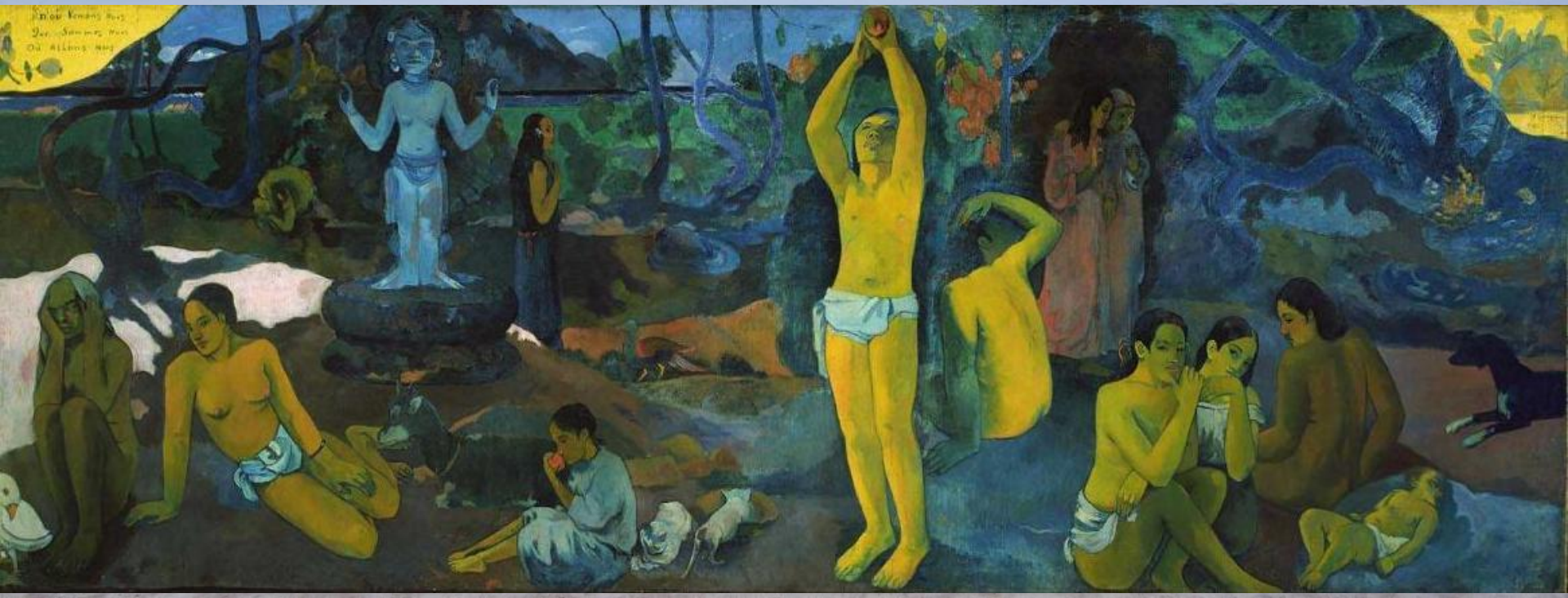
What are we?

Where do we come from?

Where are we going?

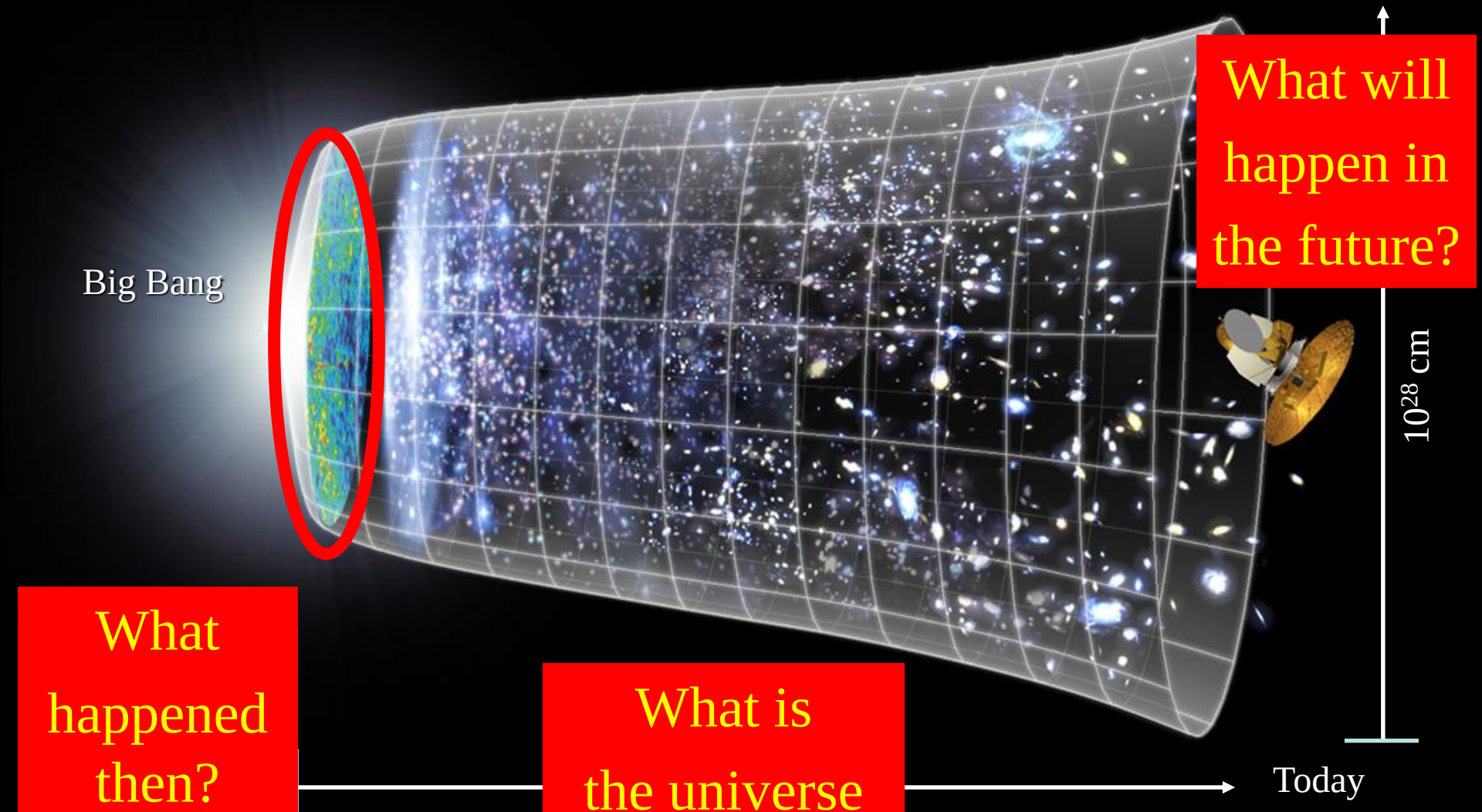


The aim of particle physics:
What is matter in the Universe made of?

