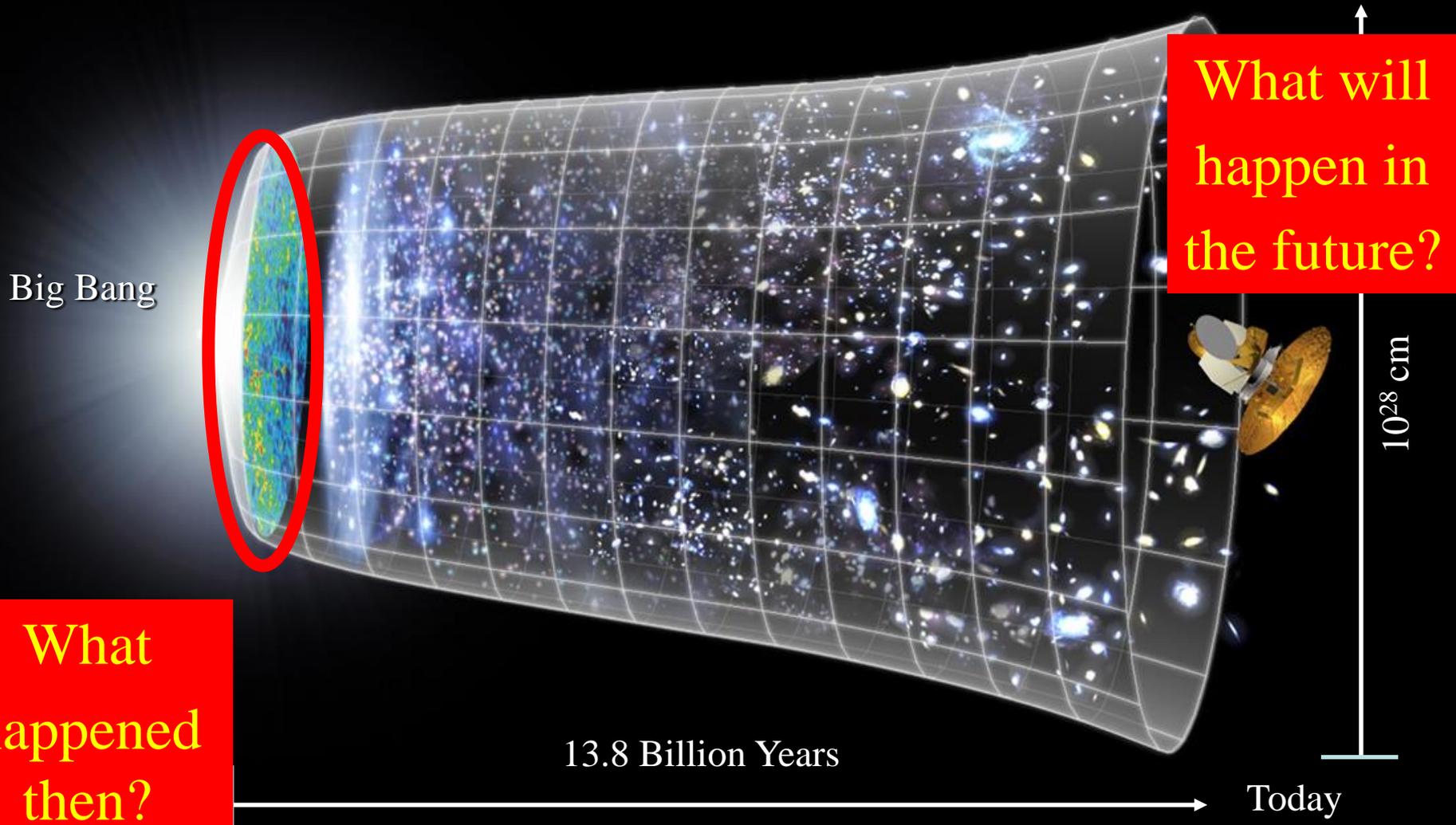


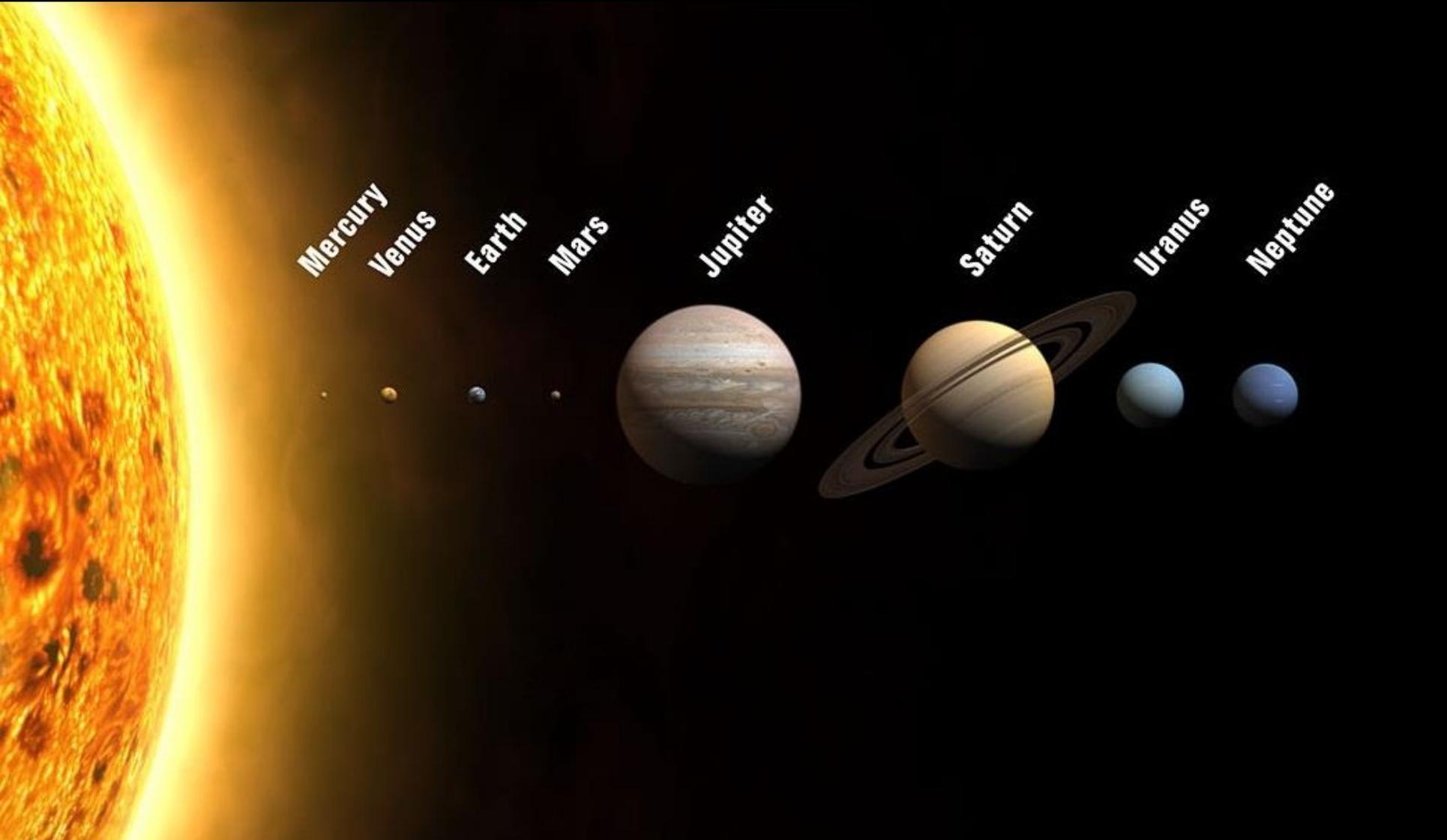
Playing with the Universe



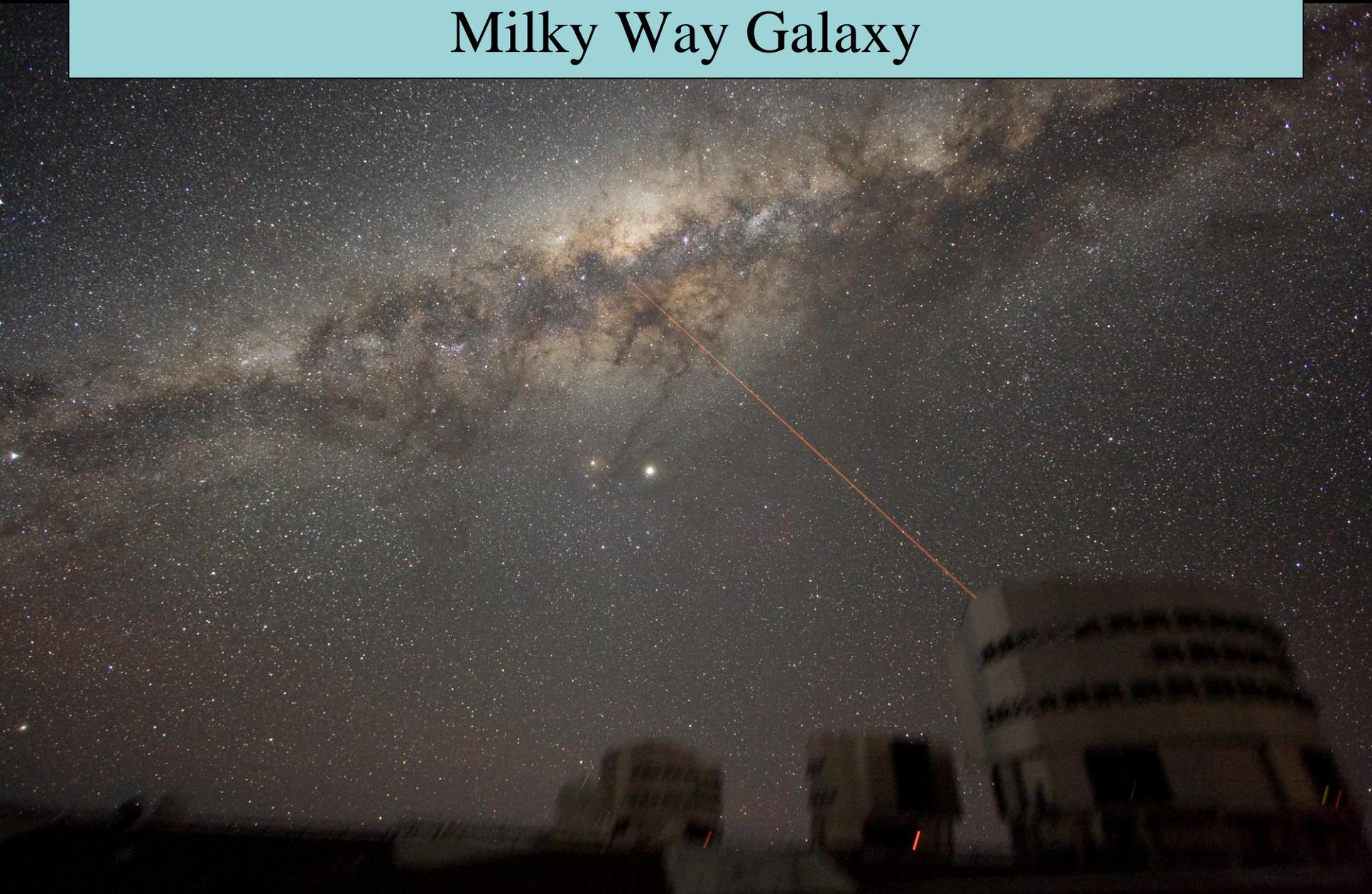
John Ellis



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

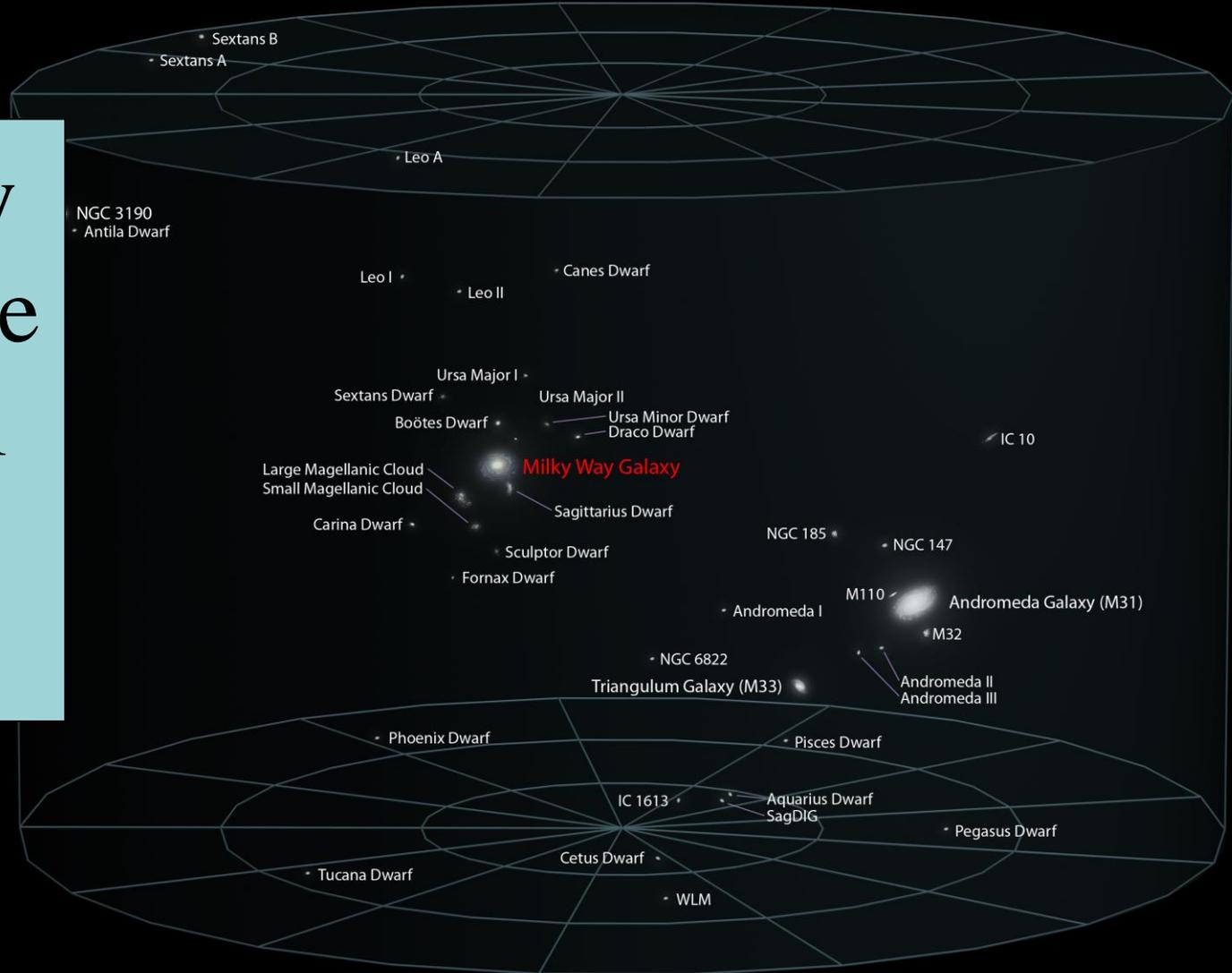


