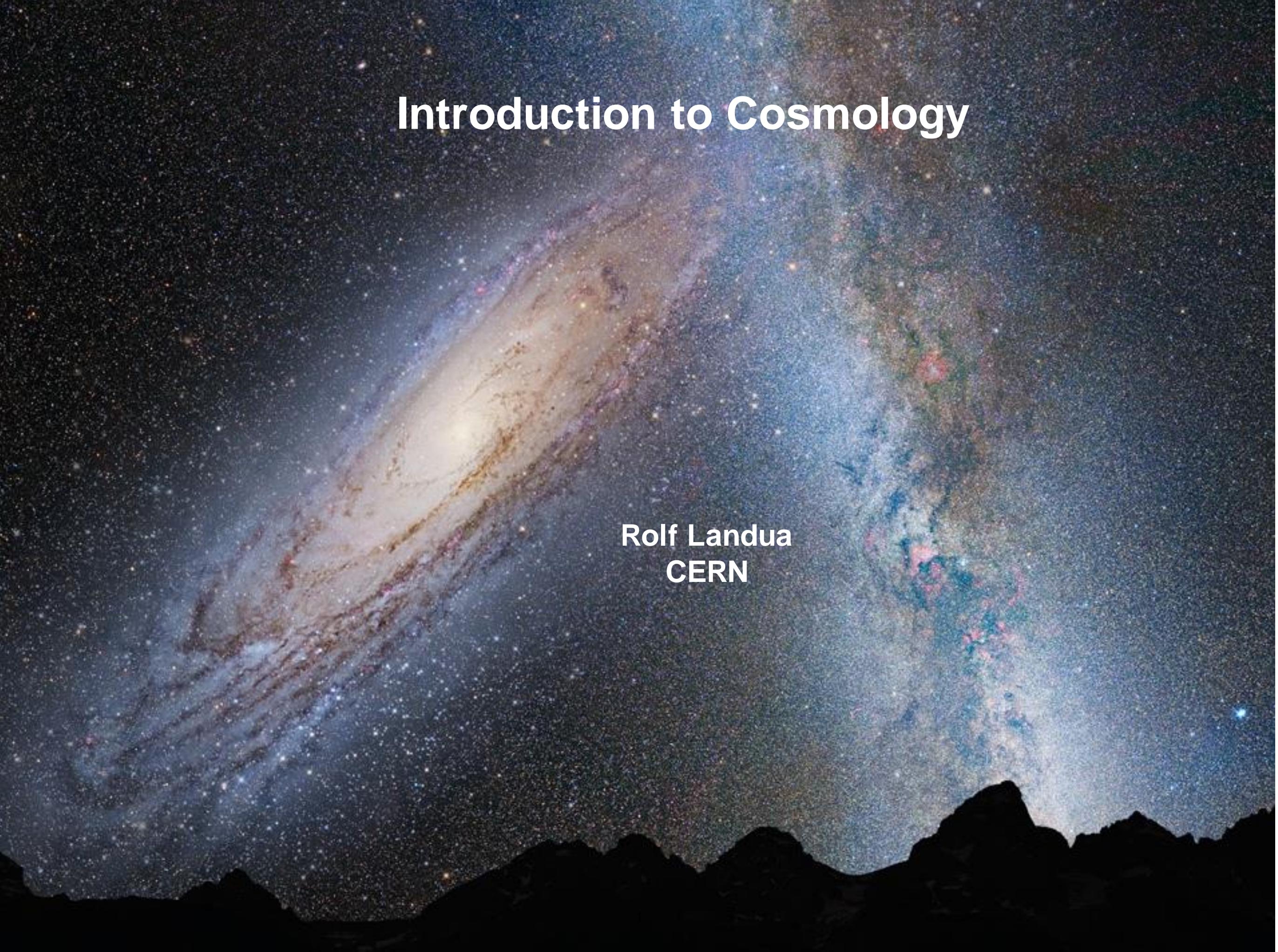


Introduction to Cosmology

Rolf Landua
CERN



My interest in cosmology began with the moon landing



Apollo 8 : Earth rising



me (1968)