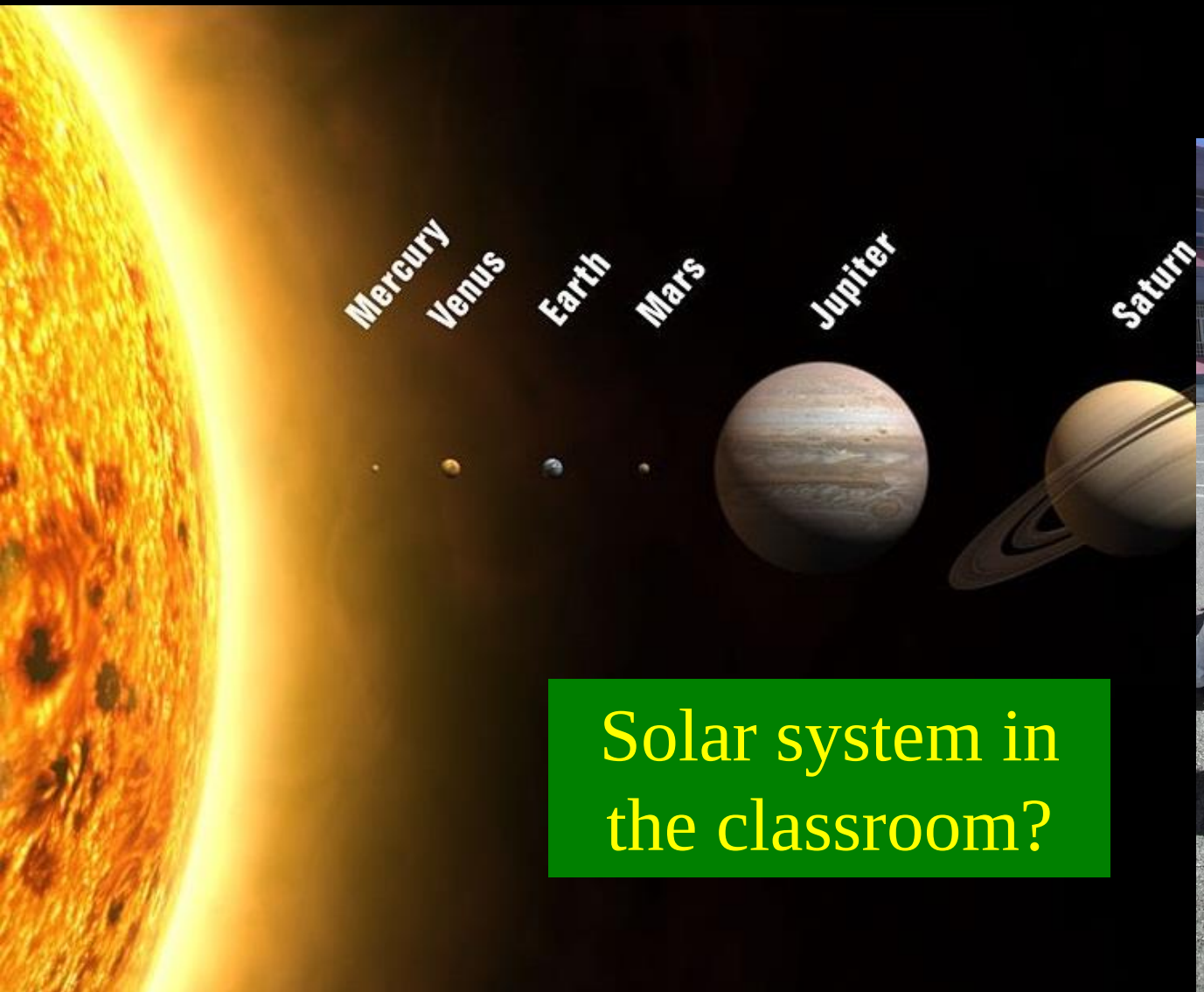
John Ellis

KING'S College LONDON

Playing with the Universe

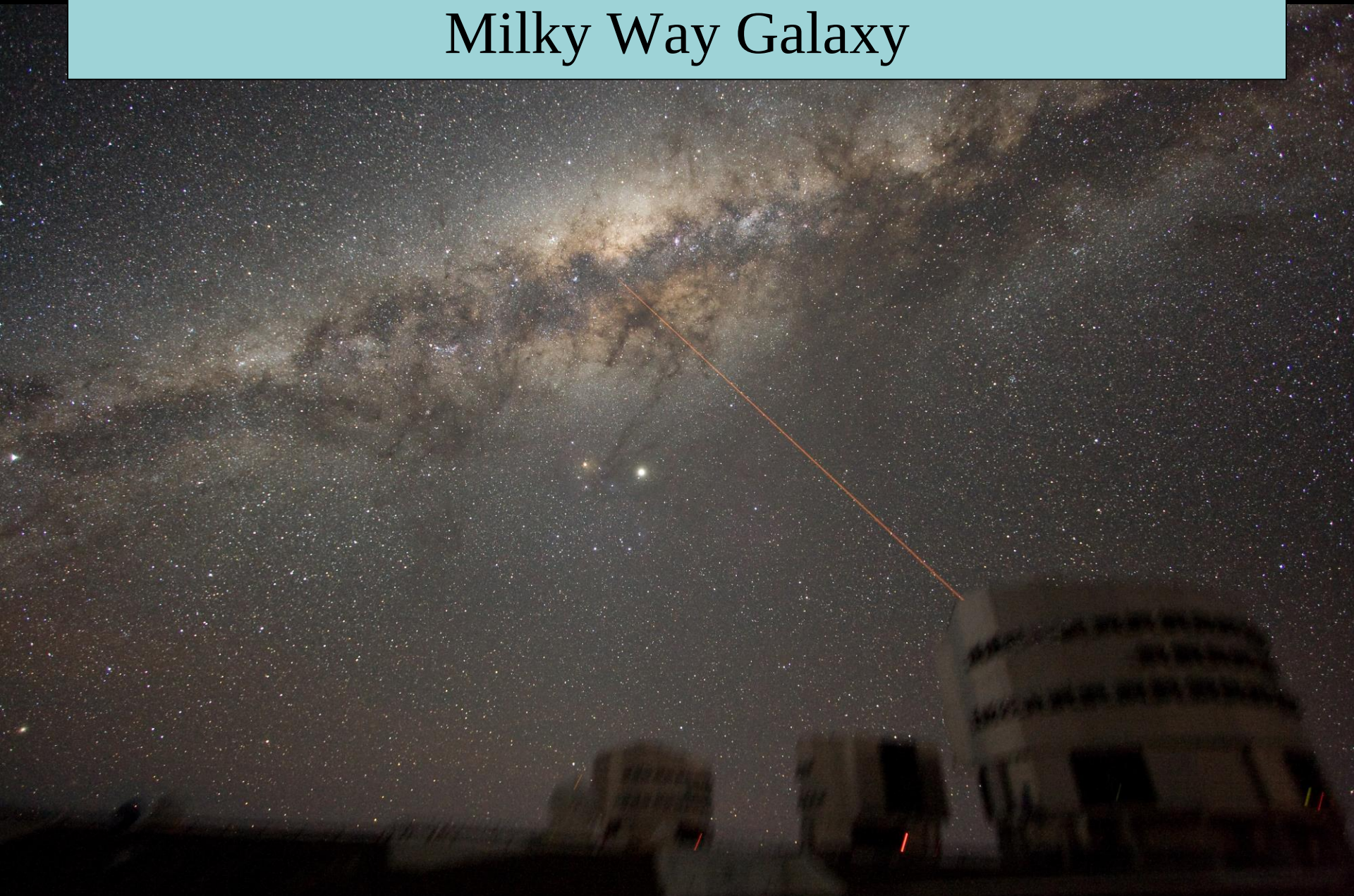


The Copernican Revolution:
The Earth is not the Centre of the Universe



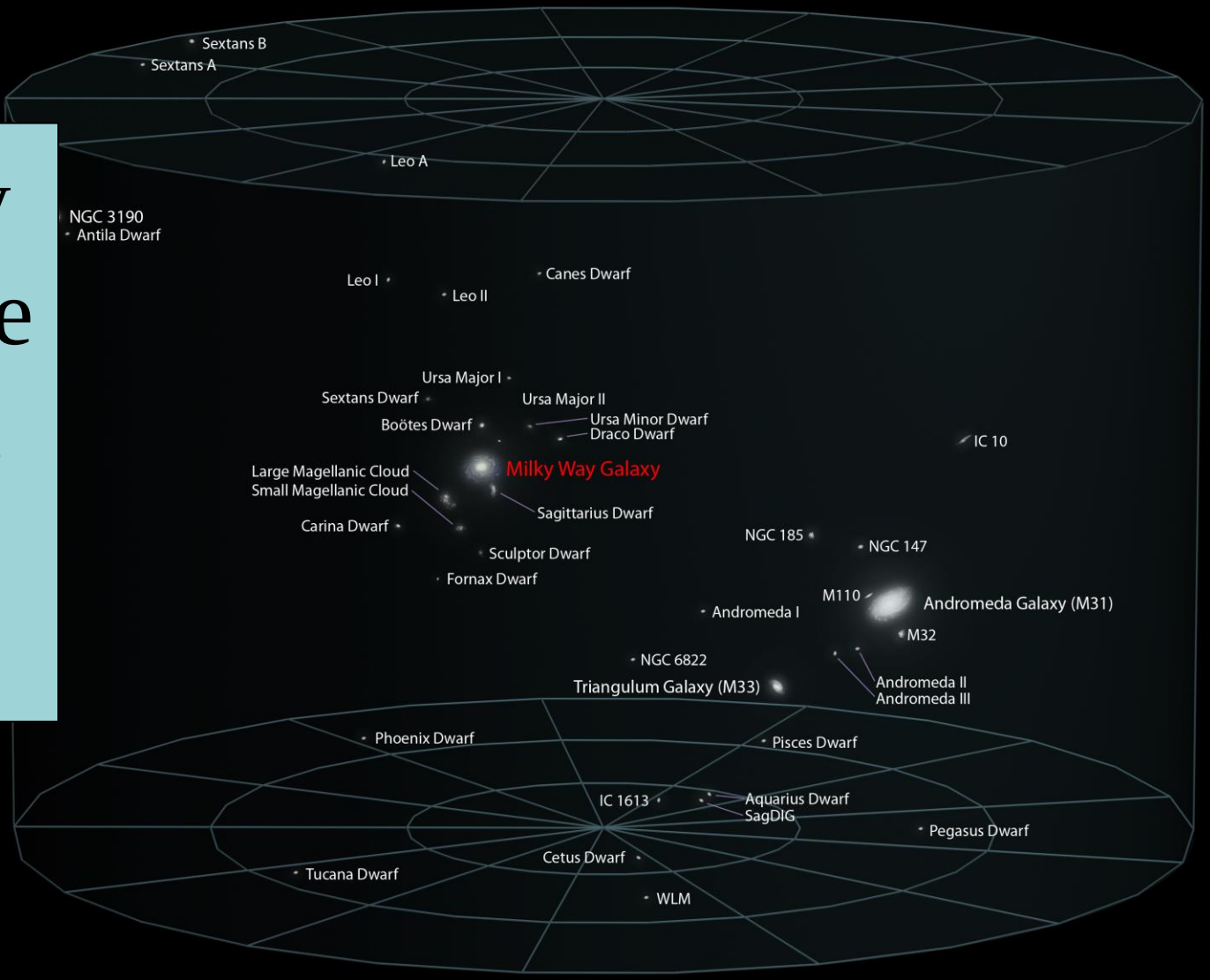
Solar system in the classroom?