The Sun is One of 100,000,000,000 Stars in the
Milky Way Galaxy



Local Galactic Group

The Milky Way is One of a Local Group of Galaxies



The Local Group is Part of the Virgo Supercluster



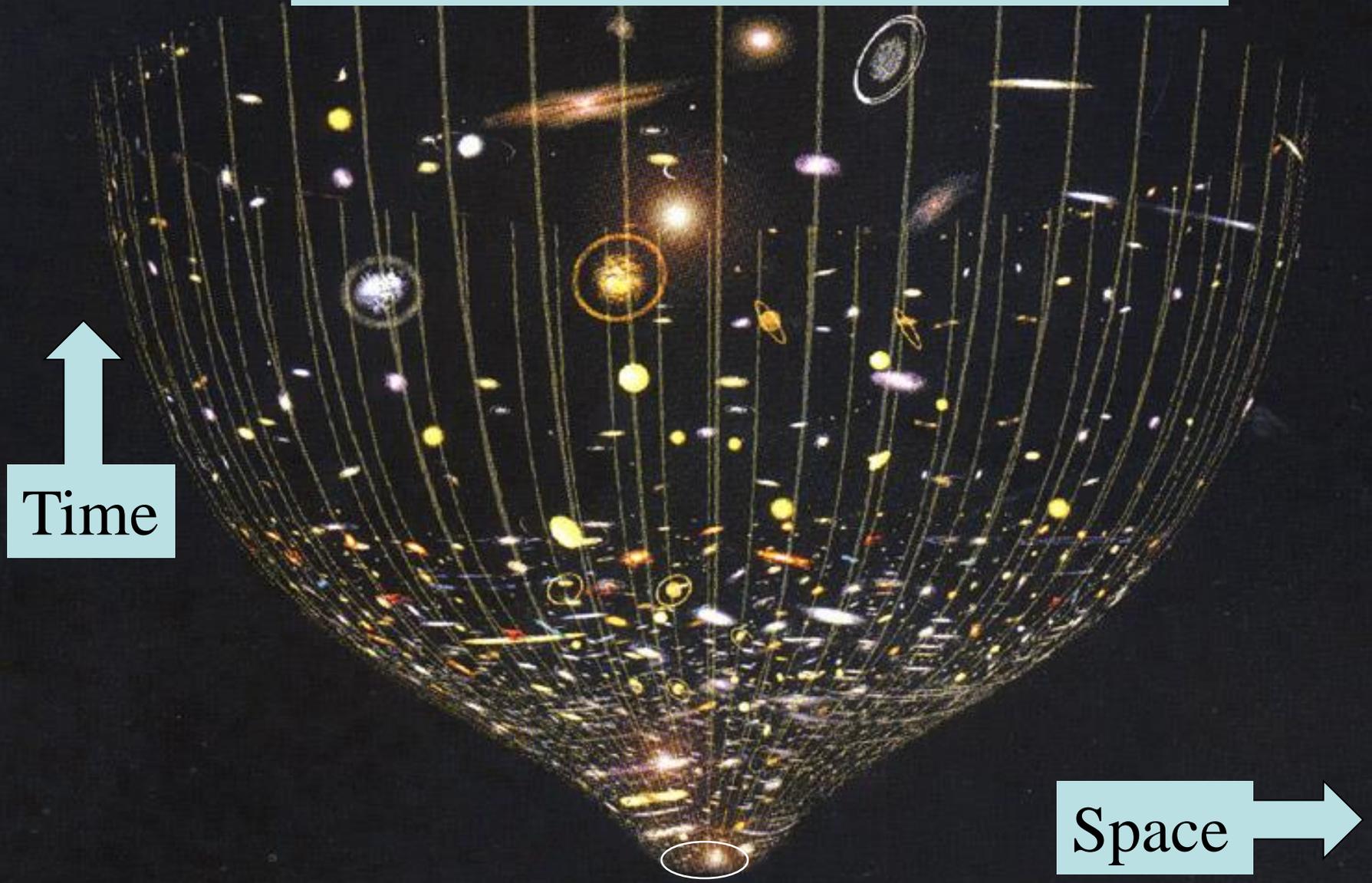
How many planets