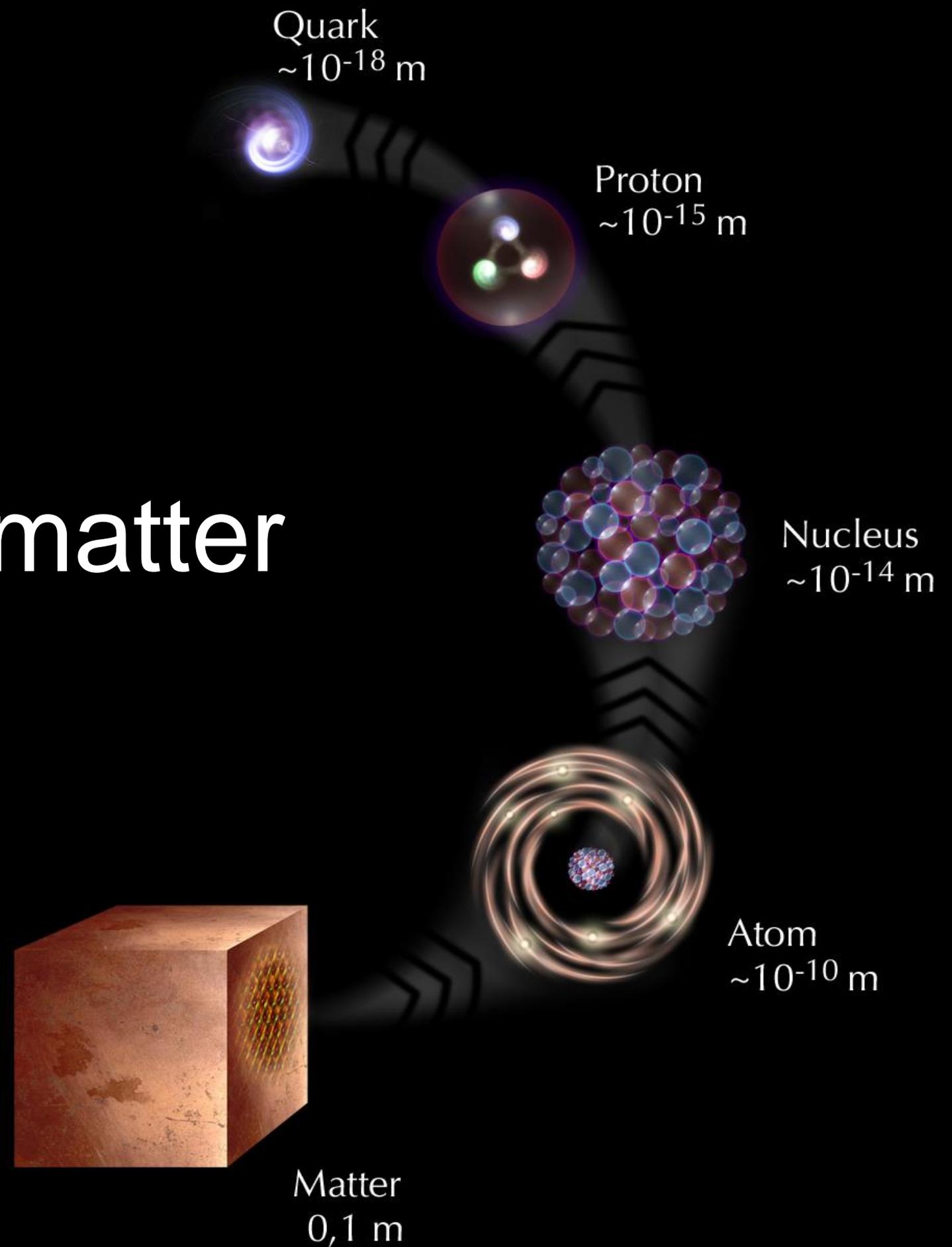
Where do we come from? What are we? Where are we going?



Paul Gauguin, 1897

- 1897: Birth of particle physics (Electron)
- 1992: Cosmology becomes precision science (COBE)
- 2010: Closer than ever to the Big Bang (LHC)

Hierarchy of matter



Voyage into matter



What are we made of ?

