Smallest and the Biggest Structures of the Universe
- Big Bang Model
- Matter, Antmatter, Dark Matter, Dark Energy
- Big Bang Problems and Their Solution
- Big Bang Nucleosynthesis (BBN)
- The Future of the Universe

From the very small to the very big: is there a link?







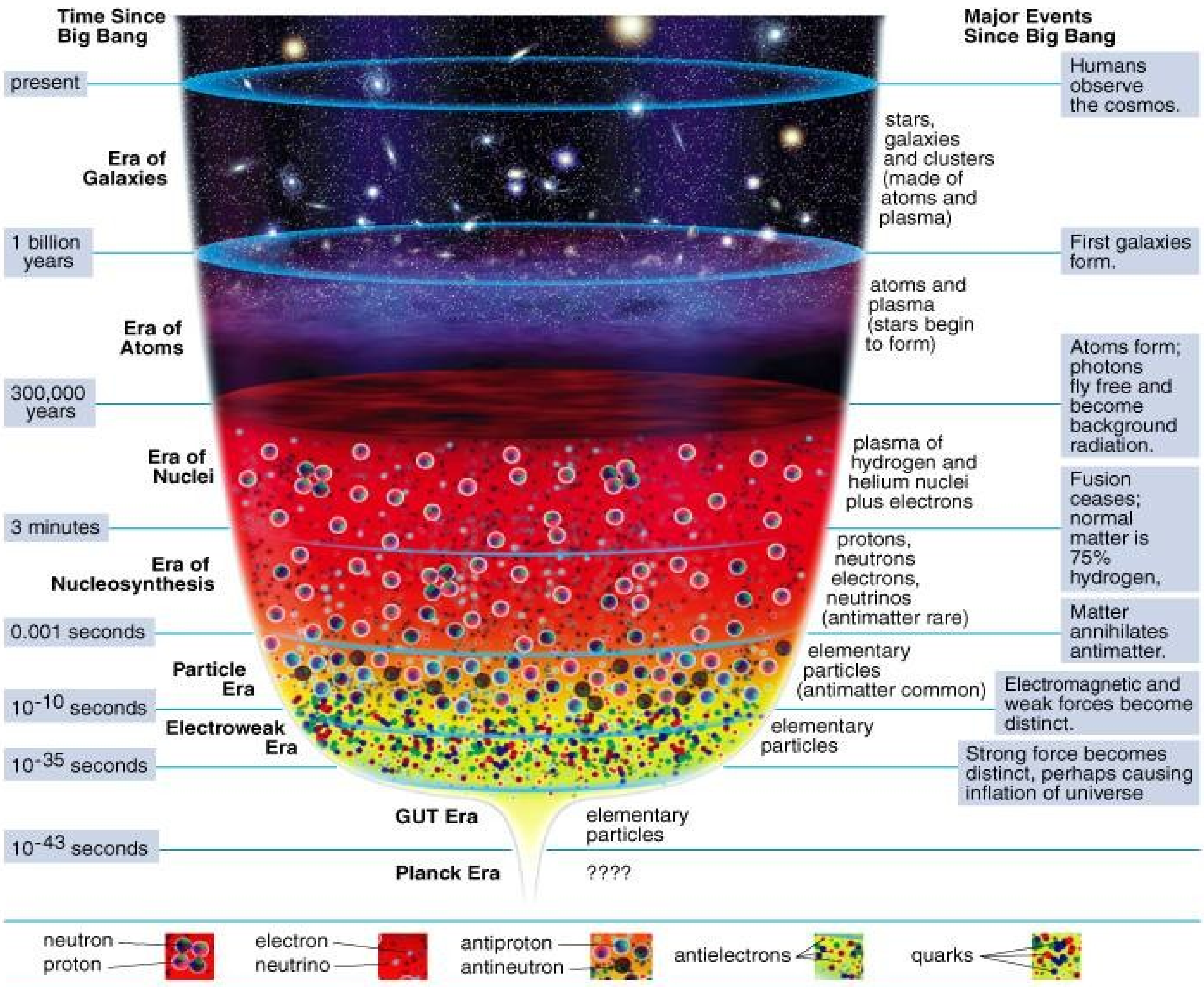


The Universe is really huge, how did it form?

The Universe is really huge,
how did it form?

With a

The smallest objects of the Universe here play a role



Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies and clusters (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
300,000 years
Atoms form; photons fly free and become background radiation.
Era of Nuclei
plasma of hydrogen and helium nuclei plus electrons
3 minutes
Fusion ceases; normal matter is 75% hydrogen,
Era of Nucleosynthesis
protons, neutrons electrons, neutrinos (antimatter rare)
0.001 seconds
Matter annihilates antimatter.
Particle Era
elementary particles (antimatter common)
10^{-10} seconds
Electromagnetic and weak forces become distinct.
Electroweak Era
elementary particles
10^{-35} seconds
Strong force becomes distinct, perhaps causing inflation of universe
GUT Era
elementary particles
10^{-43} seconds
Planck Era
????
neutron
proton
electron
neutrino
antiproton
antineutron
antielectrons
quarks

Is everything fine with the model?

Is everything fine with the model?

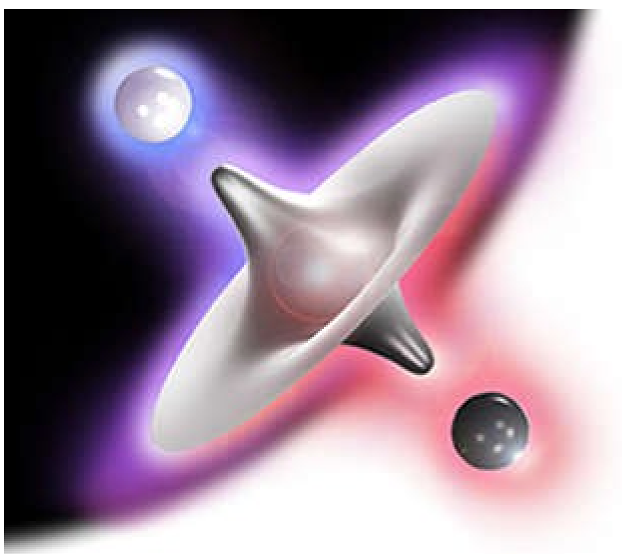
Not really, something is missing..