in the Universe?

A hundred thousand million galaxies in the visible Universe

The Universe is Expanding

↑
Time

→
Space



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!**

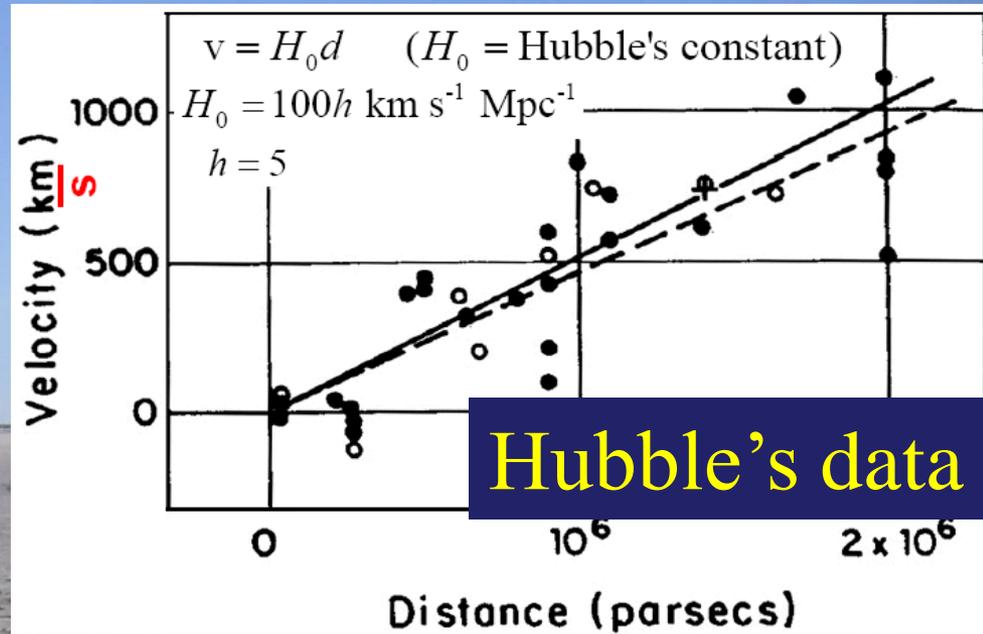
Demonstration with Döppler effect?