Only 4 particles are needed to explain the visible Universe

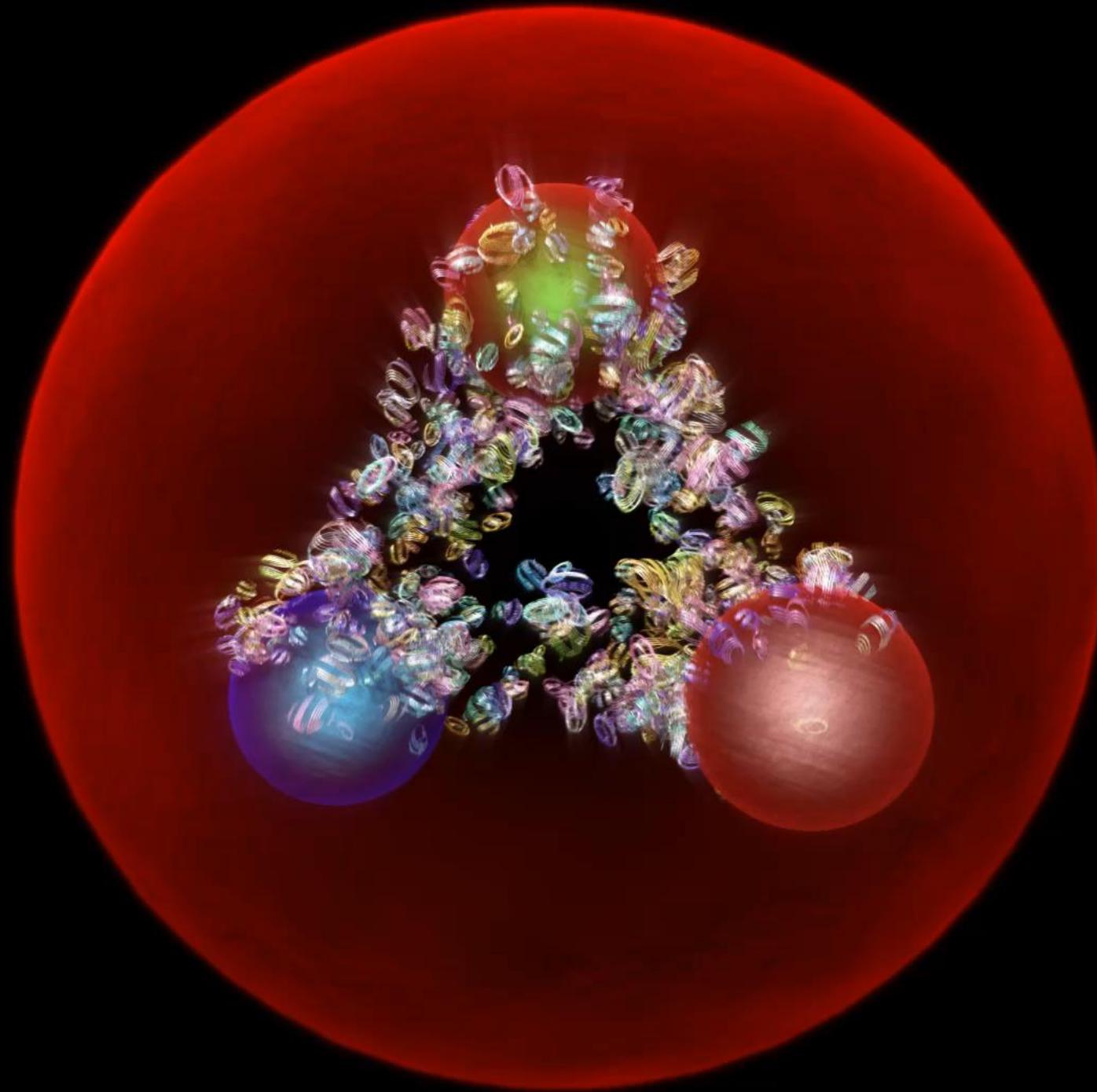
Quarks



Leptons



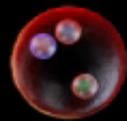
Proton: made of quarks



You : 100,000,000,000,000,000,000,000,000,000,000
“immortal” particles