Problem: Where is the Antimatter in the Universe?

At the time of Big Bang an equal amount of matter and antimatter was “created”, experimental searches for antimatter in the Universe revealed that the Universe is matter dominated, there is (almost) no antimatter. There are 2 possibilities now:

1) Something is wrong with the model

2) Something had to happen during the firsts instants of the Universe, a mechanism that may have favoured matter over antimatter



in the **very early universe**

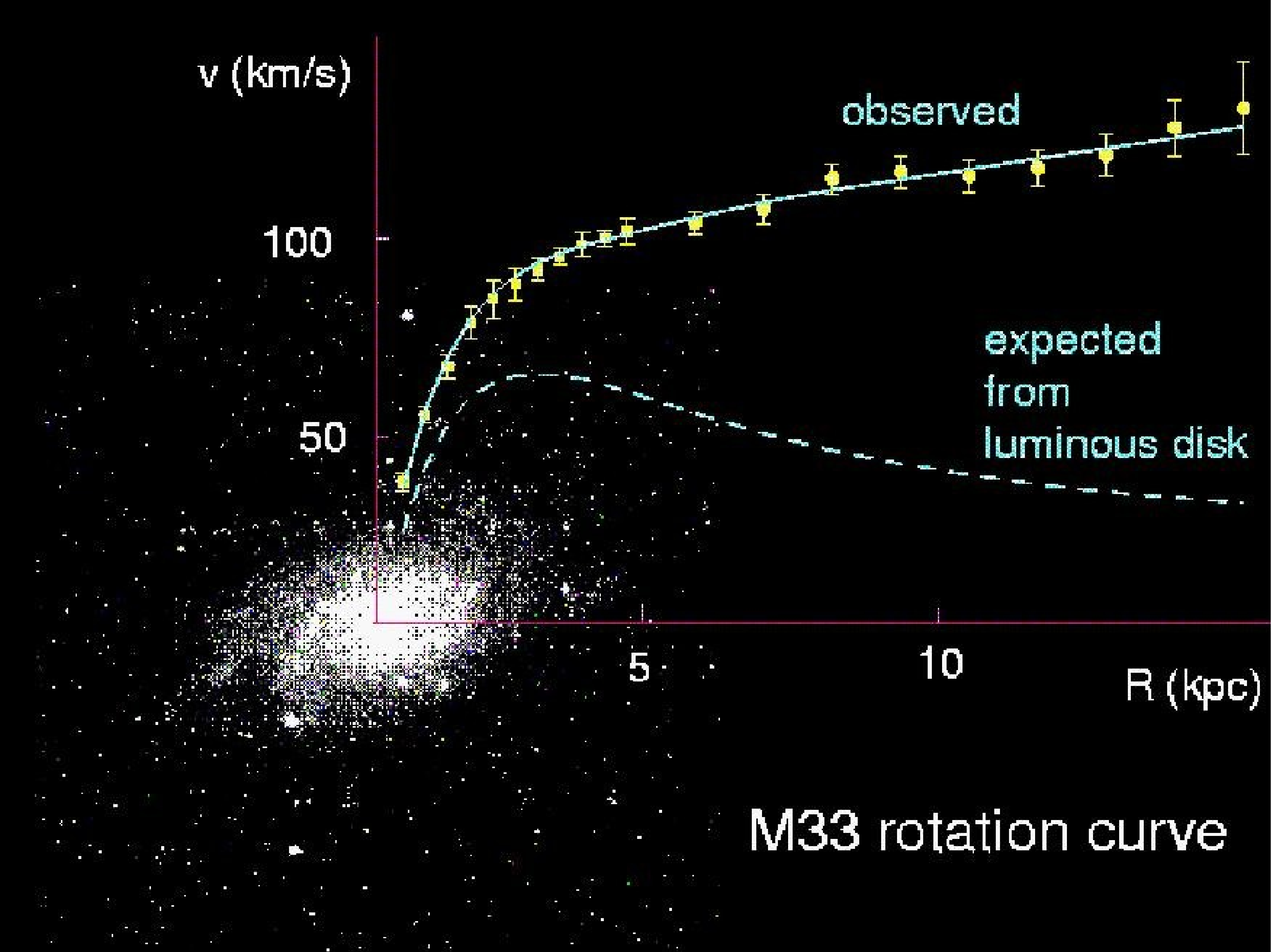
Sakharov criteria:
1) baryon number violation
2) Non thermal equilibrium processes
3) C & CP-Violation

If the three conditions are all satisfied together, matter may dominate over antimatter