The Expansion of the Universe

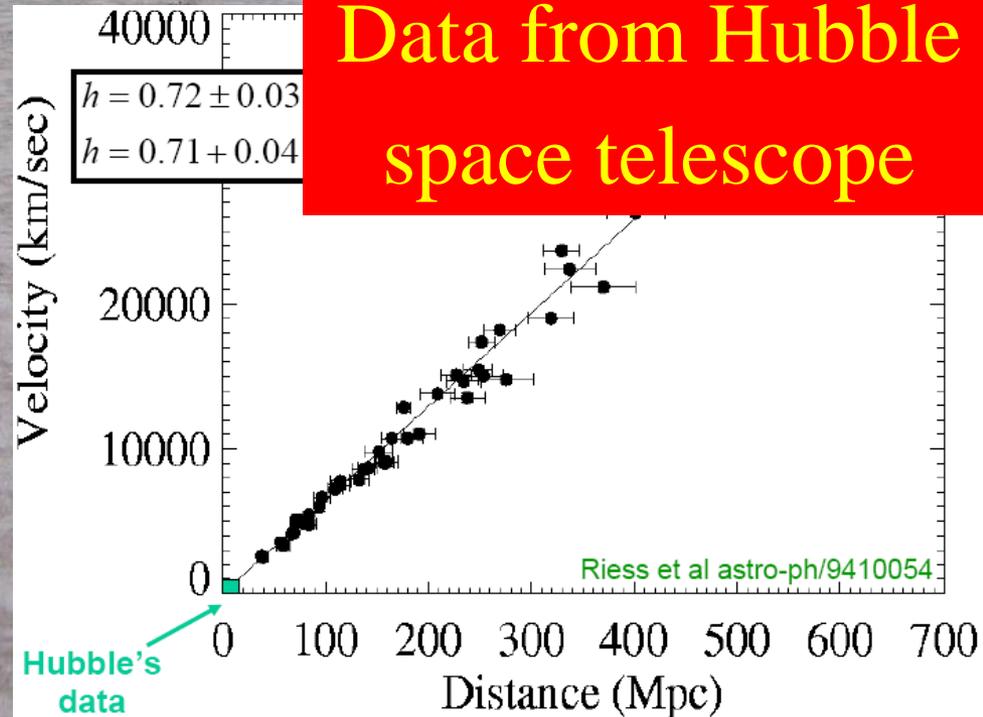
Hubble, the basketball player



University of Chicago 1909 National Champions



Data from Hubble space telescope

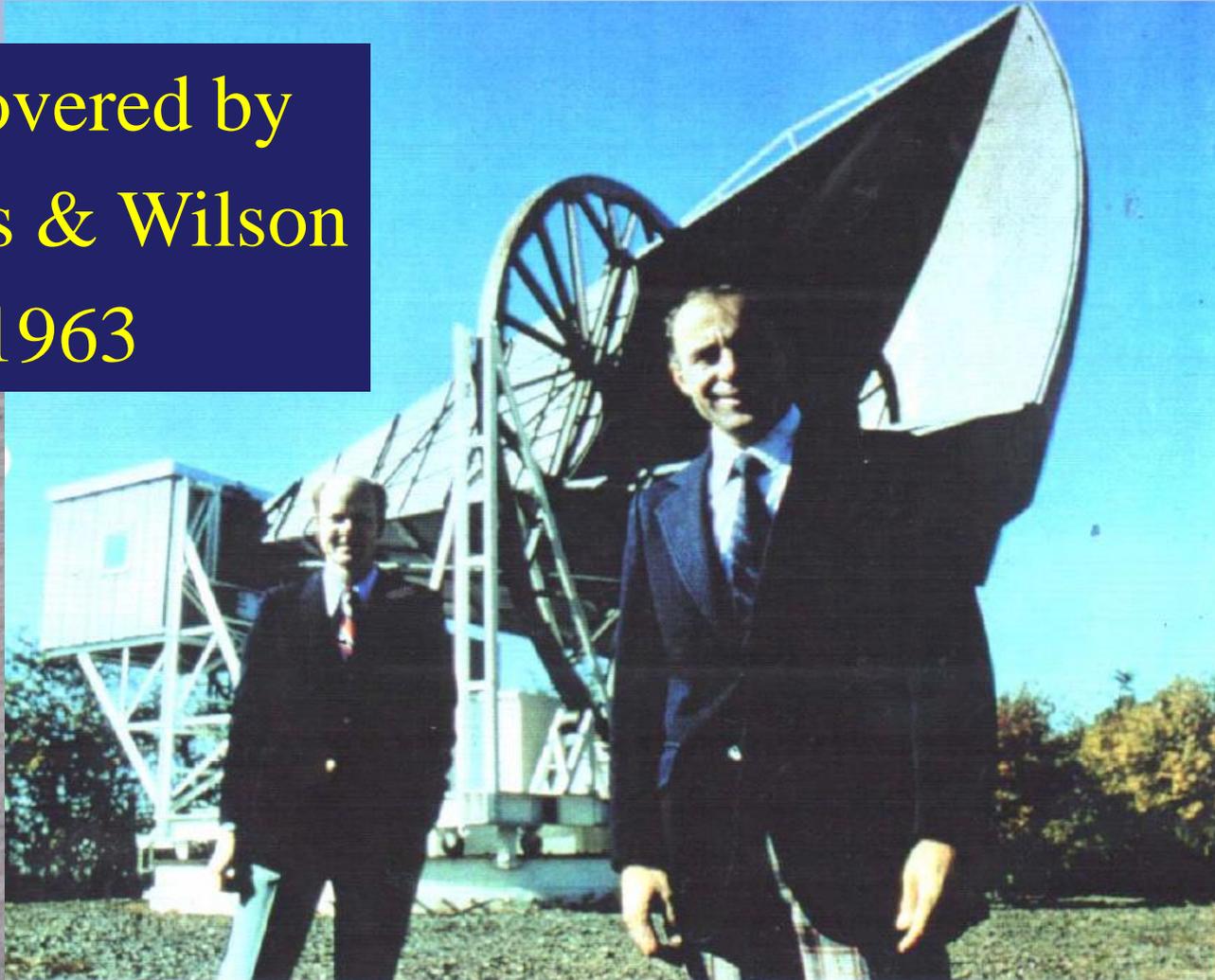


The Universe is Expanding

- The galaxies are separating
the expansion discovered by Hubble
- The Universe was once 3000 times smaller and hotter than today
the cosmic microwave background

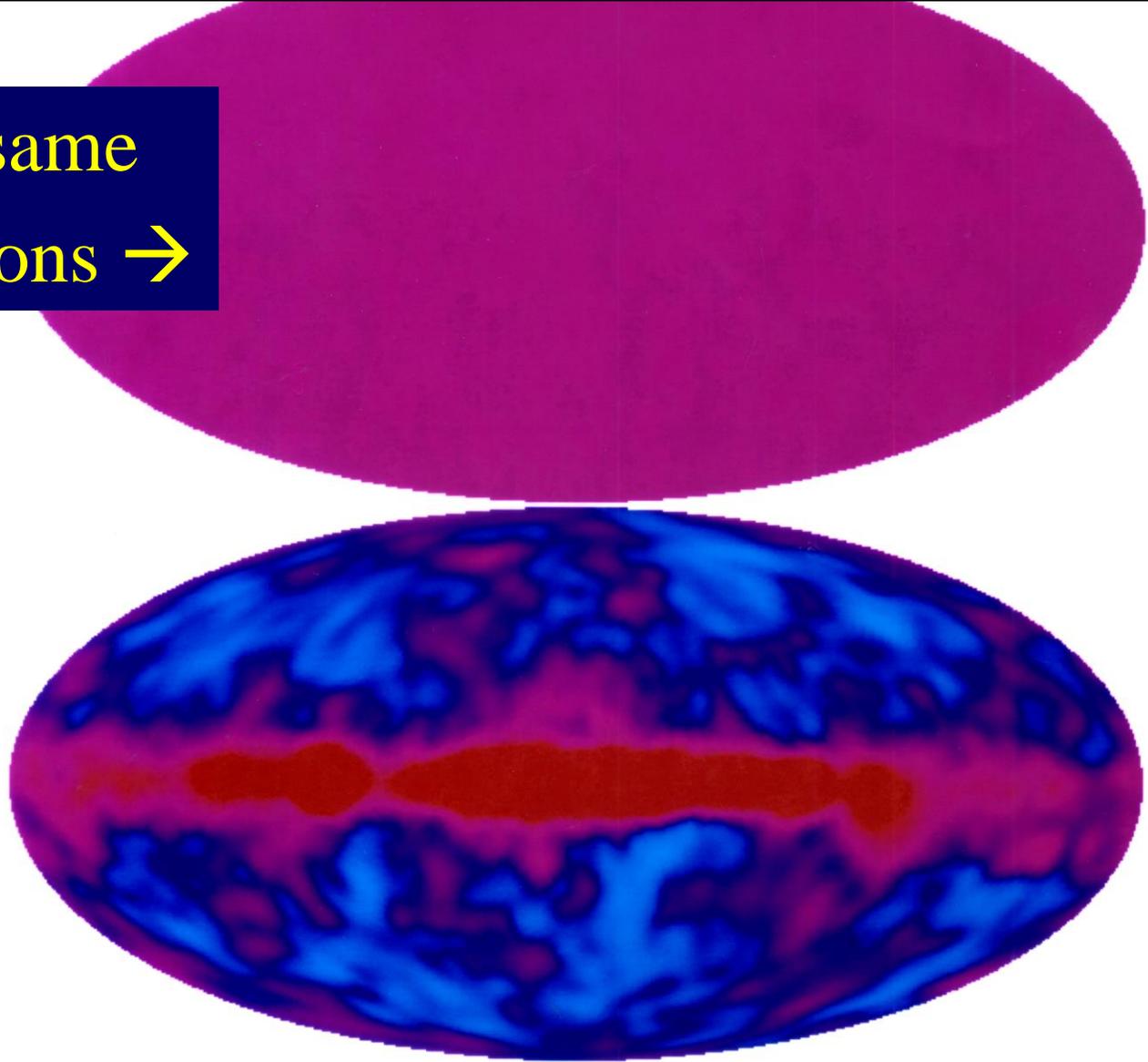
The Cosmic Microwave Background

Discovered by
Penzias & Wilson
1963



The Cosmic Microwave Background

Almost the same
in all directions →



Pigeon Pollution?



Old TV set?