Accelerators produce new particles

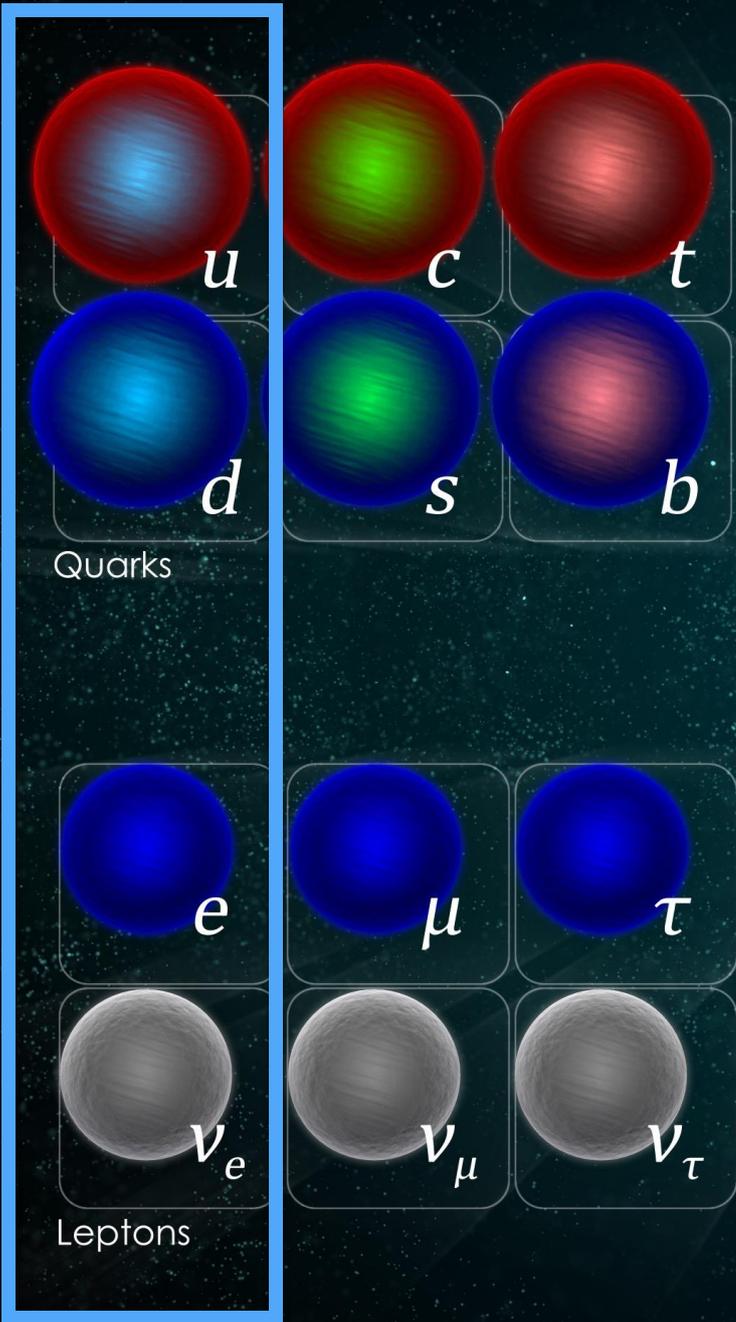
Energy to matter : $E = mc^2$



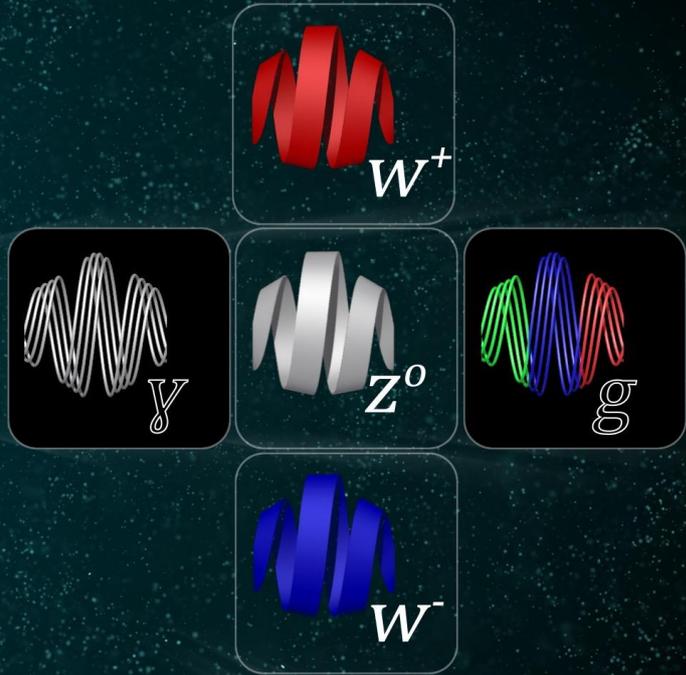
Energy into Mass



produce all
these particles ...
and more



Higgs boson



'matter'