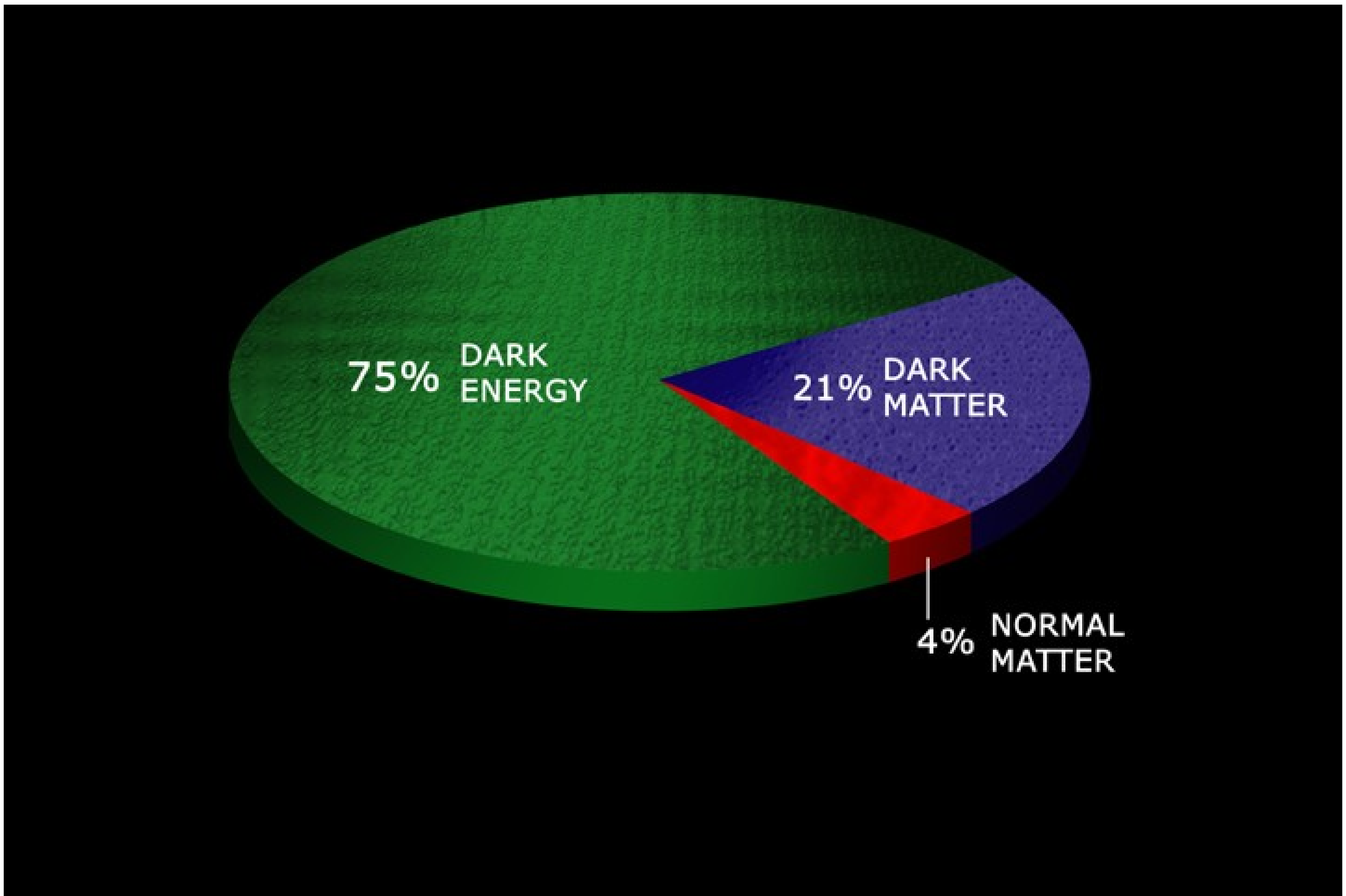
Is everything fine with the model?

Is everything fine with the model?

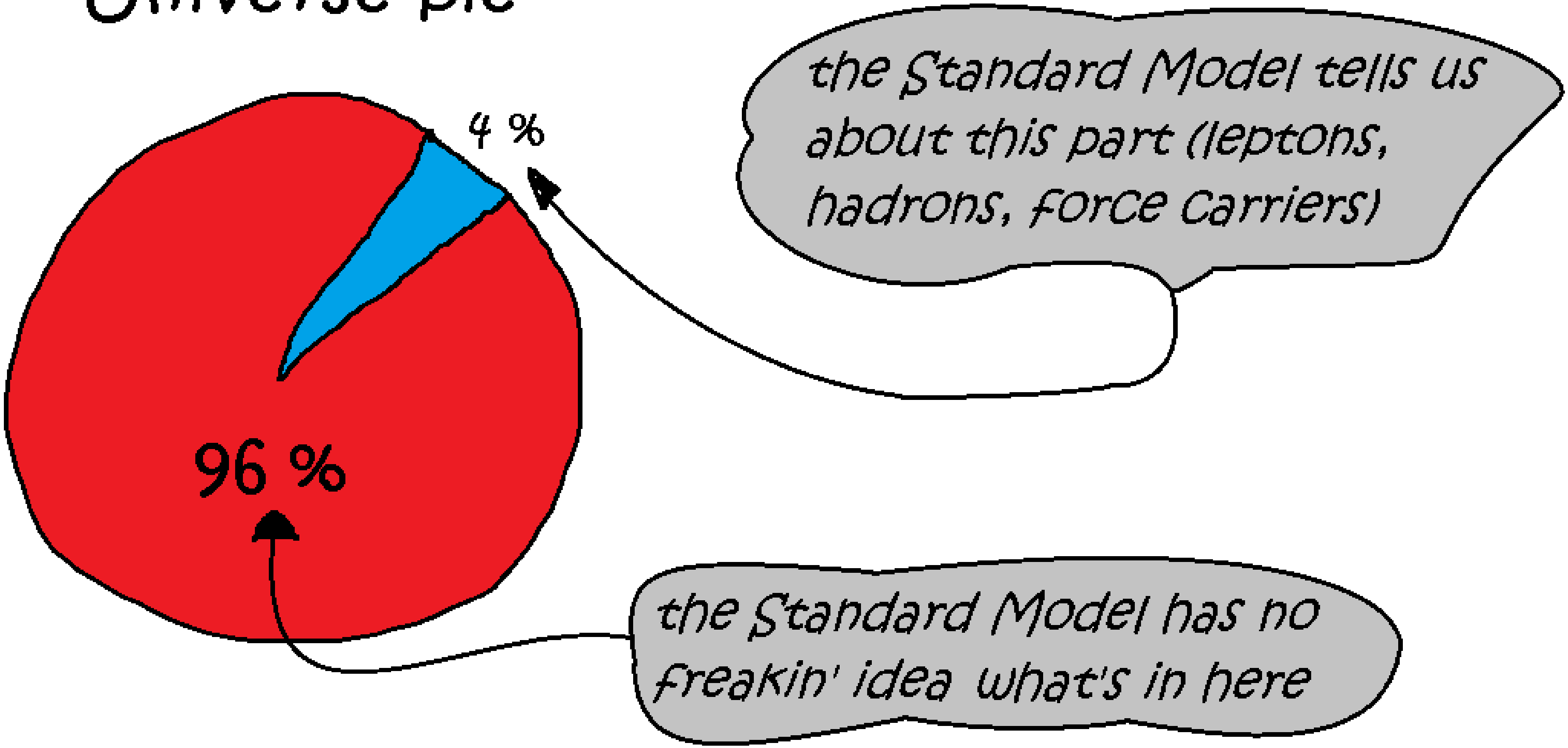
Not really, maybe it's too much...