The Sun is One of 100,000,000,000 Stars in the Milky Way Galaxy

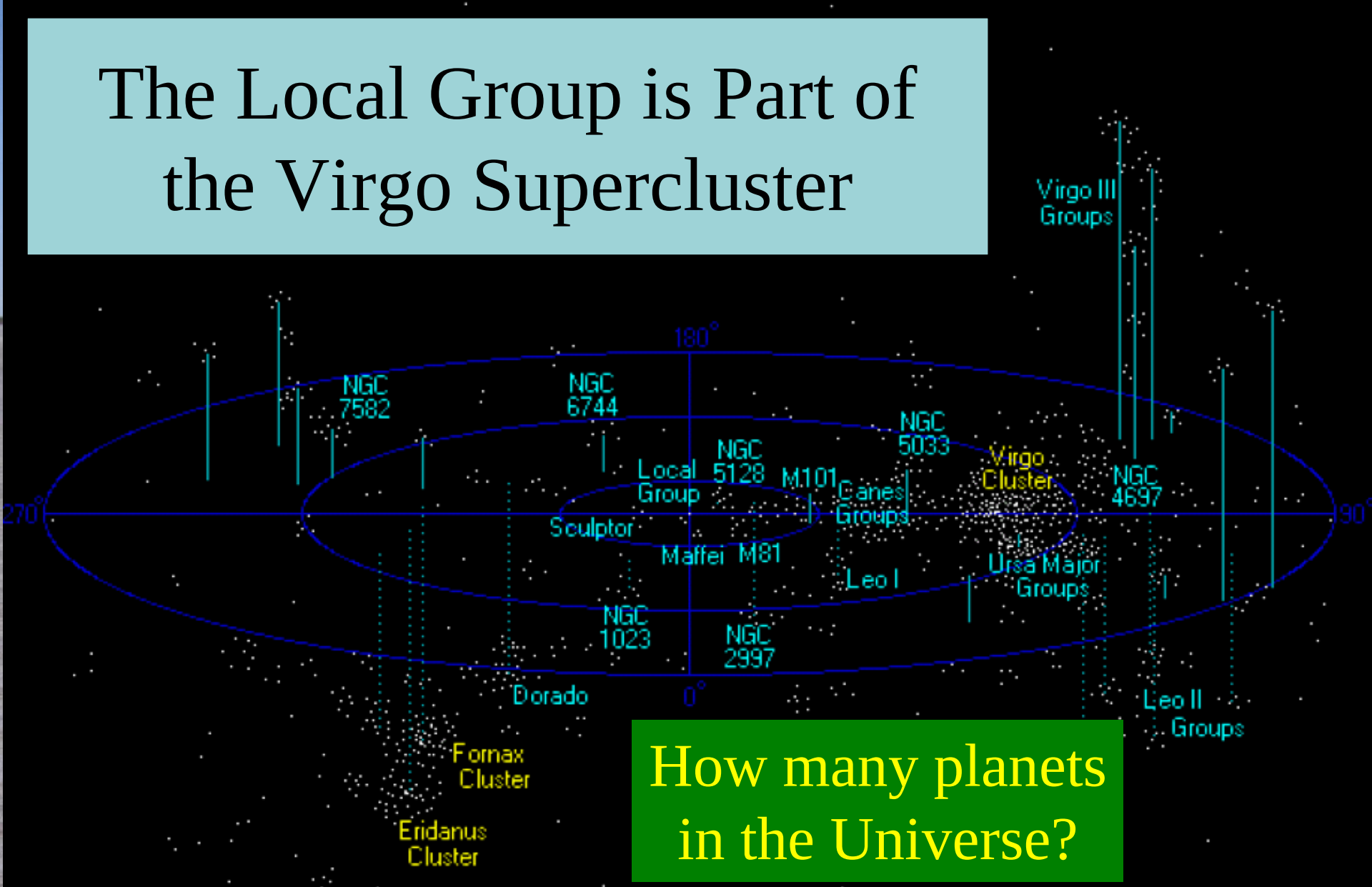


Local Galactic Group

The Milky Way is One of a Local Group of Galaxies



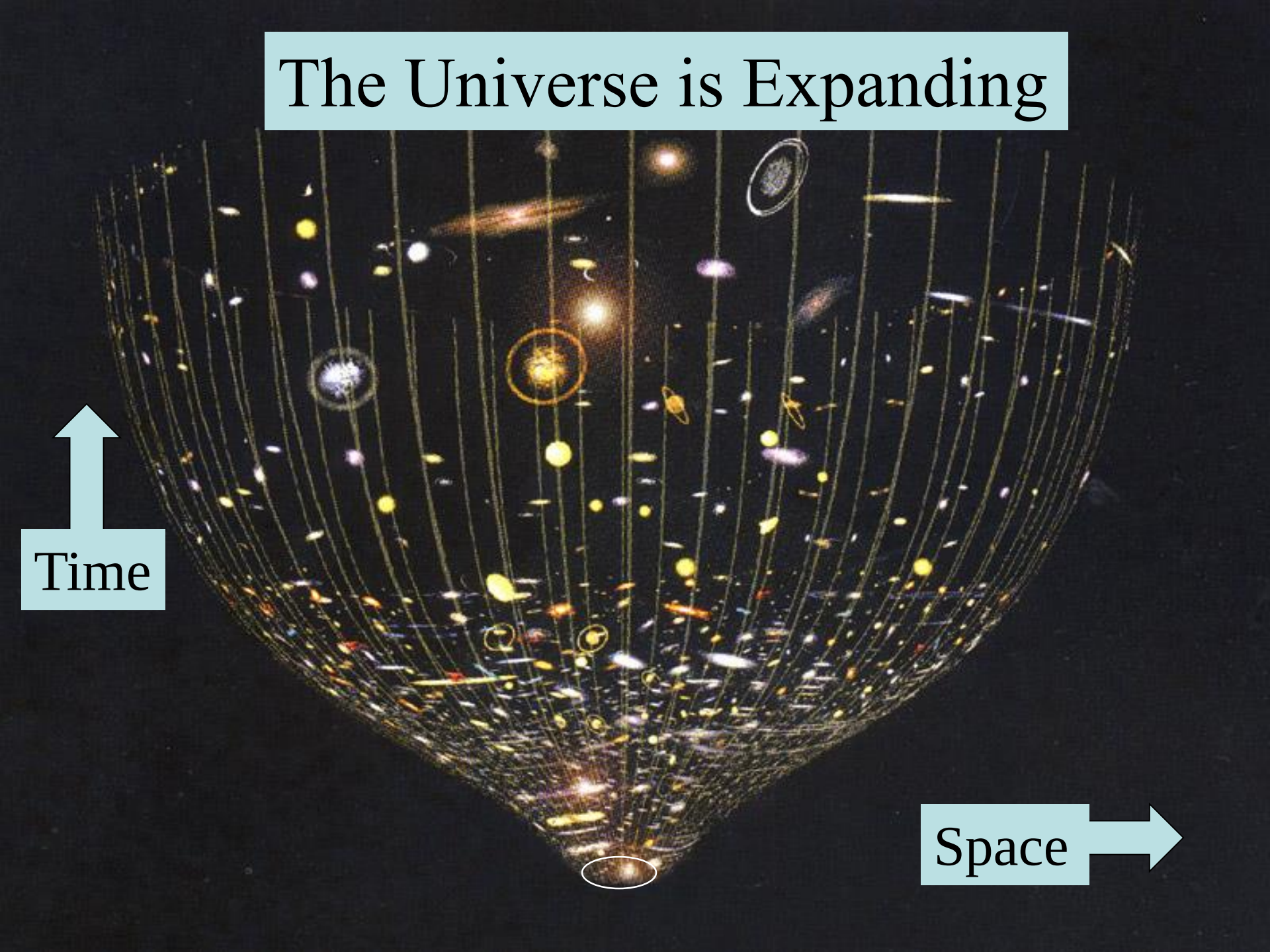
The Local Group is Part of the Virgo Supercluster



How many planets in the Universe?

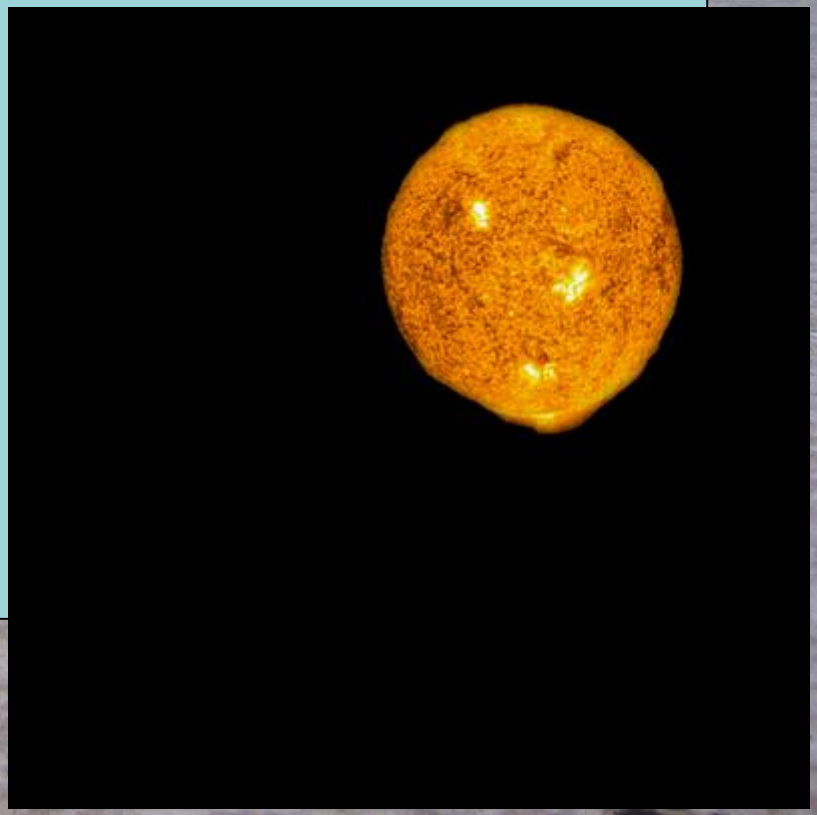
A hundred thousand million galaxies in the visible Universe

The Universe is Expanding



The Universe is Expanding

- **The sky is dark at night! (Olbers' paradox)**
- If the Universe has been behaving the same for ever (steady-state)
- In every direction there would be some star
- All the Universe would be as hot as the surface of a star



Demonstration with lights?

The Universe is Expanding

- Edwin Hubble discovered that the light from distant galaxies has been red-shifted
- This effect grows with distance
- The effect is due to the expansion of light waves as the Universe expands
- The most distant galaxies:

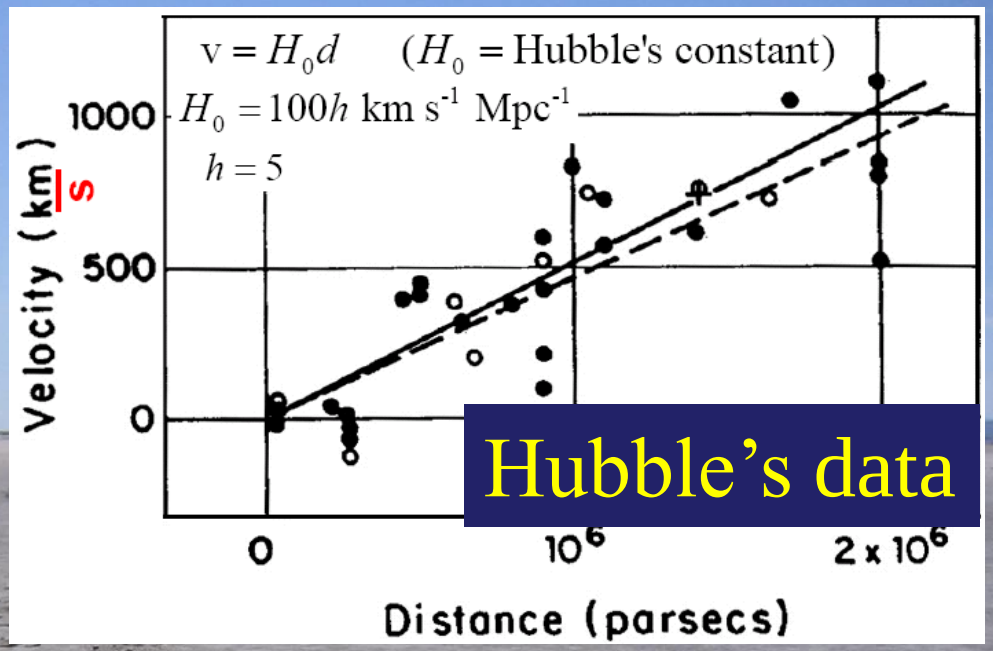
  ~ 10,000,000,000 light-years away

  Seen as ~ 10,000,000,000 years ago
- **The same physics as here and now!**

Demonstration with Döppler effect?