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

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

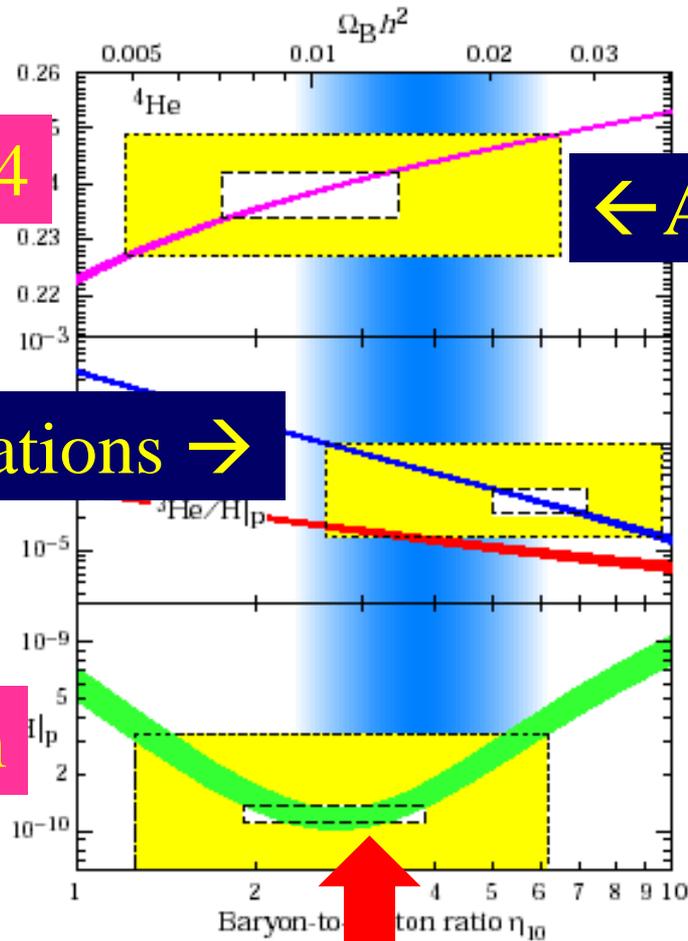
The Abundances of the Light Elements

Helium 4

← Agree with the data

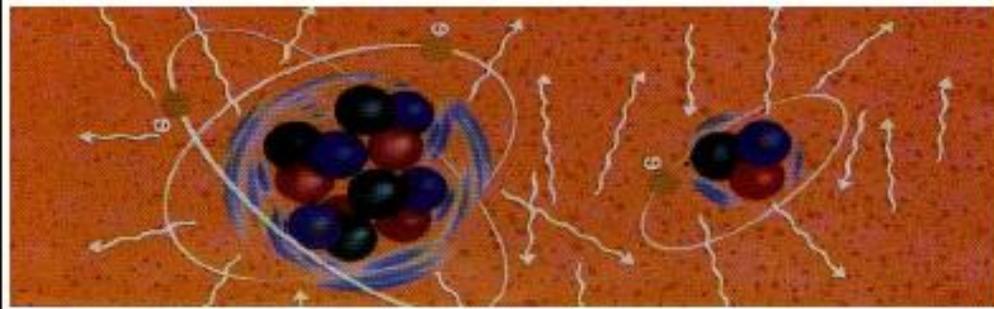
Theoretical calculations →

Lithium



Not enough normal matter to stop expansion of the Universe

300,000
years



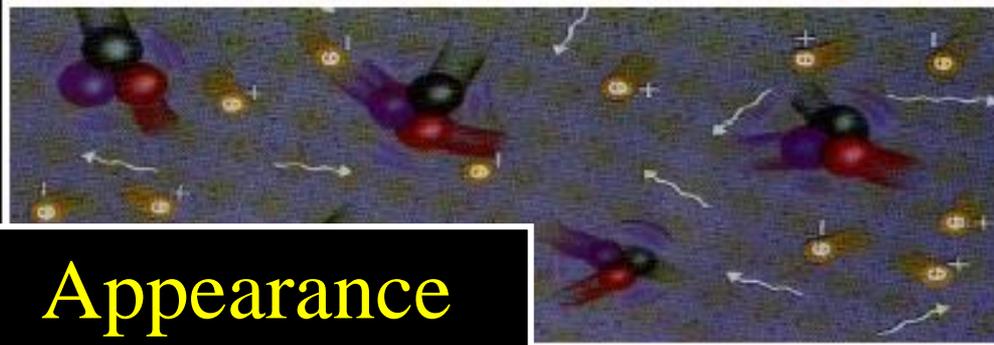
Formation
of atoms

3
minutes



Formation
of nuclei

1 micro-
second



Formation
of protons
& neutrons
Appearance

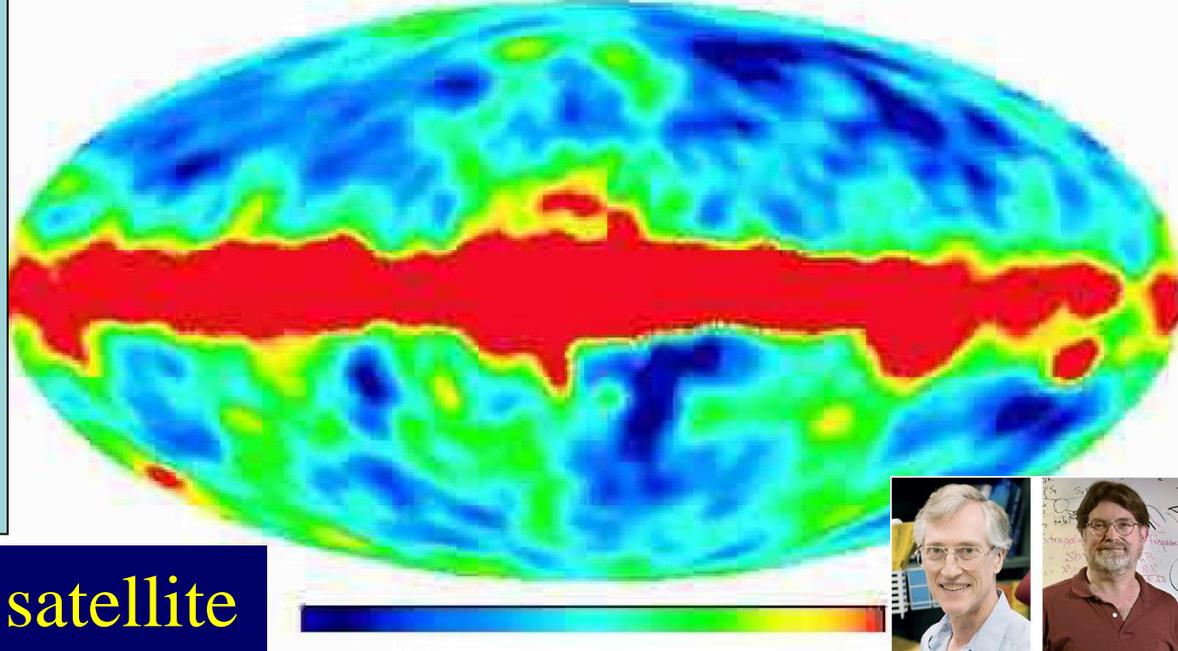
1 pico-
second

Appearance
of dark matter?

Appearance
of mass?
of matter?

BANG!