v (km/s)
100
50
observed
expected
from
luminous disk
5
10
R (kpc)
M33 rotation curve

A picture of the Universe



Universe pie



- The Universe is mainly unknown: we just know and understand the 4% of it.
- We know that within this 4% there is a big amount of missing antimatter
- We know that most probably everything originated from a big bang
- We know that the Universe is expanding
- How do we know these things?

Our knowledge is based on OBSERVATION!

The Universe is expanding: Hubble's Law

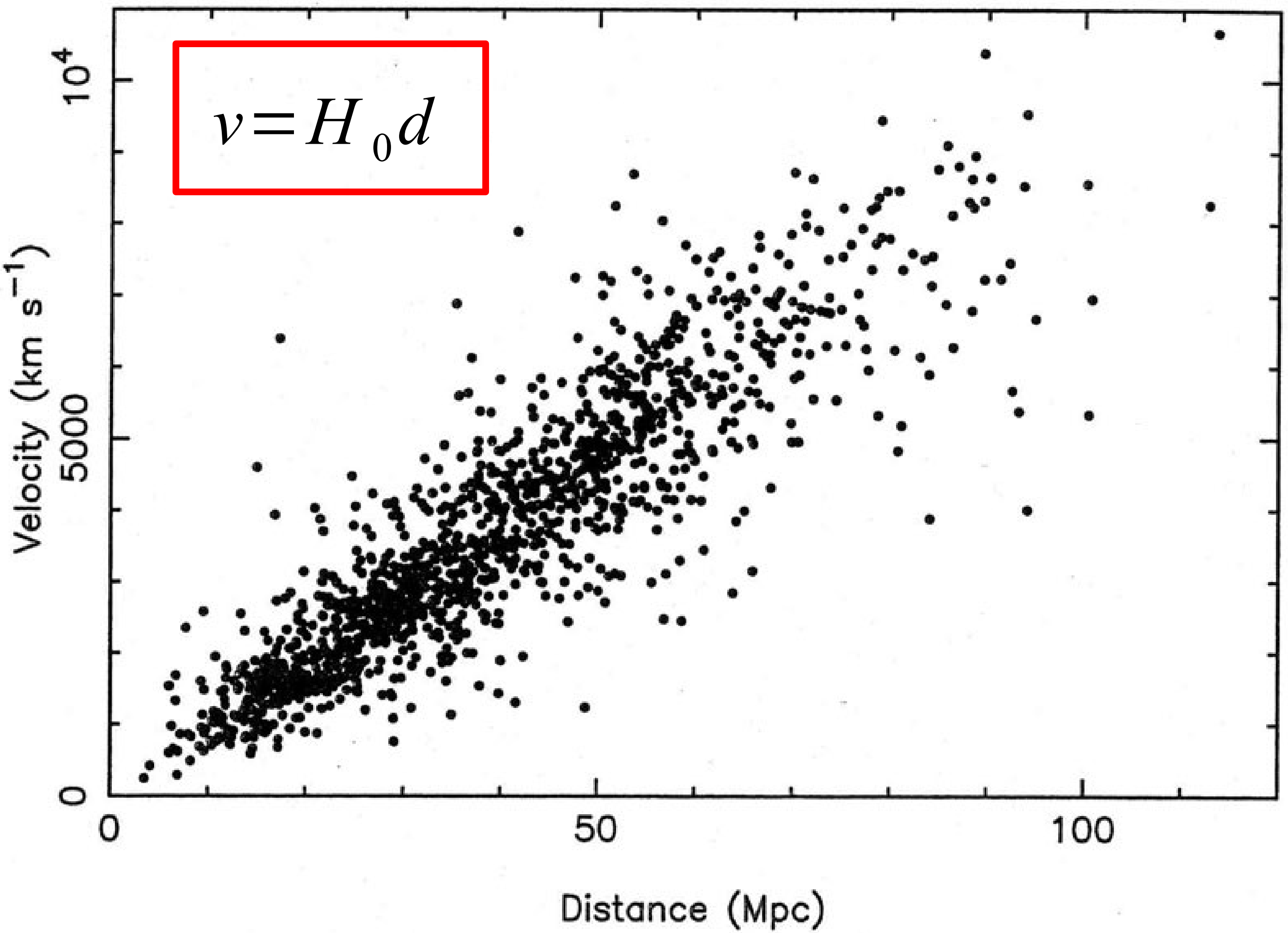
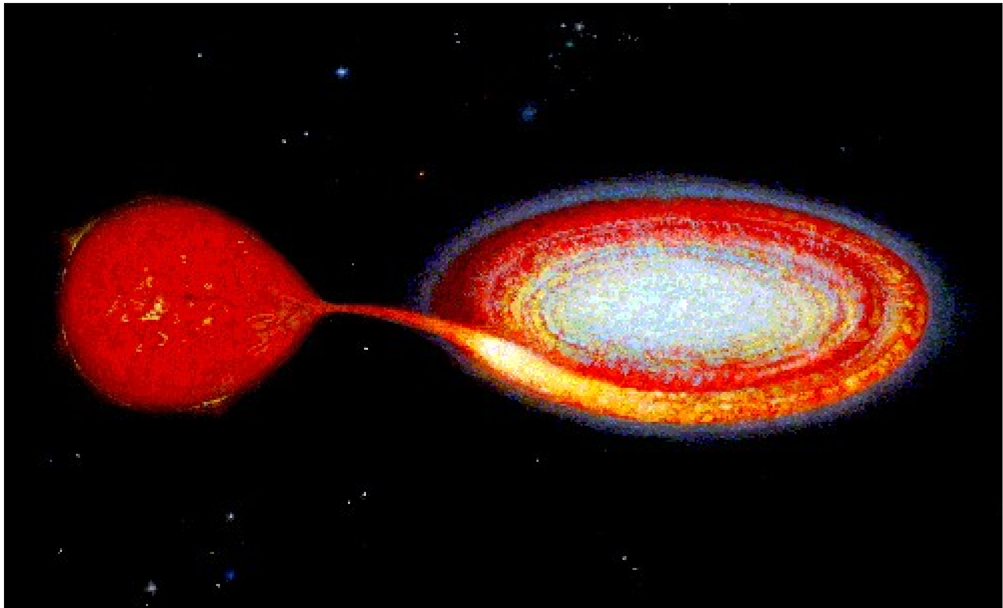