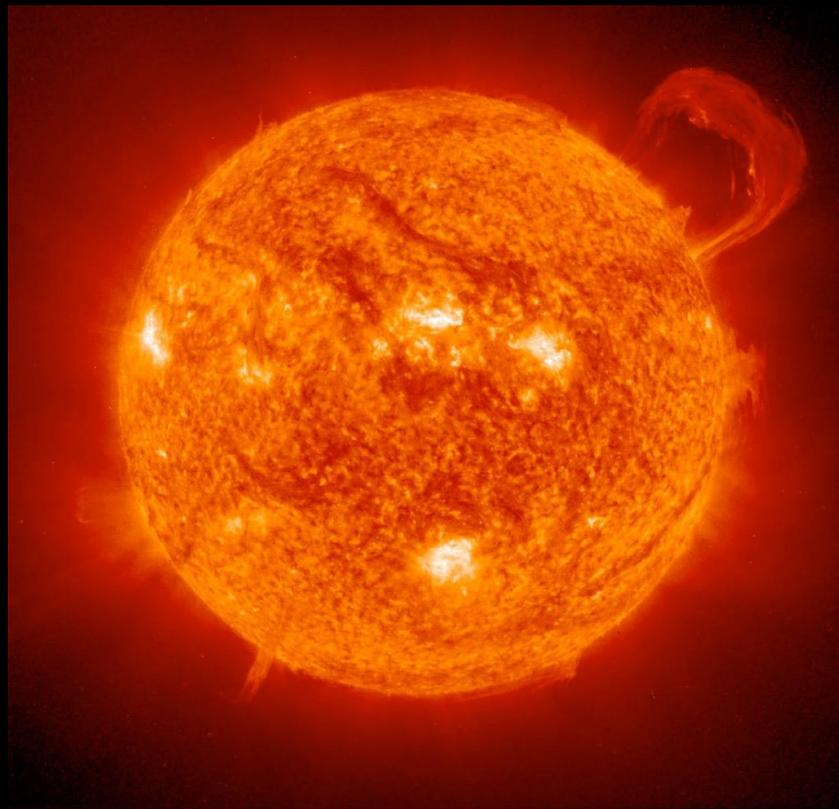
We have finally
understood
what we are made of.

And what about our
Universe?