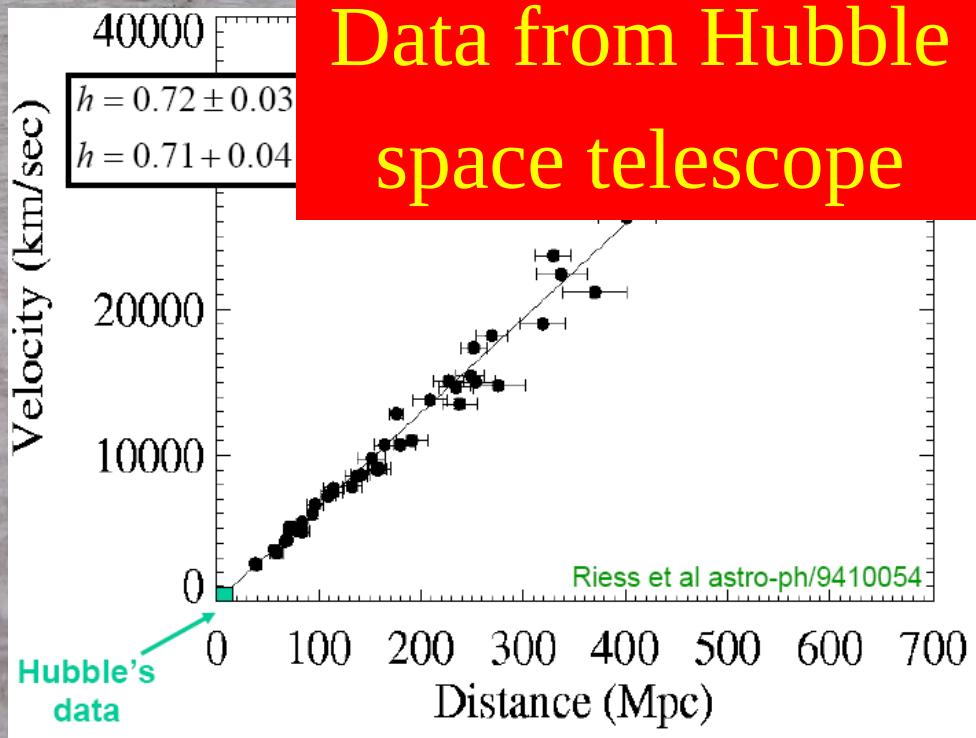
The Expansion of the Universe

Hubble, the basketball player



Hubble's data

Data from Hubble space telescope



The Universe is Expanding

- The galaxies are separating

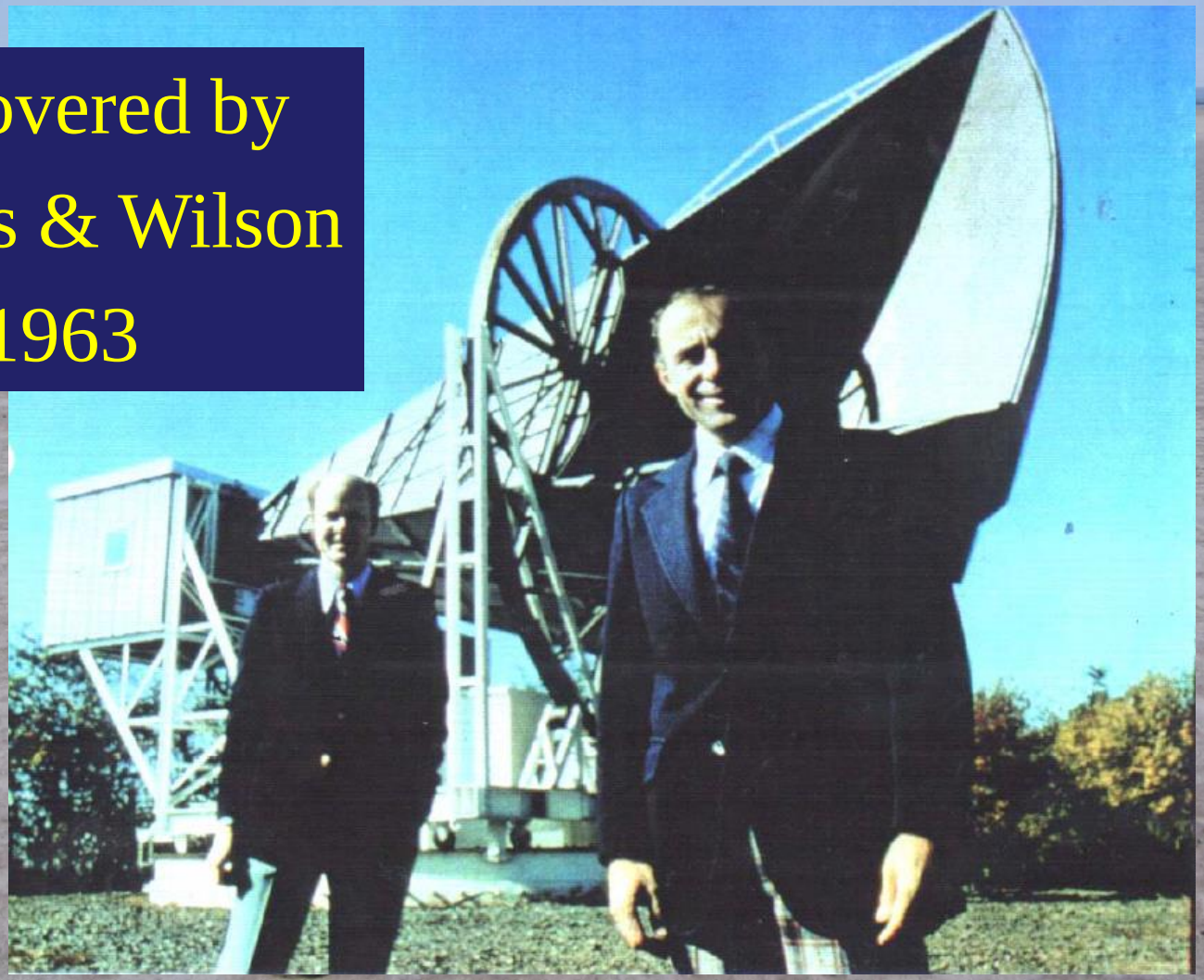
  the expansion discovered by Hubble

- The Universe was once 3000 times smaller and hotter than today

  the cosmic microwave background

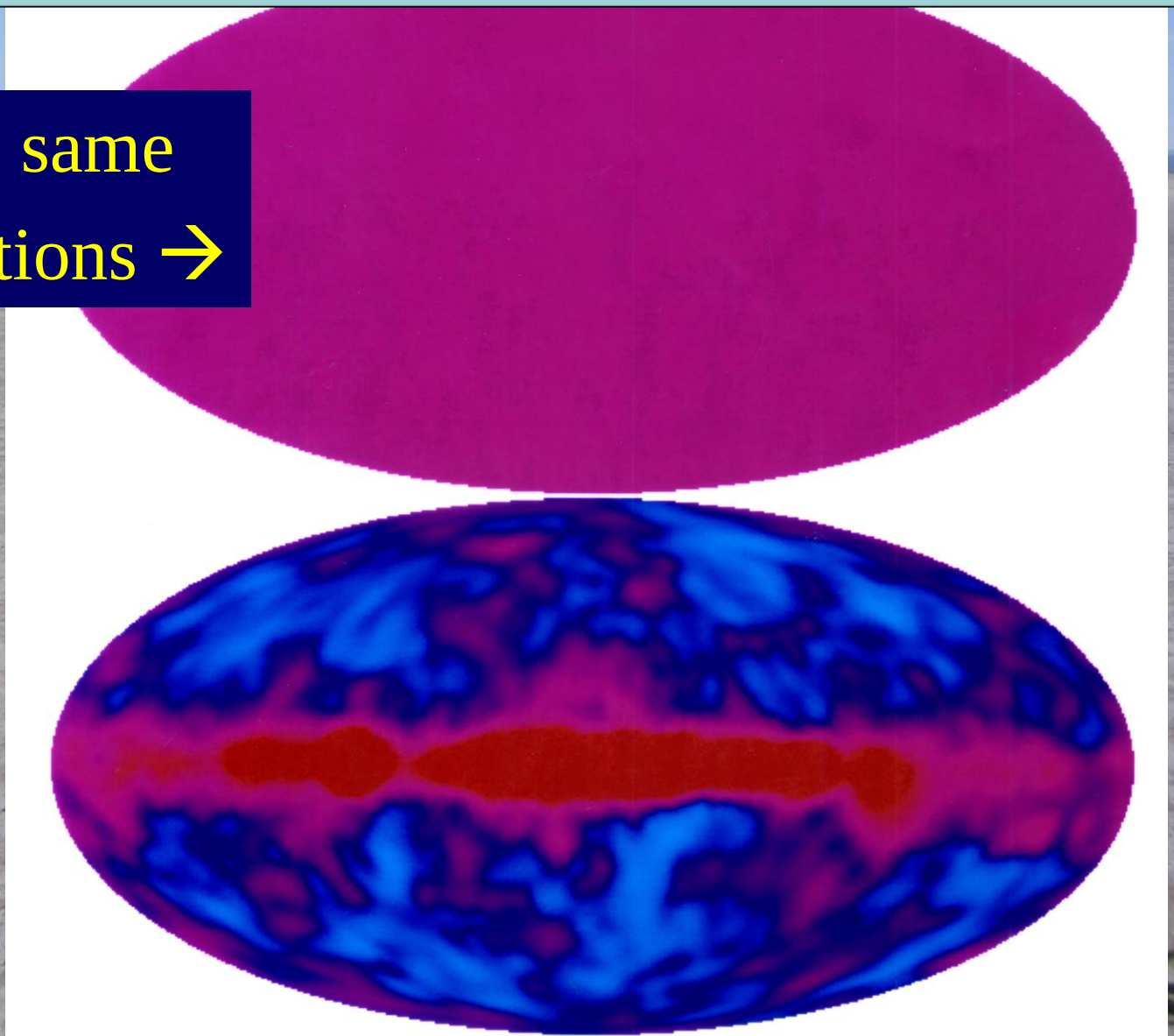
The Cosmic Microwave Background

Discovered by
Penzias & Wilson
1963



The Cosmic Microwave Background

Almost the same
in all directions →



Pigeon Pollution?