Figure 2.5 A plot of velocity versus estimated distance for a set of 1355 galaxies. A straight-line relation implies Hubble's law. The considerable scatter is due to observational uncertainties and random galaxy motions, but the best-fit line accurately gives Hubble's law. [The x-axis scale assumes a particular value of H_0.]

- If the Universe started with a Big Bang, then it had a very high expansion speed in its very early stages of evolution. But now the speed is not decreasing, the Universe is still expanding at a rate that is constantly increasing.
- Something is pushing it: Dark Energy!

We know this because we can use “standard candles” to measure the distance of an object: Supernovae Ia (see Eram's lecture)

Measuring the redshift we can understand how far they are and how fast they are moving



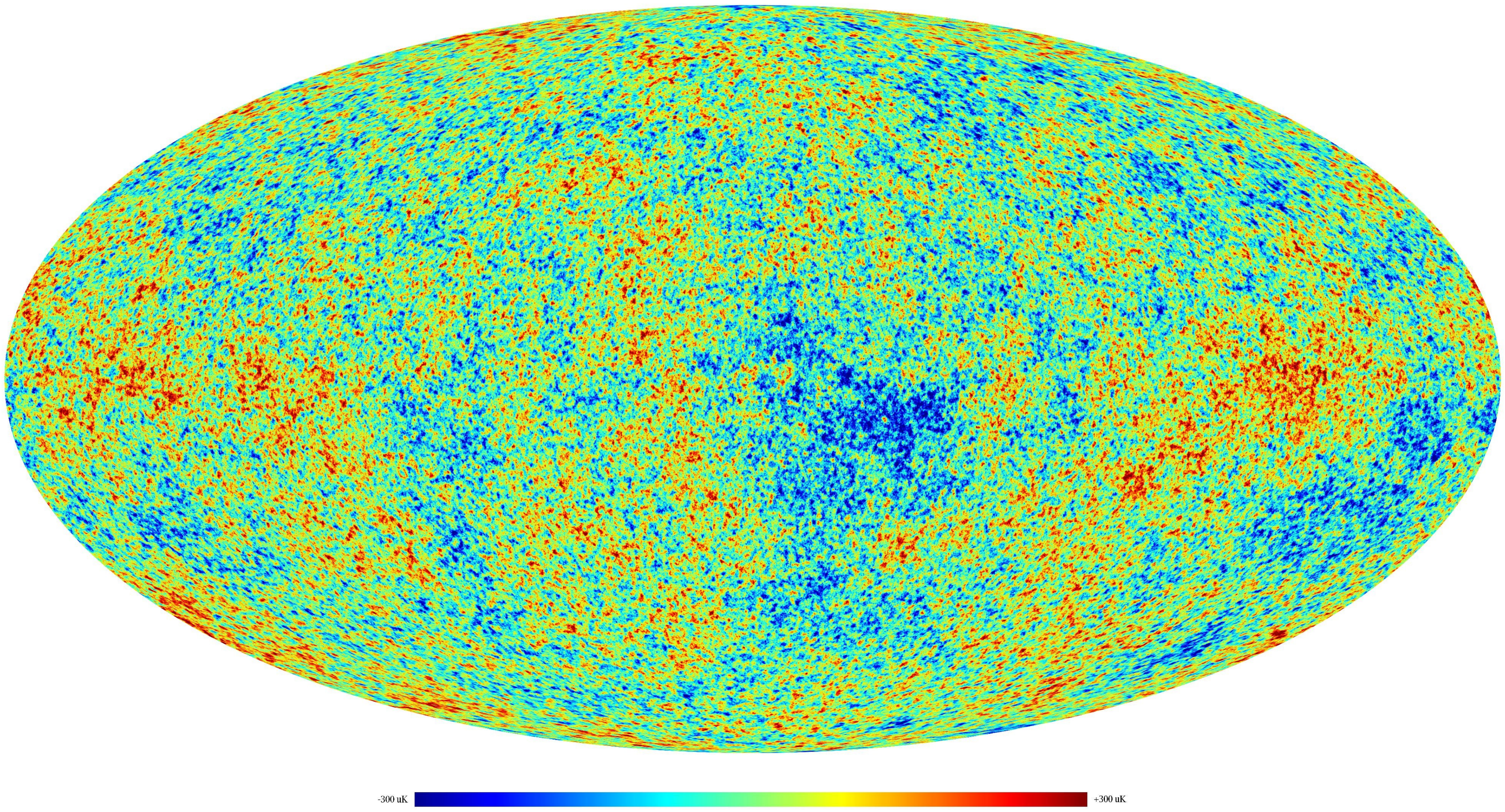
Three Problems Left...