More on the Cosmic Microwave Background

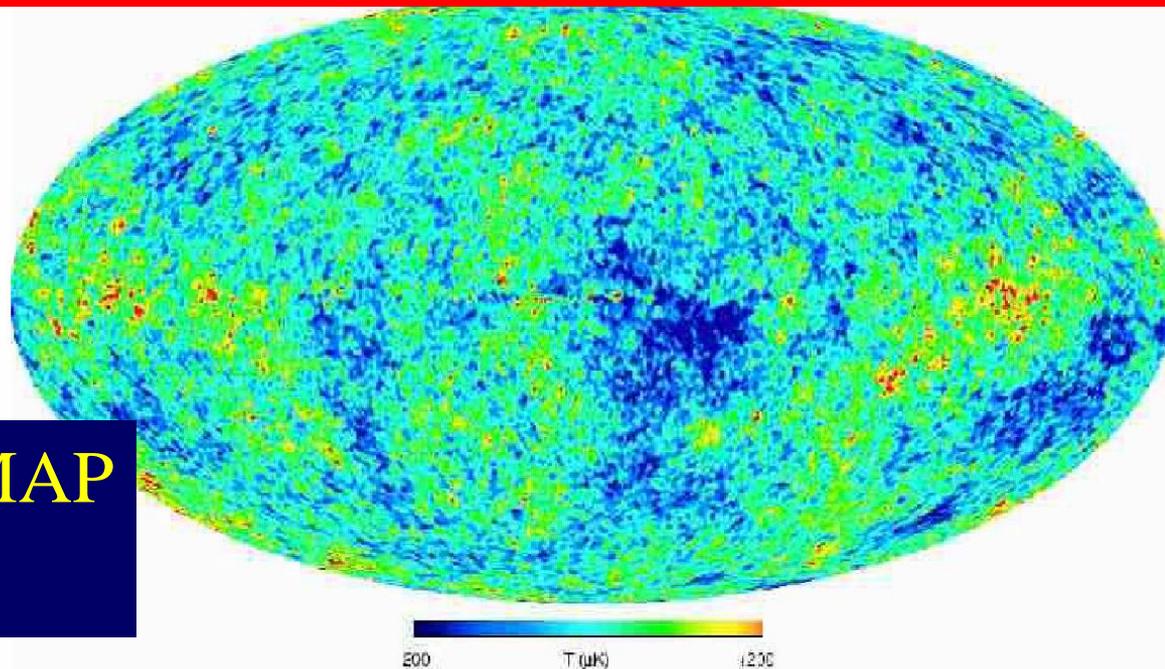


According to COBE satellite

Nobel Prize 2006: John Mather & George Smoot

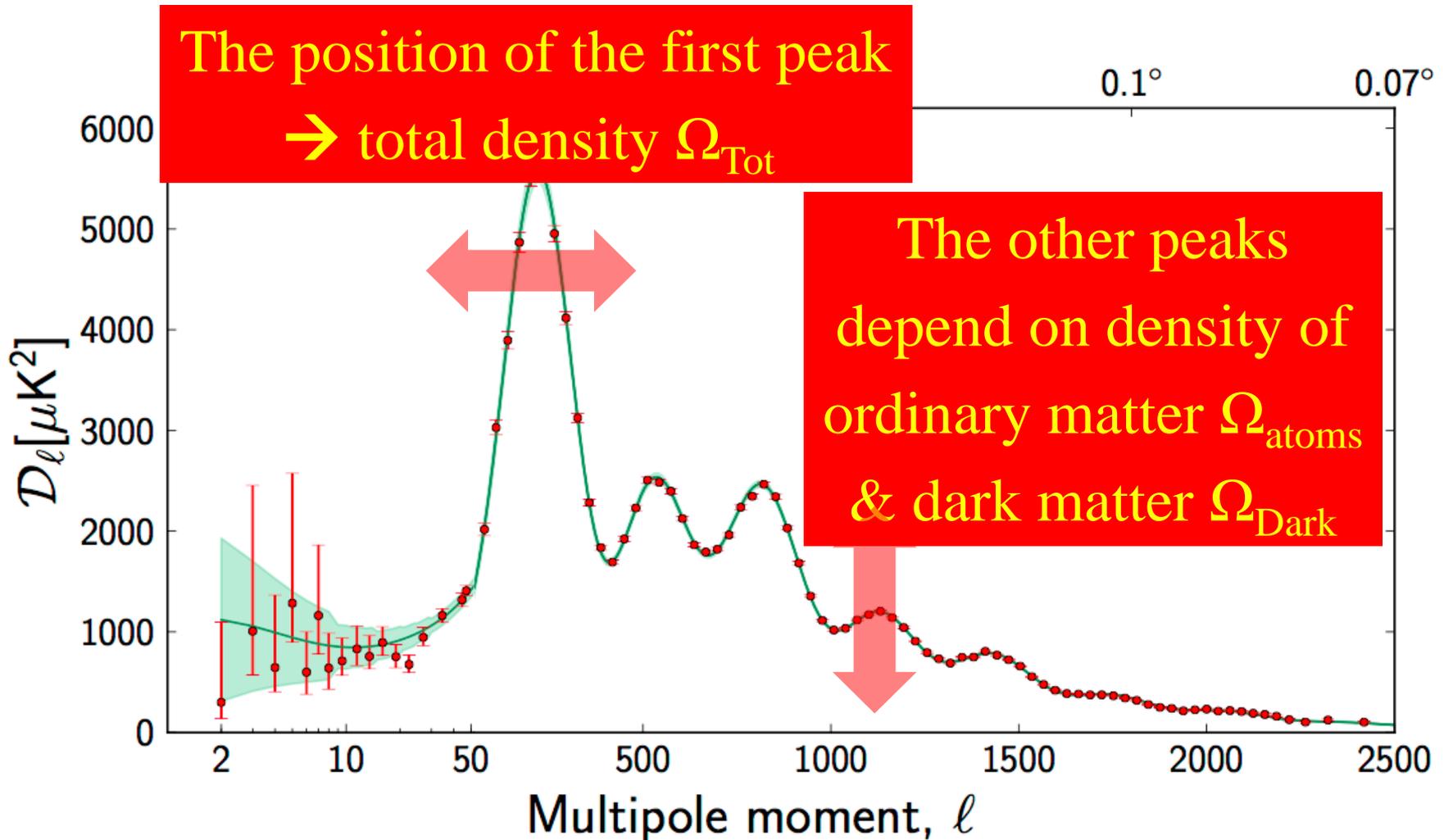


According to WMAP
satellite



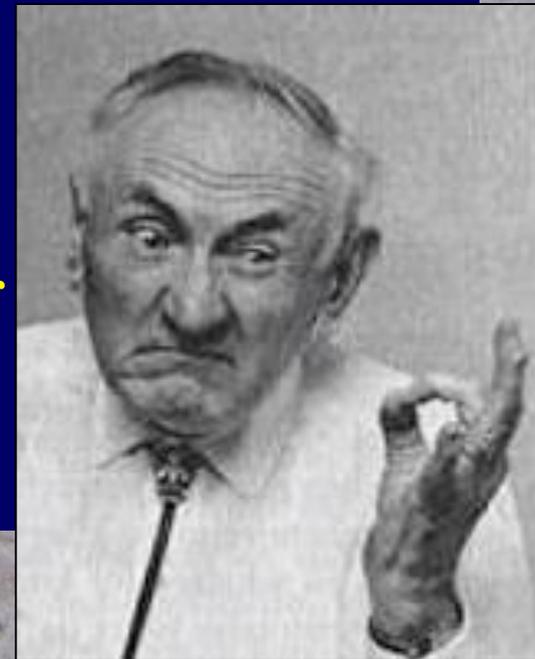


The Spectrum of Fluctuations in the Cosmic Microwave Background



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 also required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**