Our Universe started
13 799 ± 38 million years
ago

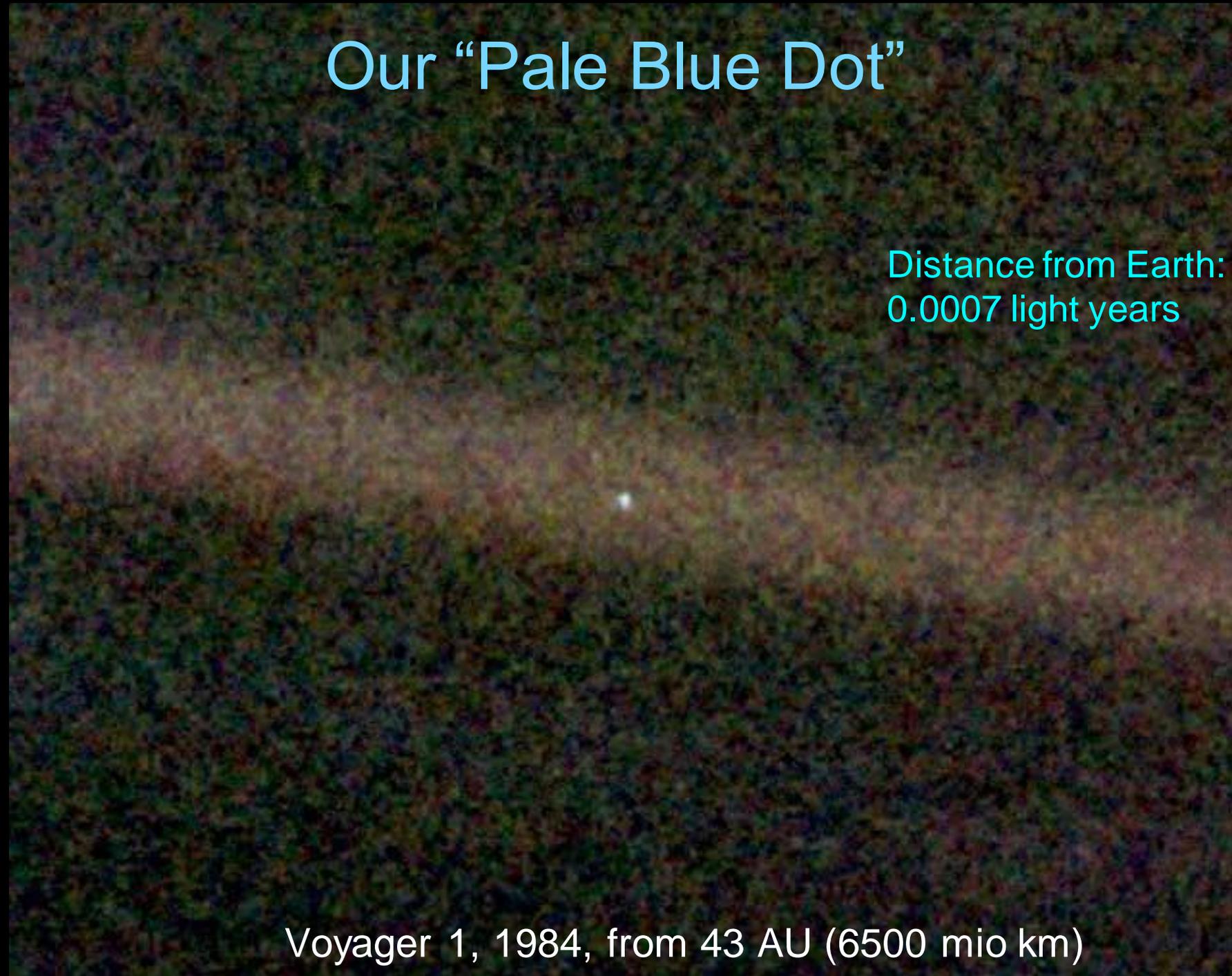


What evidence?
How do we know?



Earth, third planet from Sun, distance ~ 150 mio km (1 AU)

Not a very big object ...



Our planet is a lonely speck in the great enveloping cosmic dark
(Carl Sagan)

Our nearest neighbour



Proxima Centauri, 266 000 AU (4.22 Light-years)