- Flatness: the Universe appears to be flat
- Horizon: very far regions have the same temperature
- Magnetic Monopoles: we do not observe magnetic monopoloes

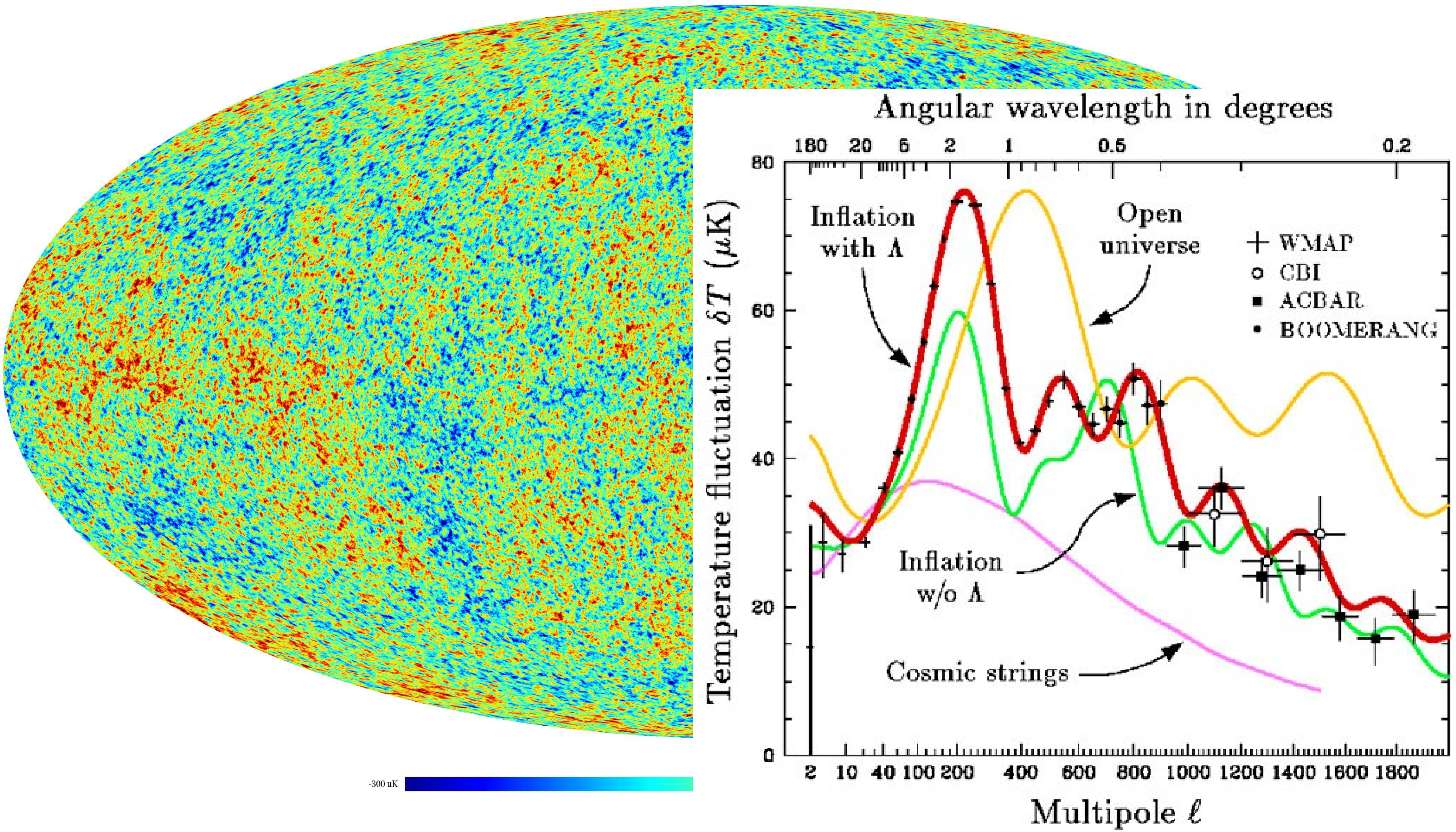
...and a prediction: the cosmic microwave background...

Think about cosmic neutrino background, you may get a free ticket to Stockholm ;)

Planck Satellite Measurment of CMB Fluctuation



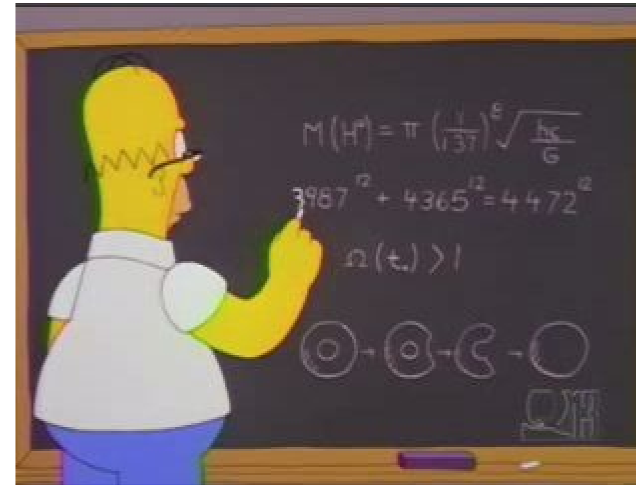
Planck Satellite Measurment of CMB Fluctuation



Einstein's Law of Gravity: curvature = mass

$$R_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Λ: Cosmological constant, initially introduced from Einstein to allow for a static Universe, then considered by himself as his biggest error, but...