- Looked for alternative explanations of signal
- Pigeons were nesting
- Trapped and removed
- Signal still there
- White noise on old TV

The Cosmic Microwave Background

- We are bathed in microwave radiation

  with a temperature of ~ 2.7 degrees above absolute zero

- *Almost* the same in all directions

  we are moving at ~ 700 km/sec relative to it

- There are small fluctuations in this radiation

  ~ 1 / 100,000

- Originated in the very young Universe?

  when it had an age of
  0.000,000,000,000,000,000,000,000,000,000, 001 seconds?

The Universe is Expanding

- The galaxies are separating

  the expansion discovered by Hubble

- The Universe was once 3000 times smaller and hotter than today

  → the cosmic microwave background

- The Universe was once 1,000,000,000 times smaller and hotter than today

  the light elements originated in the Big Bang

Cosmological Nucleosynthesis

- The Universe contains ~ 24% of Helium 4

  and smaller amounts of Deuterium, Helium 3, Lithium 7

- Manufactured by nuclear reactions in the early Universe

  when it was 1,000,000,000 times smaller and hotter than today

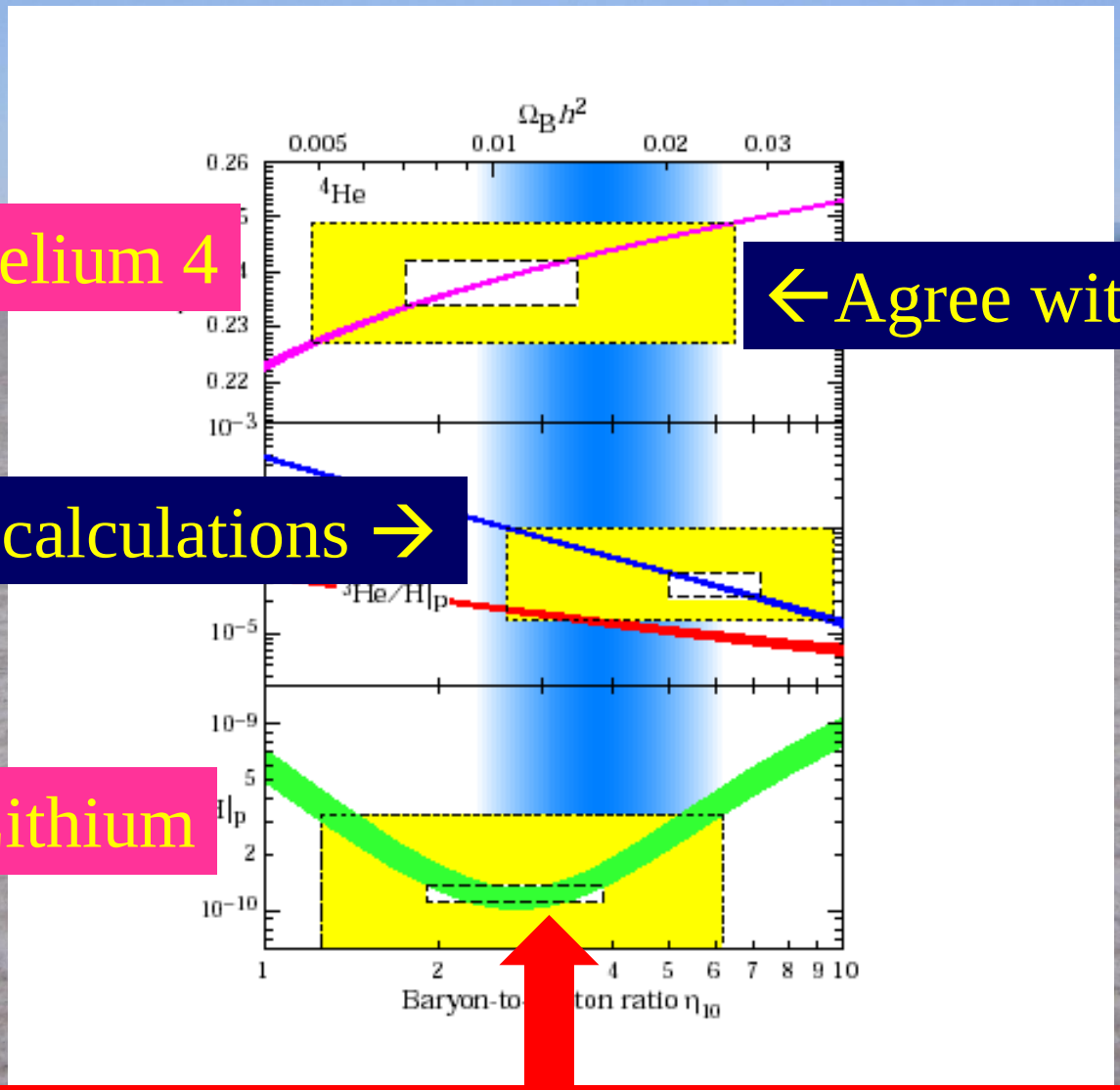
- The abundances depend on the amount of matter in the Universe

  not enough to stop the expansion, or to make galaxies

- The abundances also depend on the number of types of elementary particles

  measured at particle accelerators

The Abundances of the Light Elements



Helium 4

←Agree with the data

Theoretical calculations →

Lithium

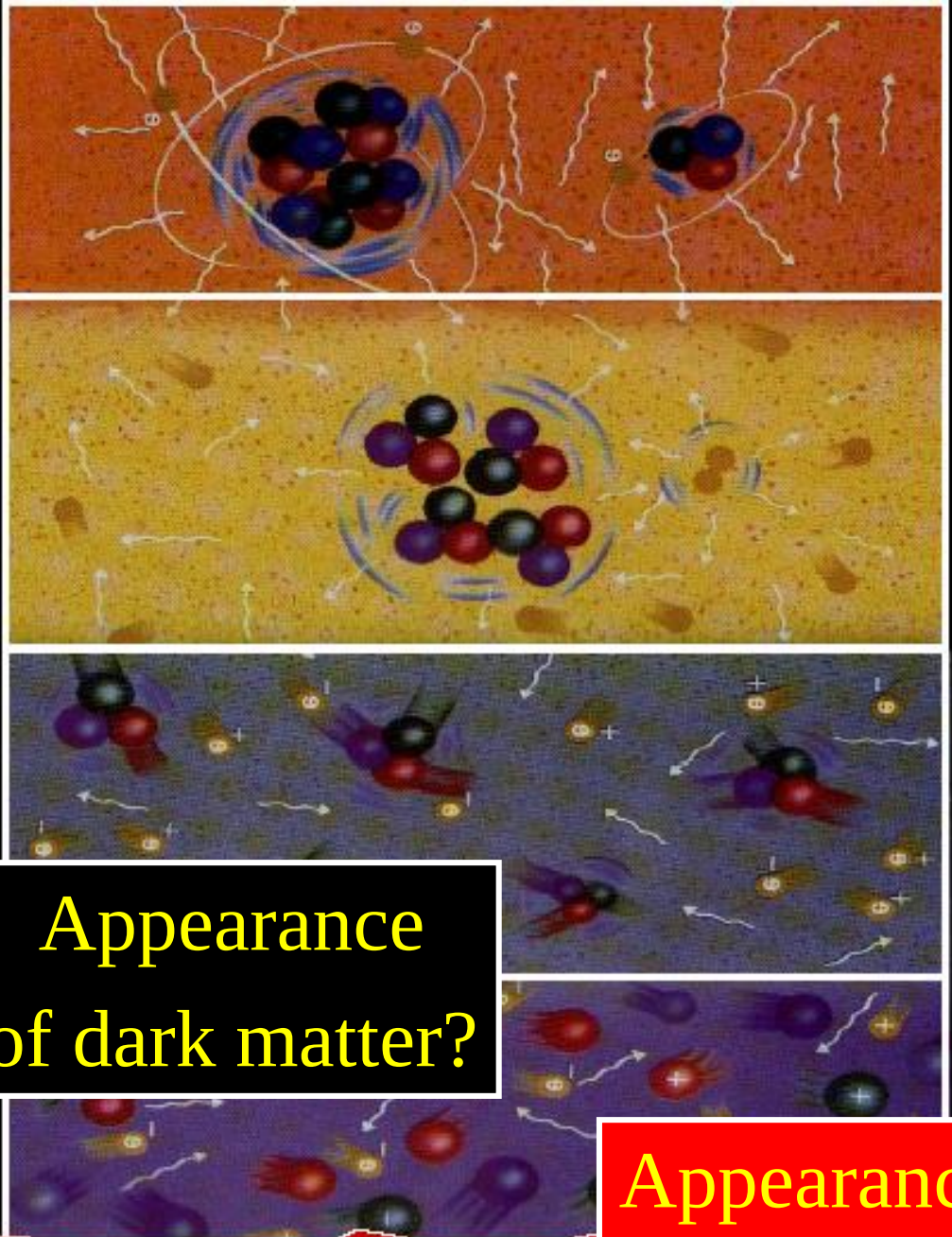
Not enough normal matter to stop expansion of the Universe