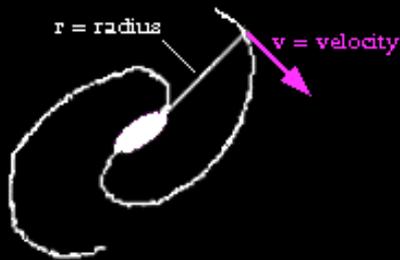


Evidence for Dark Matter

- 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



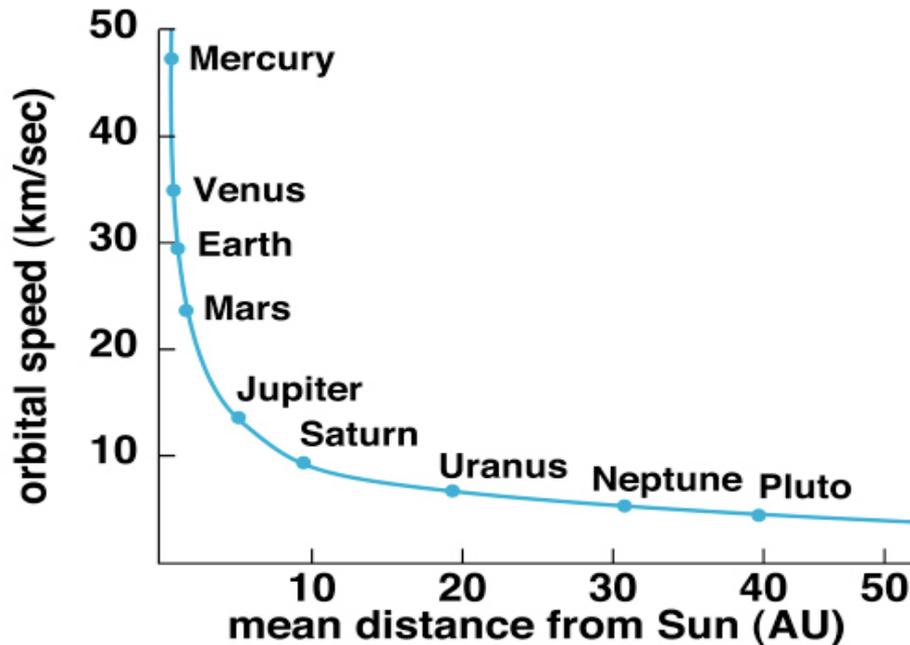
Gravity = Centripetal Acceleration

$$\frac{GM}{r^2} = \frac{v^2}{r}$$



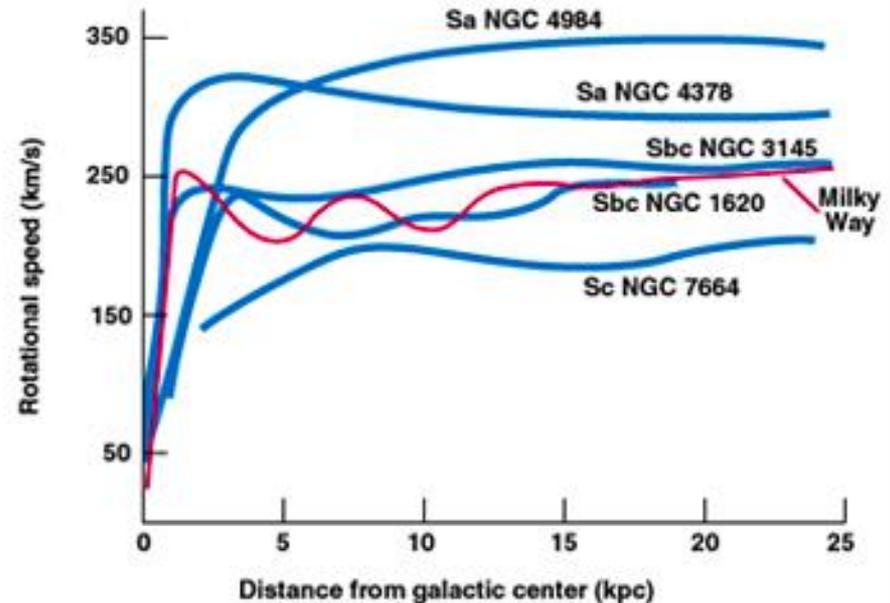
Rotation Curves

- In the Solar System



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

- In galaxies

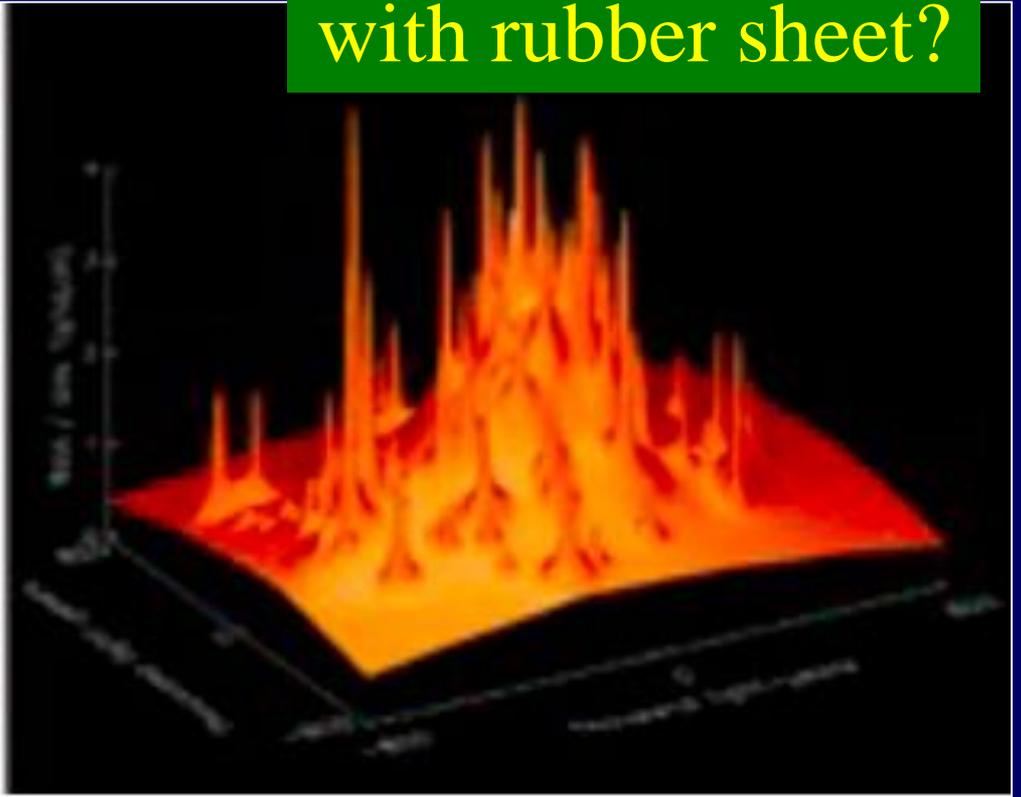


- The velocities do not decrease with distance
- Dark matter spread out

Gravitational Lensing

- Reveal all the matter

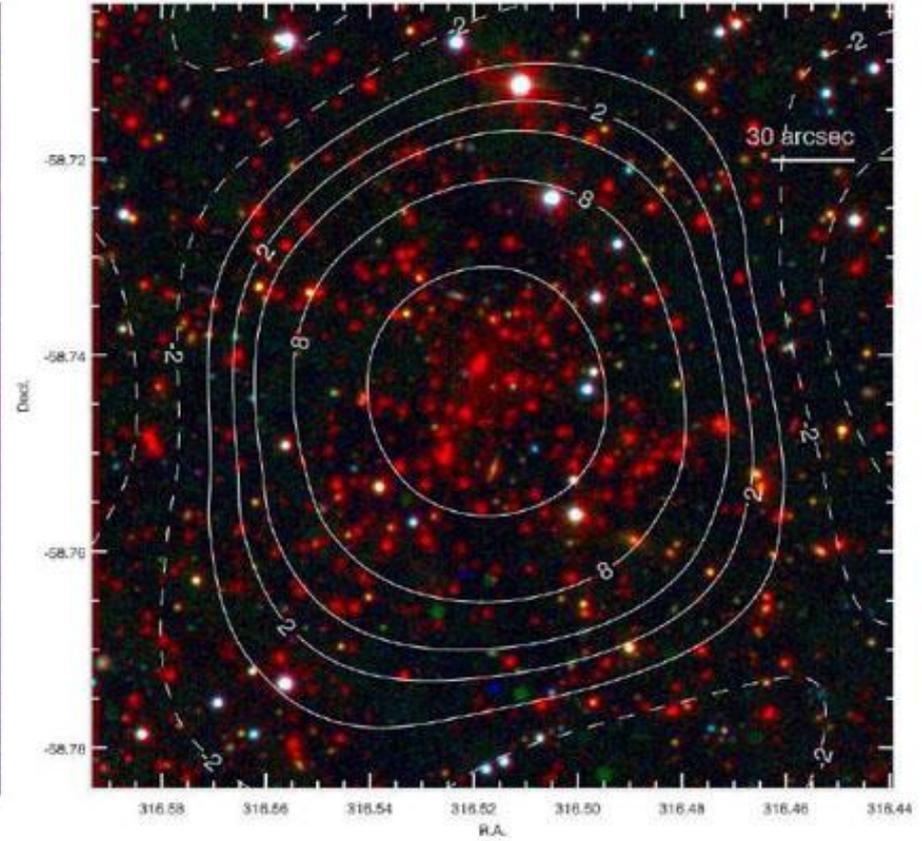
Demonstration
with rubber sheet?