Friedmann's equation (1)

$$H^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2}$$

$$\rho_c = \frac{3H^2}{8\pi G}$$ Critical density

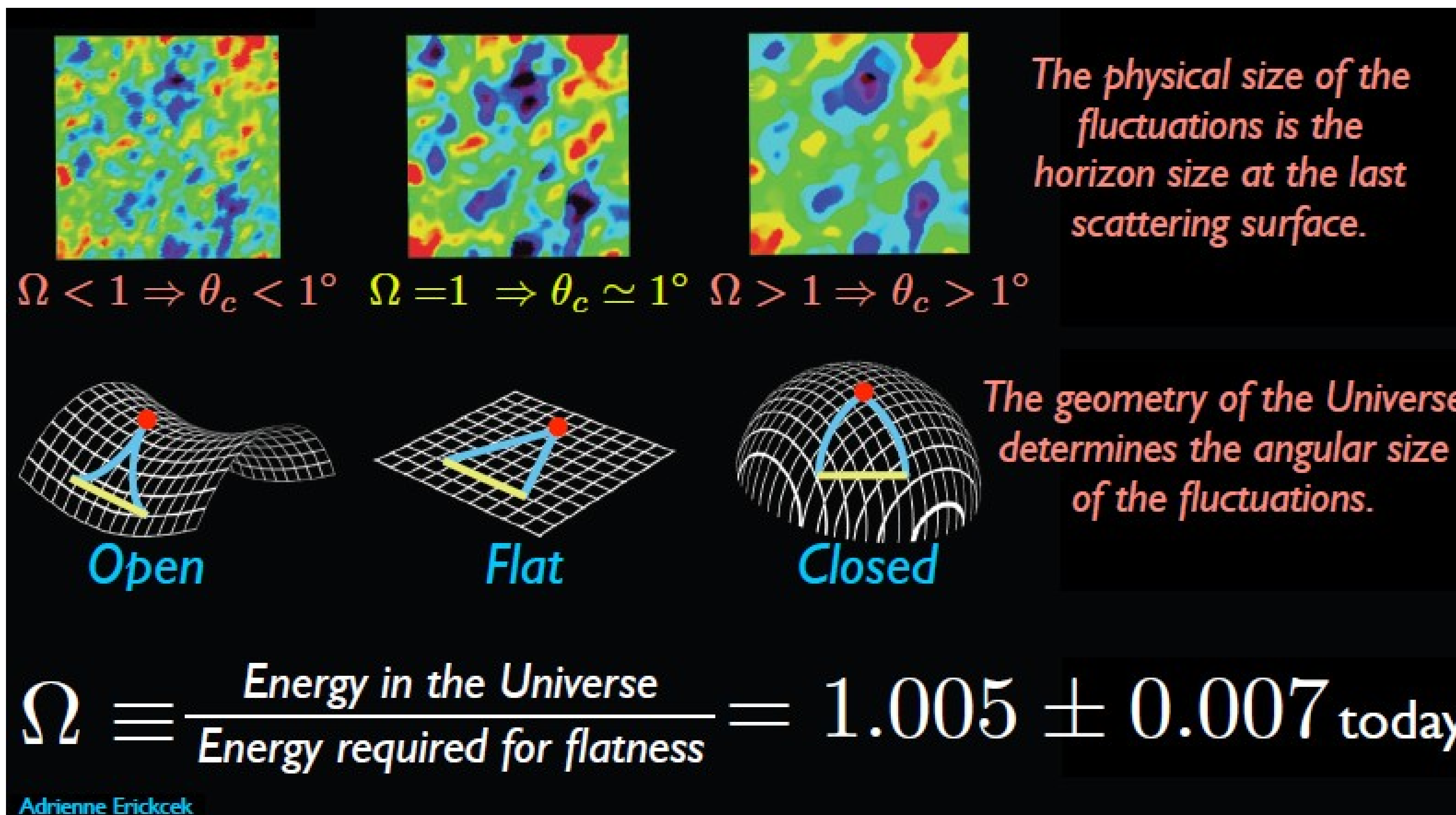
$$\frac{\rho_c}{\rho_0} = \Omega$$ Curvature

Friedmann's equation (2)