300,000 years

3 minutes

1 micro-second

1 pico-second



Formation of atoms

Formation of nuclei

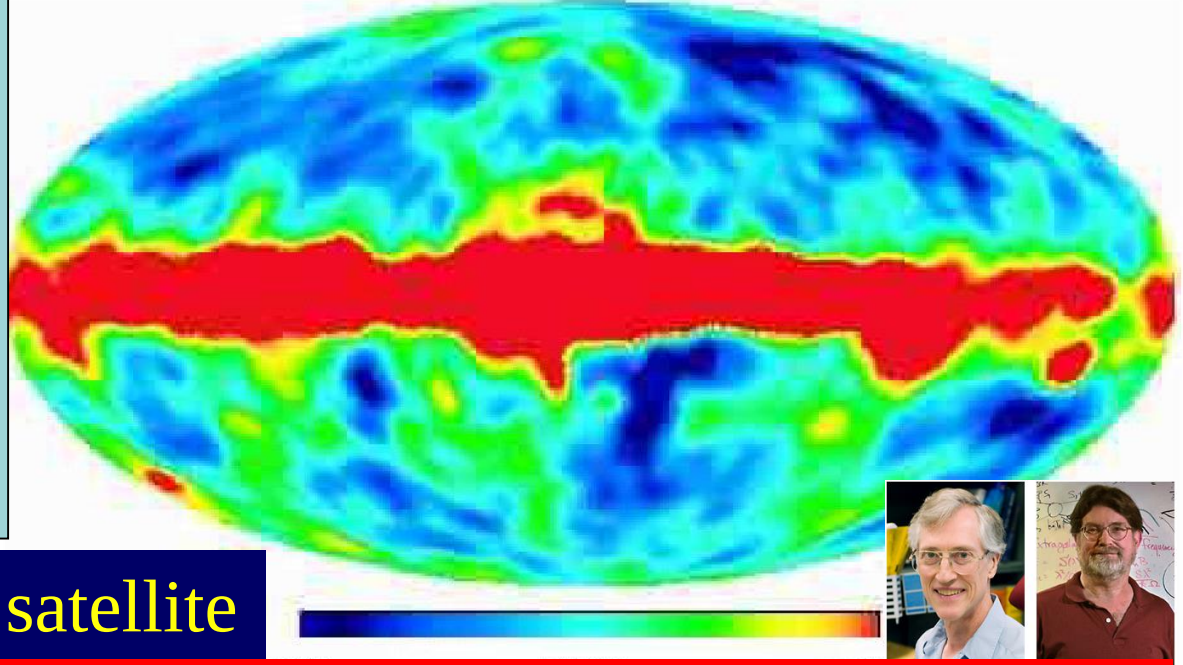
Formation of protons & neutrons

Appearance of mass?

Appearance of dark matter?

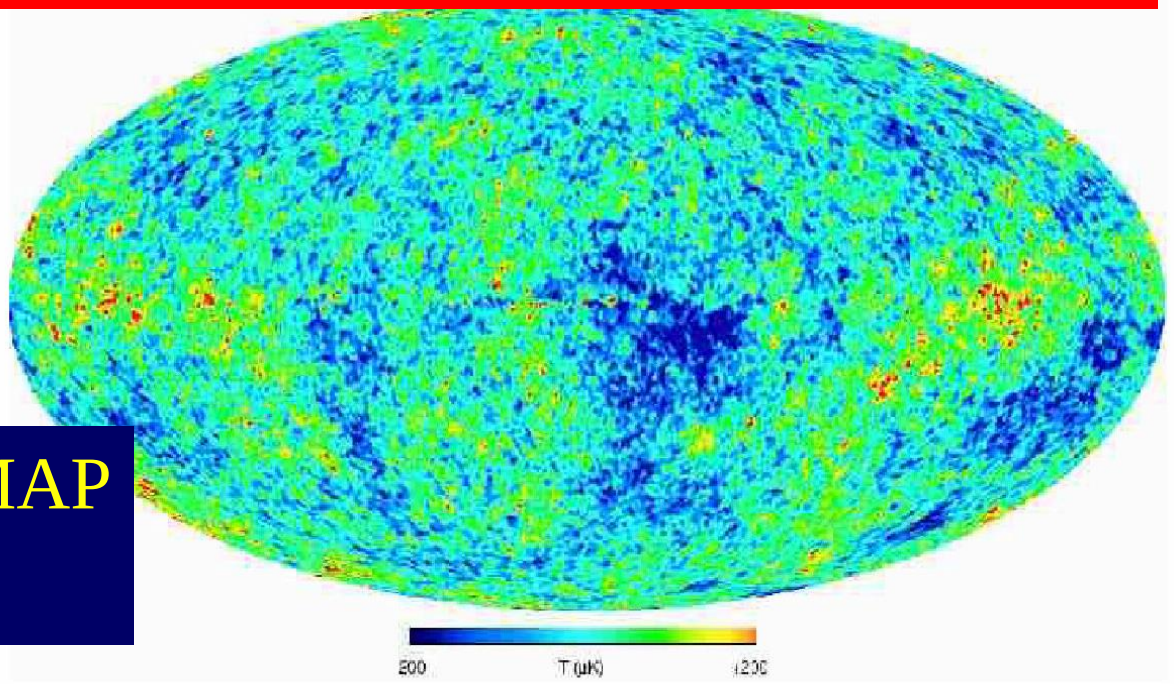
Appearance of matter?

More on the Cosmic Microwave Background



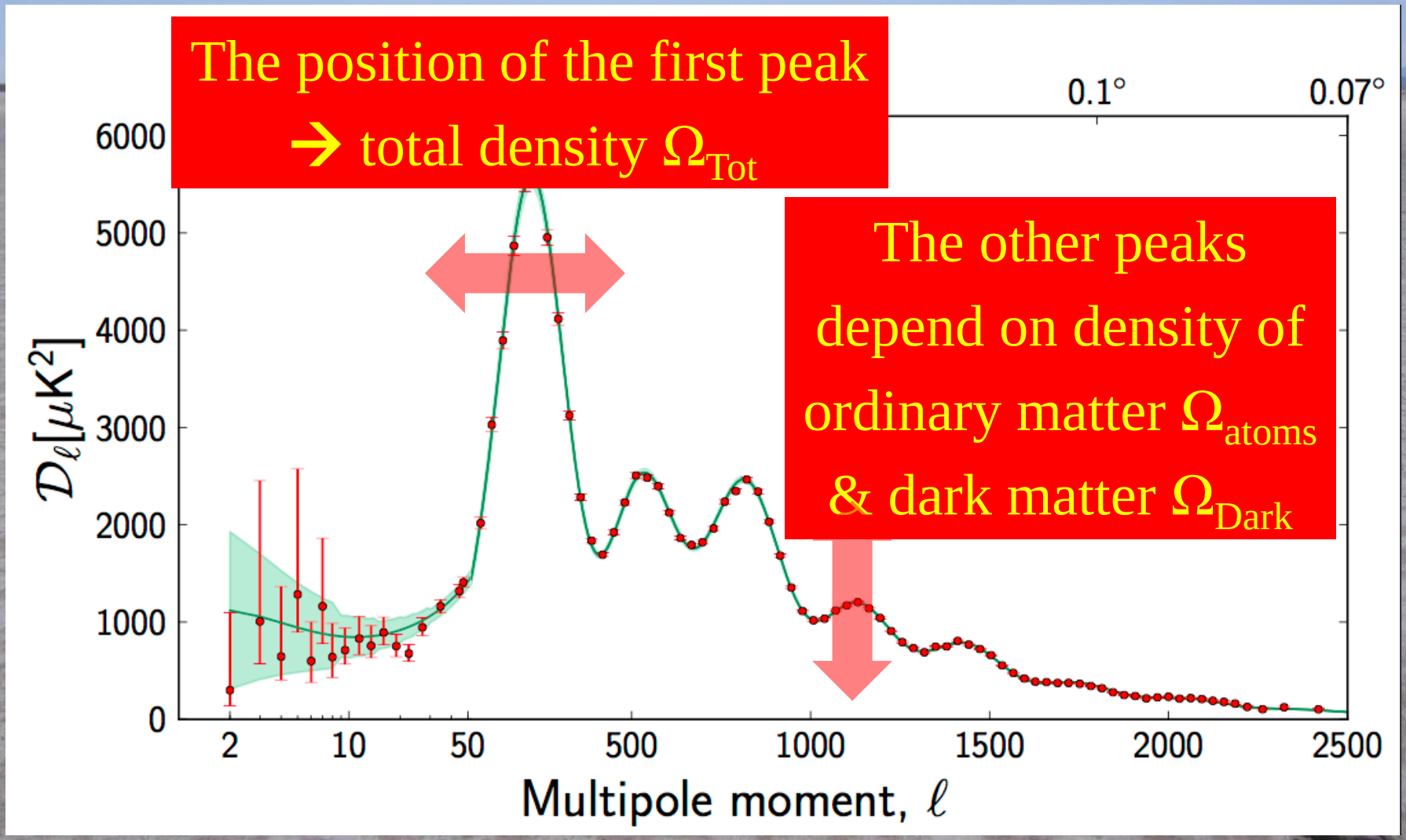
According to COBE satellite

Nobel Prize 2006: John Mather & George Smoot



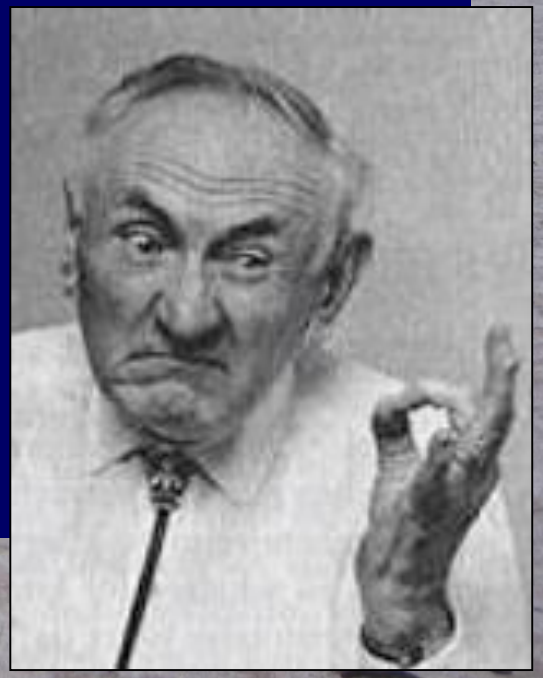
According to WMAP satellite

The Spectrum of Fluctuations in the Cosmic Microwave Background



The Dark Matter Hypothesis

- Motivated by Fritz Zwicky's observations of the Coma galaxy cluster
- The galaxies move too quickly
- The observations require a stronger gravitational field than provided by the visible matter
- **Dark matter?**