- Galaxies = peaks on a background of dark matter

X-Rays from Galaxy Clusters

- High temperature and pressure

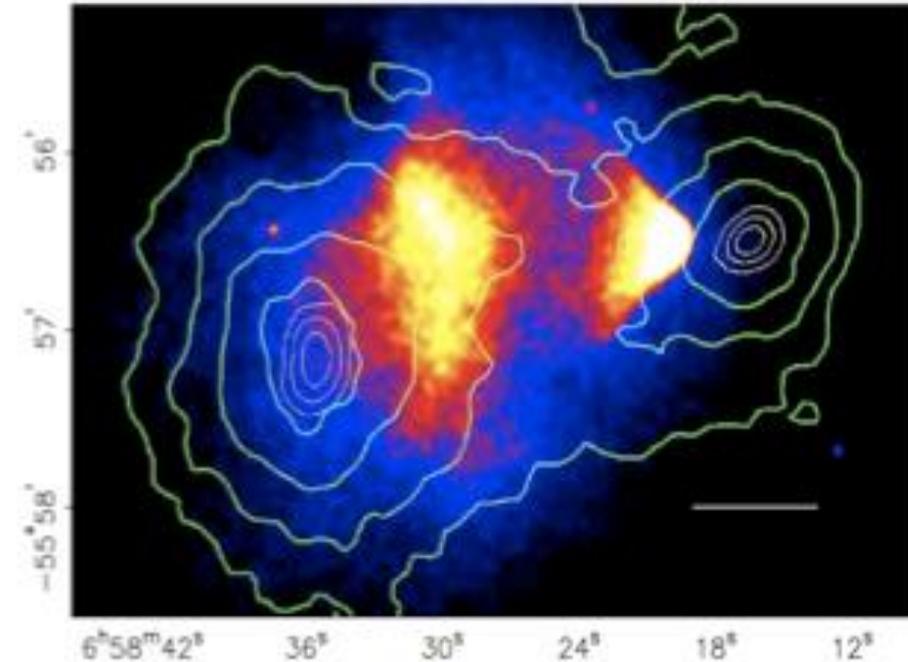
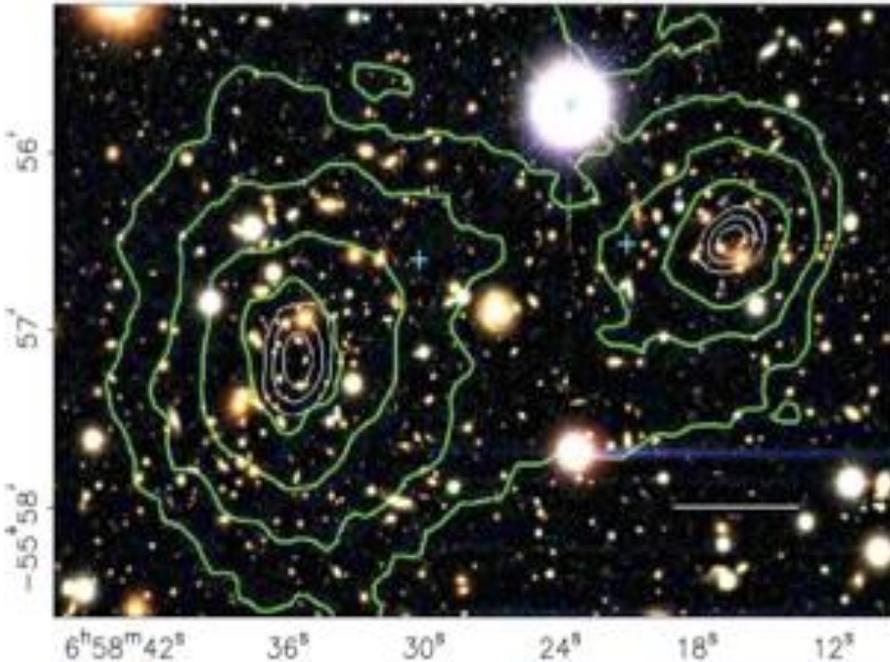


- Need extra gravity to hold them together

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



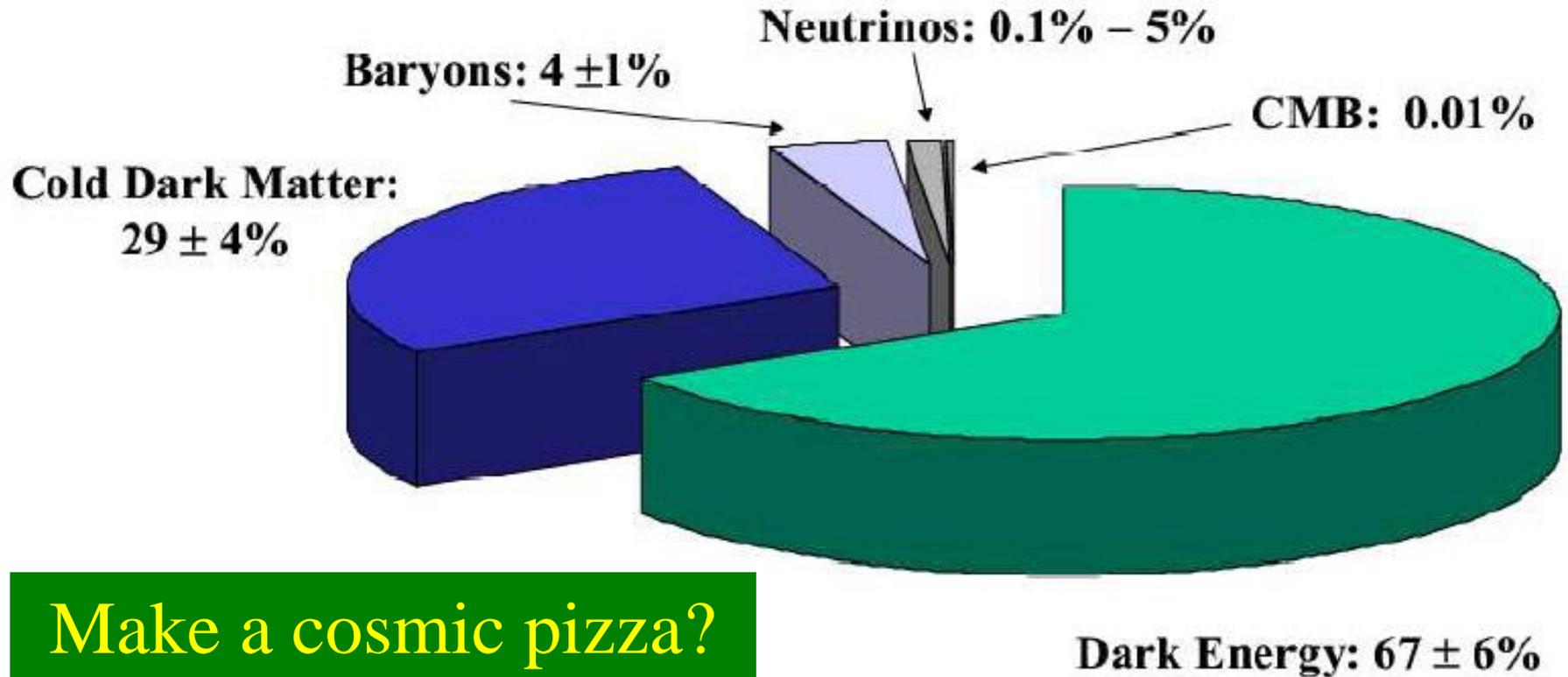
Detection of dark matter?

Clowe et al, 2006

Dark Energy

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

Strange Recipe for a Universe



The 'Standard Model' of the Universe indicated by astrophysics and cosmology

Ideas for Playing with the Universe

- 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