$$\frac{3a^2}{8\pi G} H^2 = \rho a^2 - \frac{3kc^2}{8\pi G}$$

$$\rho_c a^2 - \rho a^2 = \frac{-3kc^2}{8\pi G}$$

$$(\Omega^{-1} - 1)\rho a^2 = \frac{-3kc^2}{8\pi G}$$

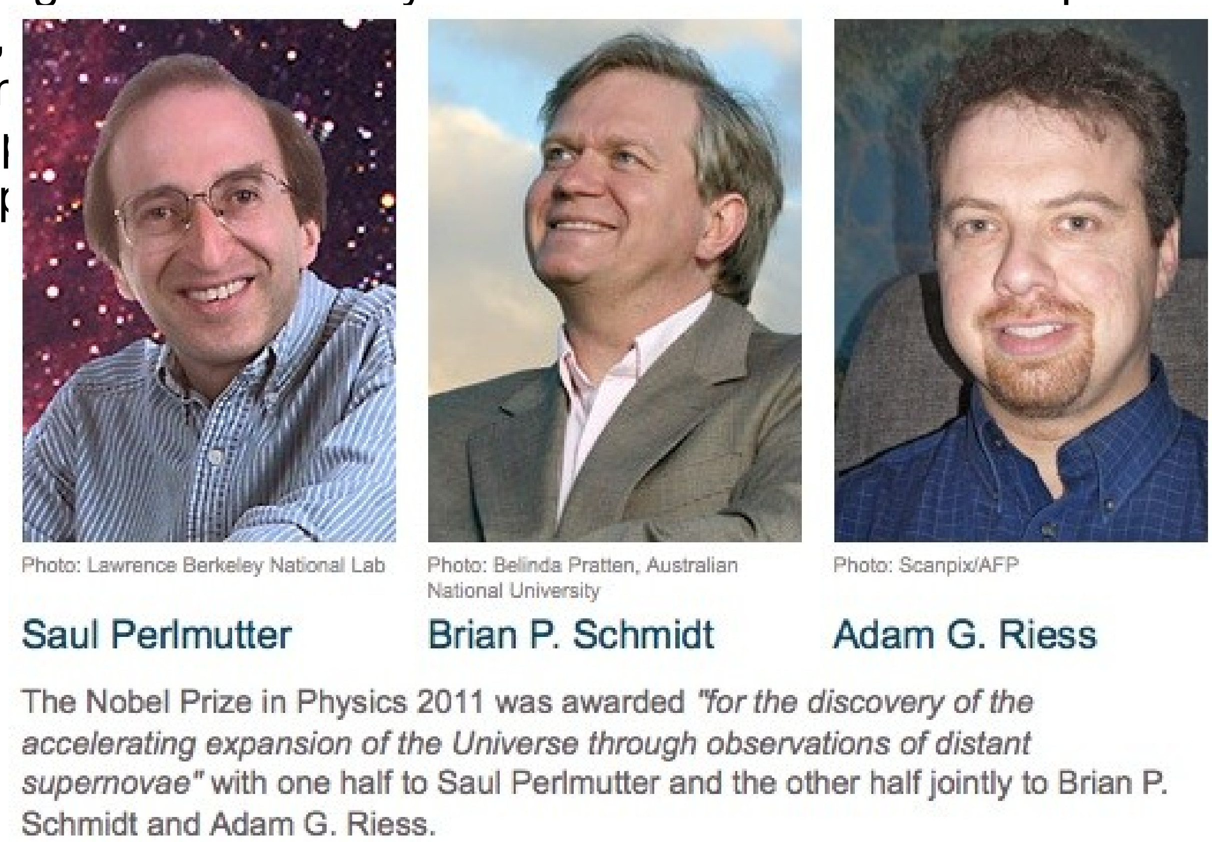


Inflation: flatness, horizon and monopoles are not an issue...

After the Big Bang there was a very intense acceleration of the expansion of the Universe, this has stretched the Universe making it flat (flatness problem), region that were very close have been moved apart at a very fast speed (horizon problem), and the very same expansion has pushed the magnetic monopoles toward the very “edge” of the Universe (monopoles problem).

Inflation: flatness, horizon and monopoles are not an issue...

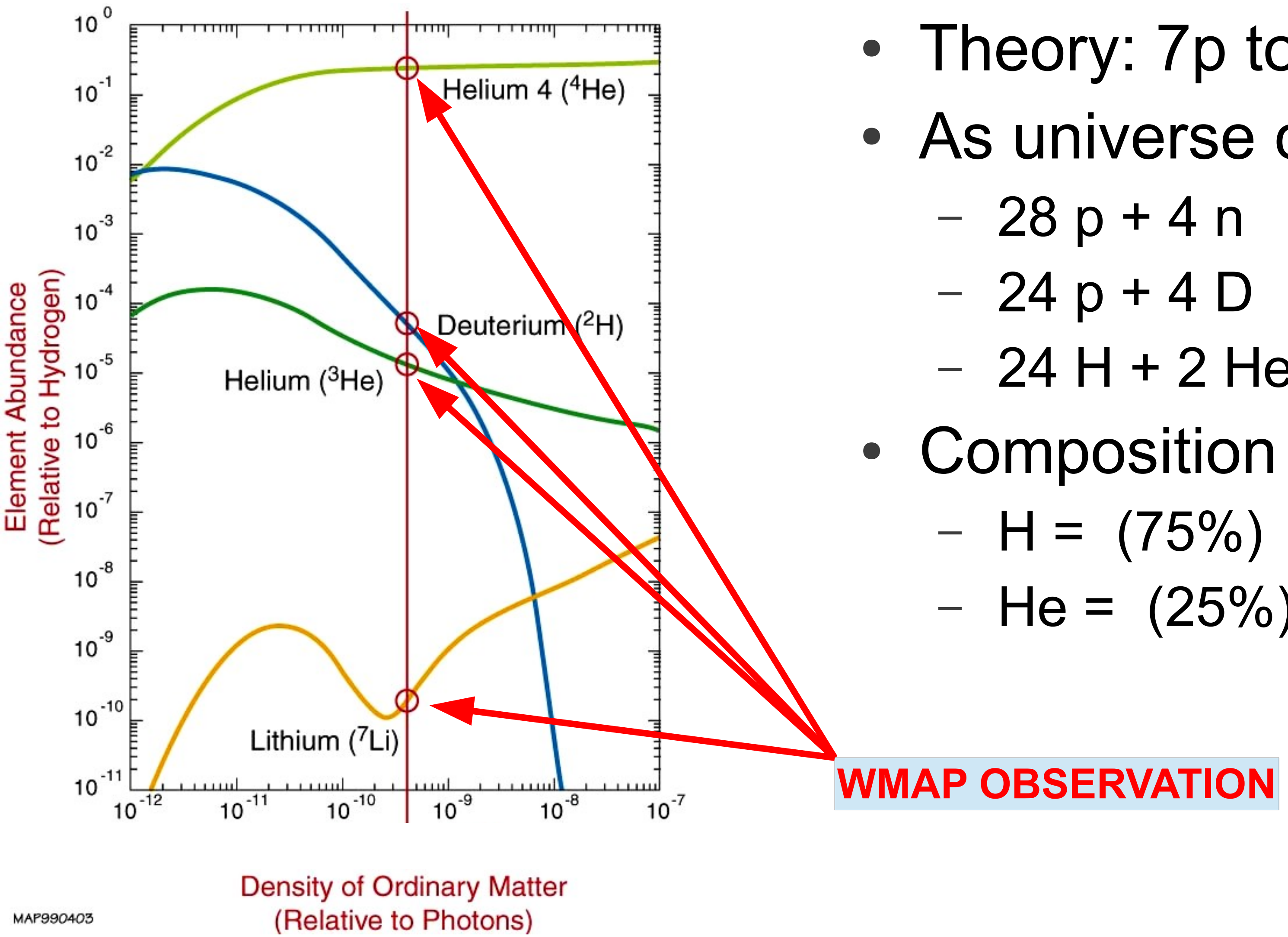
After the Big Bang there was a very intense acceleration of the expansion of the Universe, problem), regior st speed (horizon magnetic monop problem).



A Last prediction...

Predicted Abundance

Light Elements



- Theory: 7p to 1n
- As universe cools
  - 28 p + 4 n
  - 24 p + 4 D
  - 24 H + 2 He
- Composition by mass
  - H = (75%)
  - He = (25%)

The future of the Universe: the end of cosmology