The Rotation Curves of Galaxies

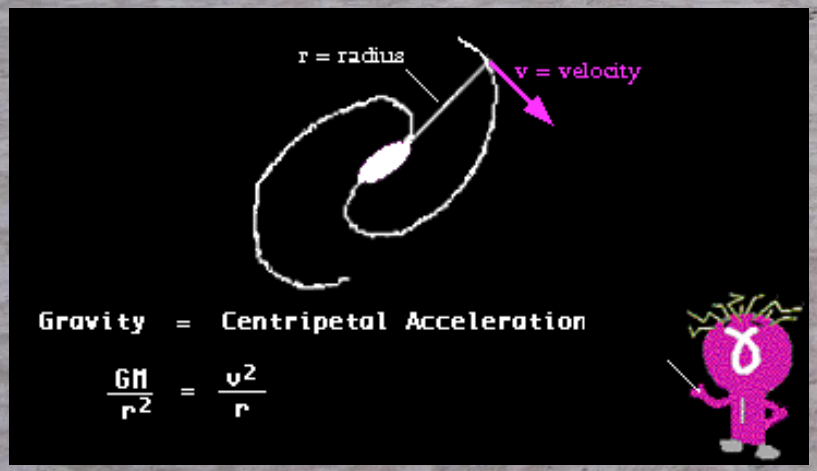
- Measured by Vera Rubin
- The stars also orbit ‘too quickly’
- Her observations aslo required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**

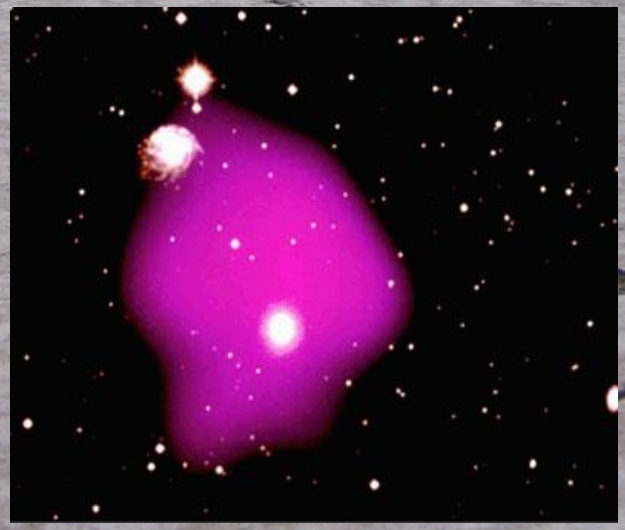
Evidence for Dark Matter

•Galaxies rotate more rapidly
•than allowed by centripetal
•force due to visible matter

•X-ray emitting gas held
•in place by extra
•dark matter

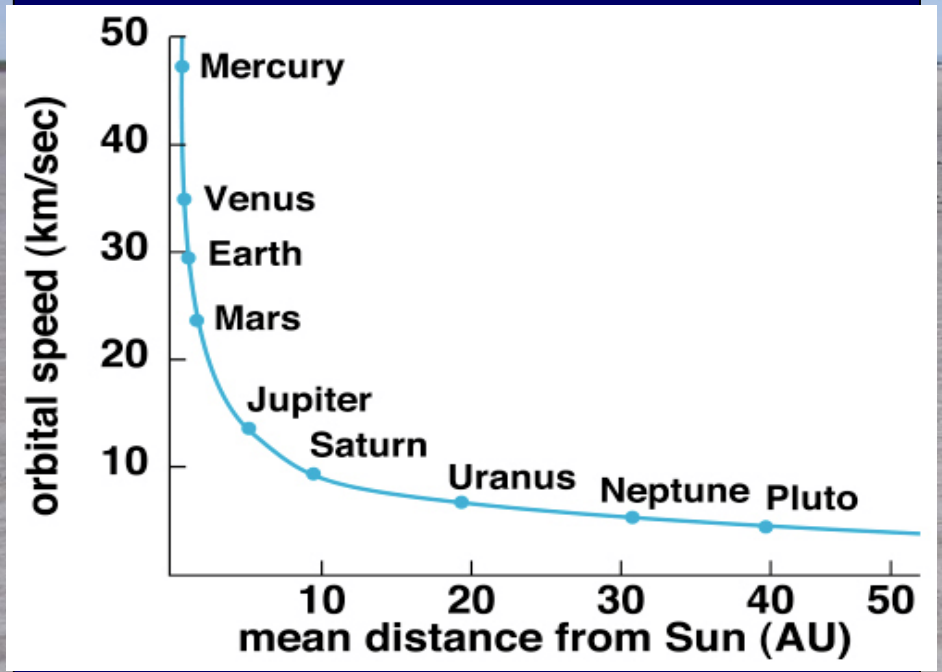
•Even a
• ‘dark galaxy’
•without stars





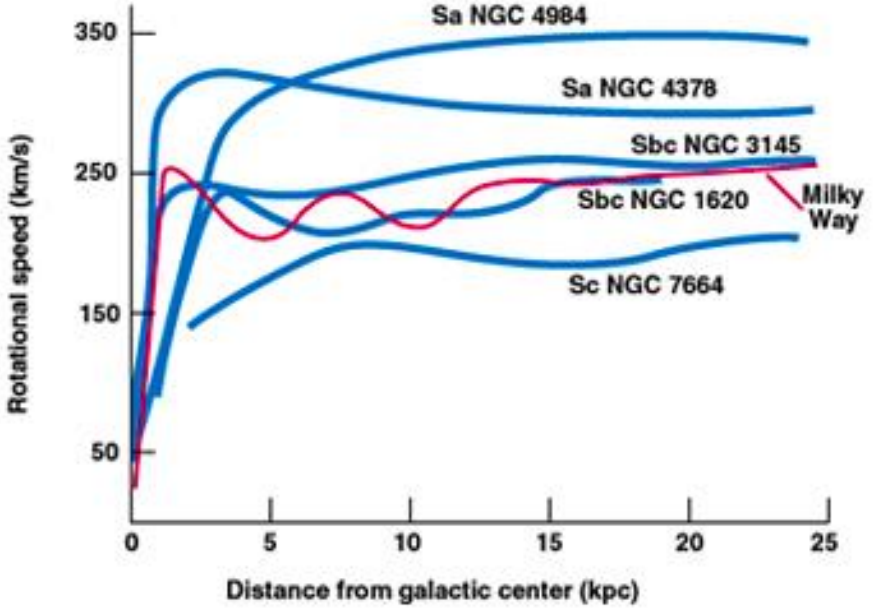
Rotation Curves

- In the Solar System



- The velocities decrease with distance from Sun
- Mass lumped at centre

- In galaxies

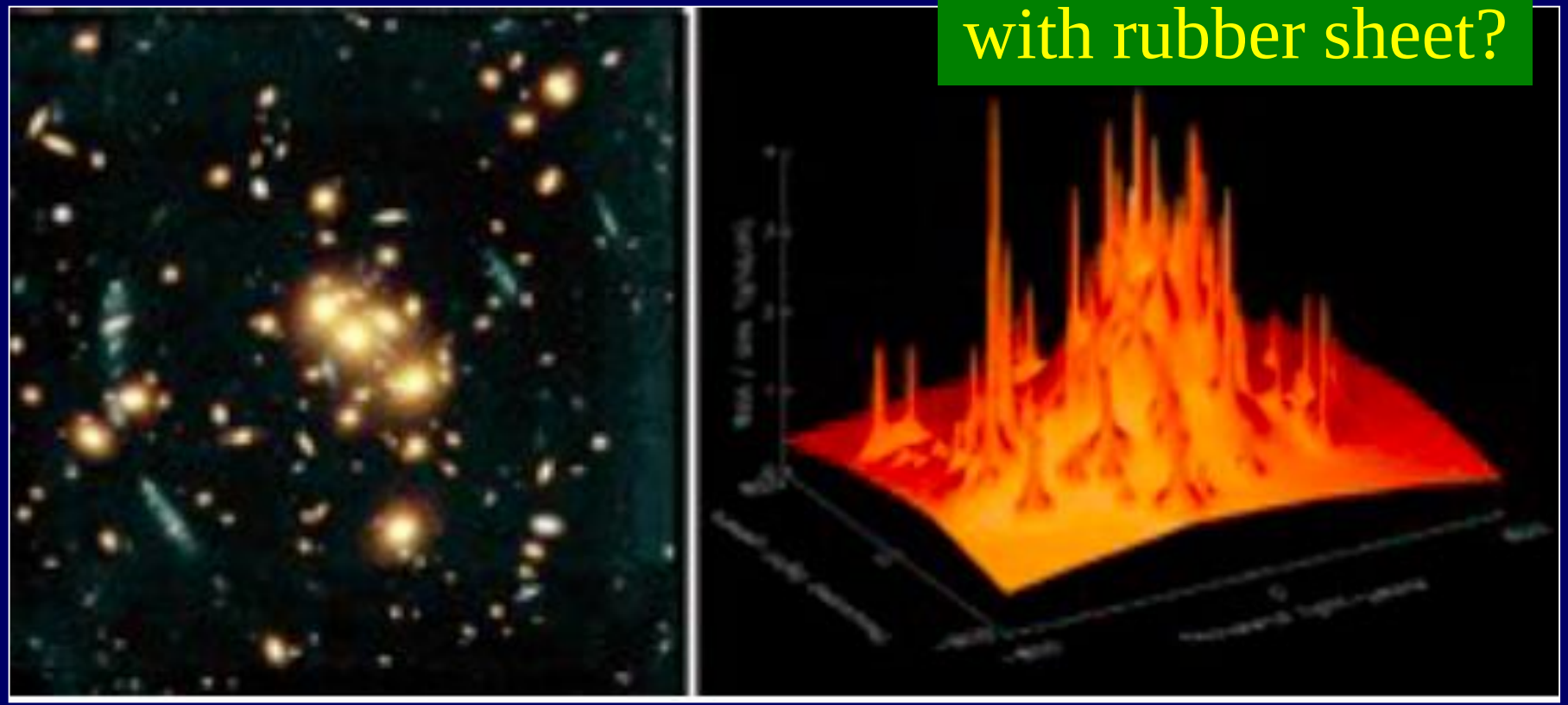


- The velocities do not decrease with distance
- Dark matter spread out

Gravitational Lensing

- Reveal all the matter

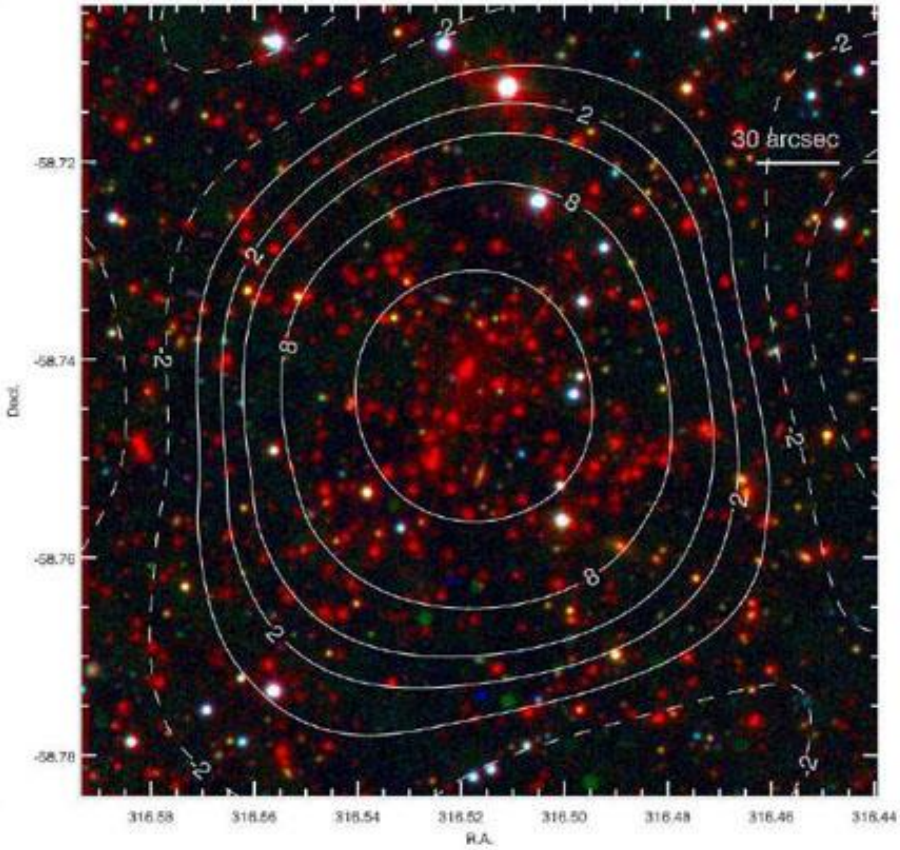
Demonstration with rubber sheet?



- Galaxies = peaks on a background of dark matter

X-Rays from Galaxy Clusters

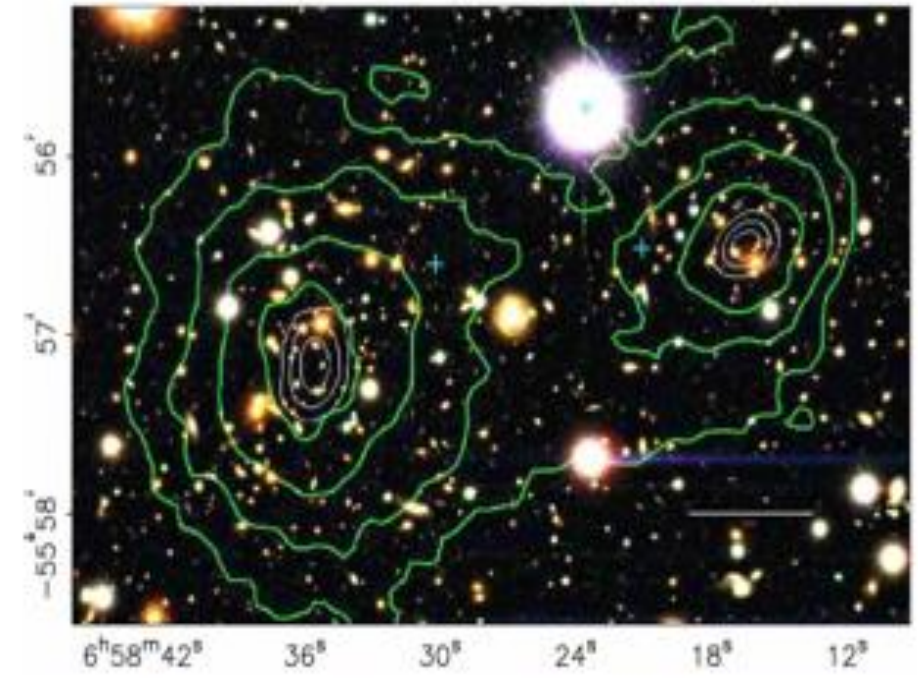
- High temperature and pressure



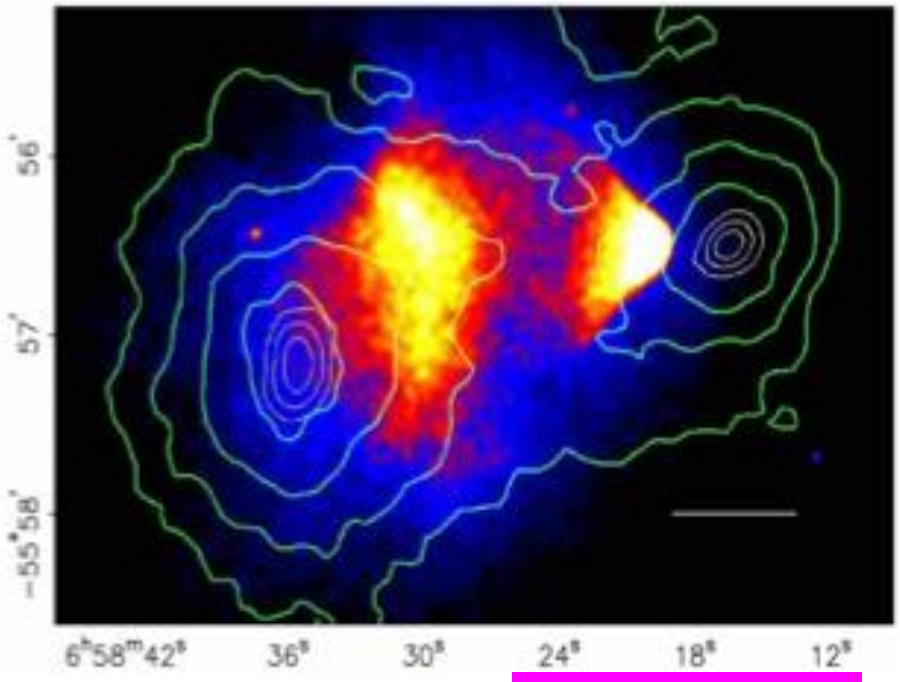
- Need extra gravity to hold them together

More Evidence for Dark Matter

Collision between
2 clusters of galaxies:
Dark matter passes through



Collision between
2 clusters of galaxies:
Gas interacts, heats and stops



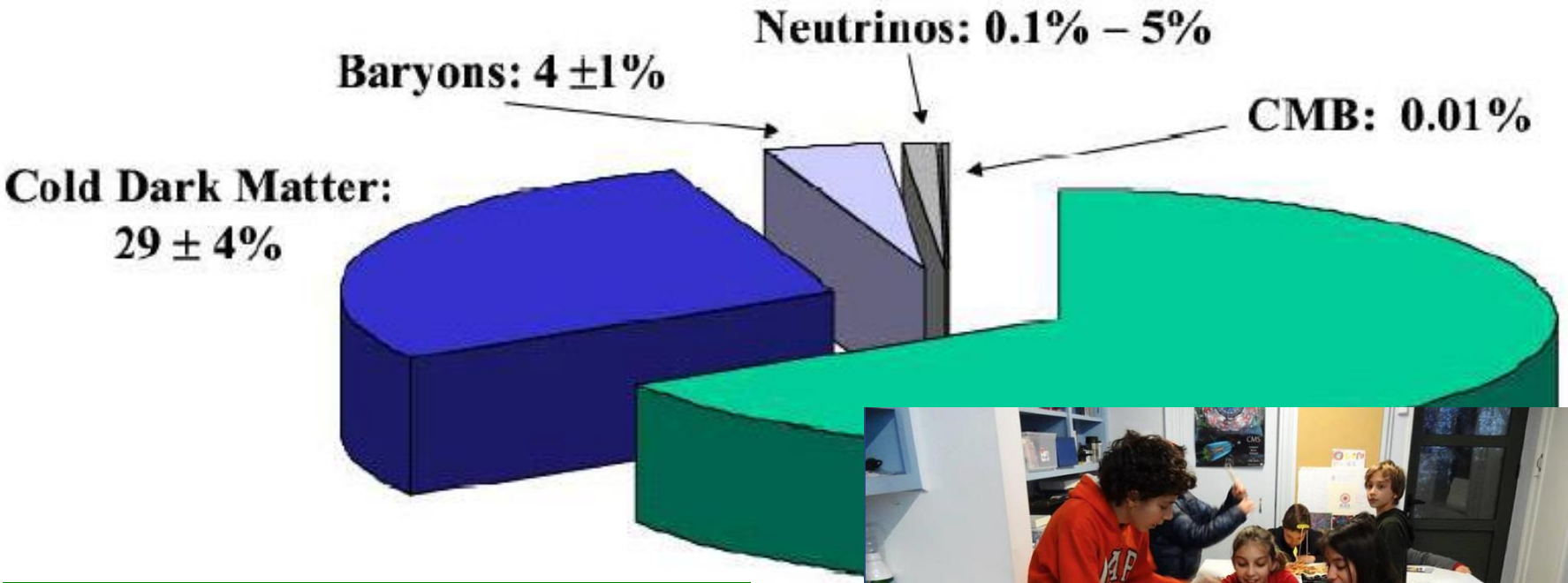
Clowe et al, 2006

Detection of dark matter?

Dark Energy

- Energy density spread throughout space
- Not clustered like matter in galaxies, etc.
- Apparently ~ constant for billions of years
- Expect in many theories of fundamental physics
- Mystery is why it is so small

Strange Recipe for a Universe



Make a cosmic pizza?

The ‘Standard Model’ of the Universe indicated by astrophysics and cosmology

Ideas for Playing with the Universe

- Solar system in the classroom?
- How many planets?
- Olbers' paradox using lights
- Döppler shift
- Microwave background in old TV
- Lensing using rubber sheet
- Detection of dark matter
- Make a cosmic pizza