Our Milky Way has about 300 billion stars like the Sun

Our galaxy

Diameter of Milky Way ~ 100,000 Lyr



you are here



Distance to centre of Milky Way ~ 26,000 Lyr

The Universe

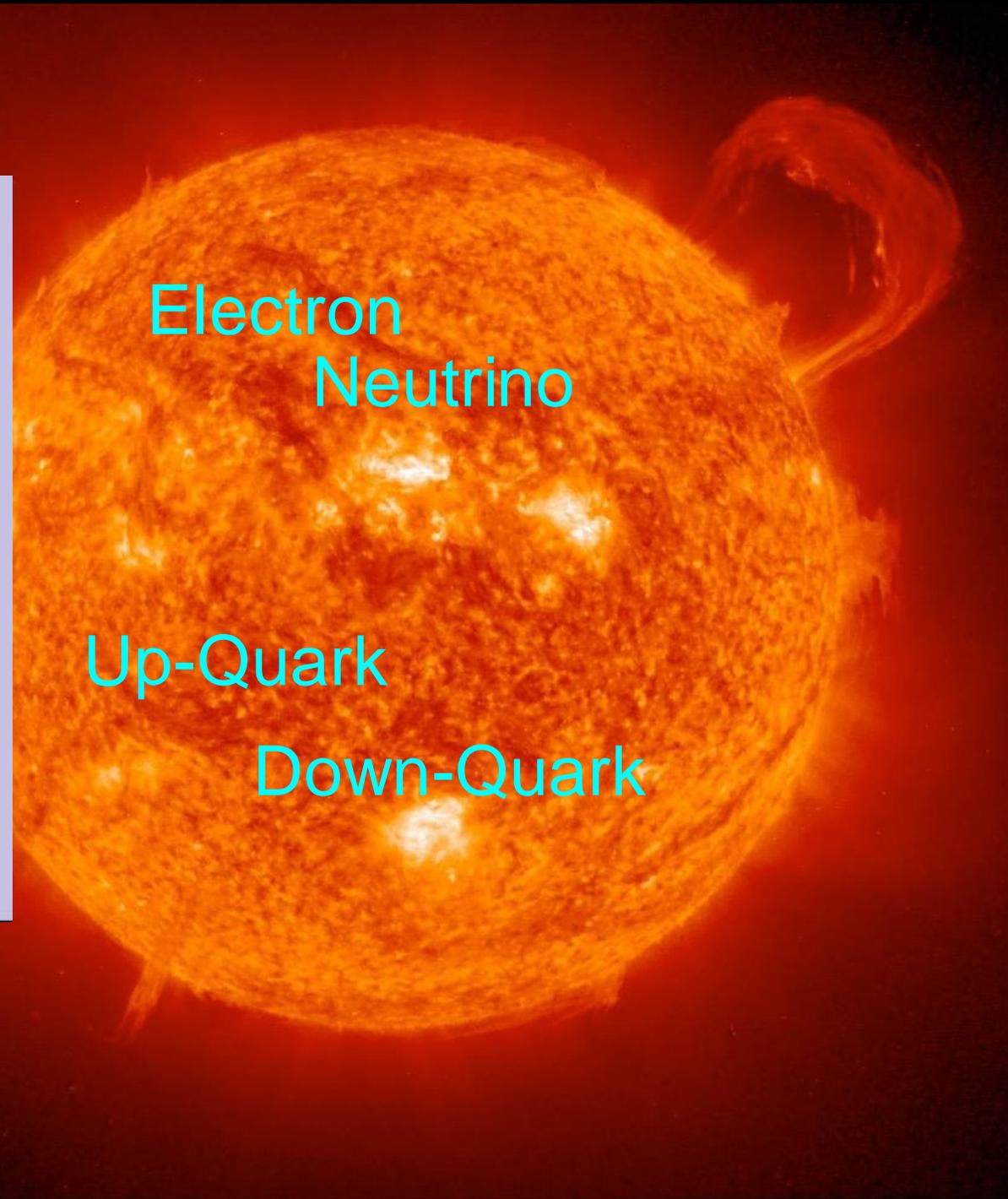
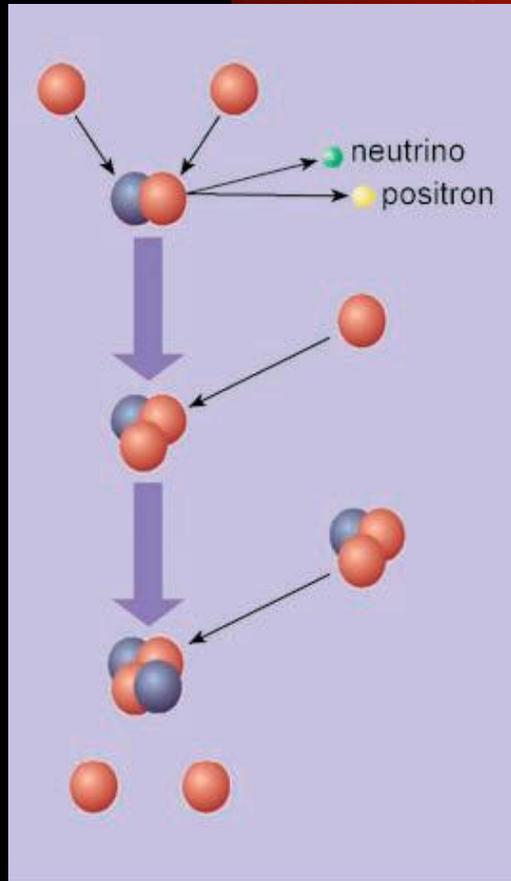


~100 billion galaxies

billions of light years away

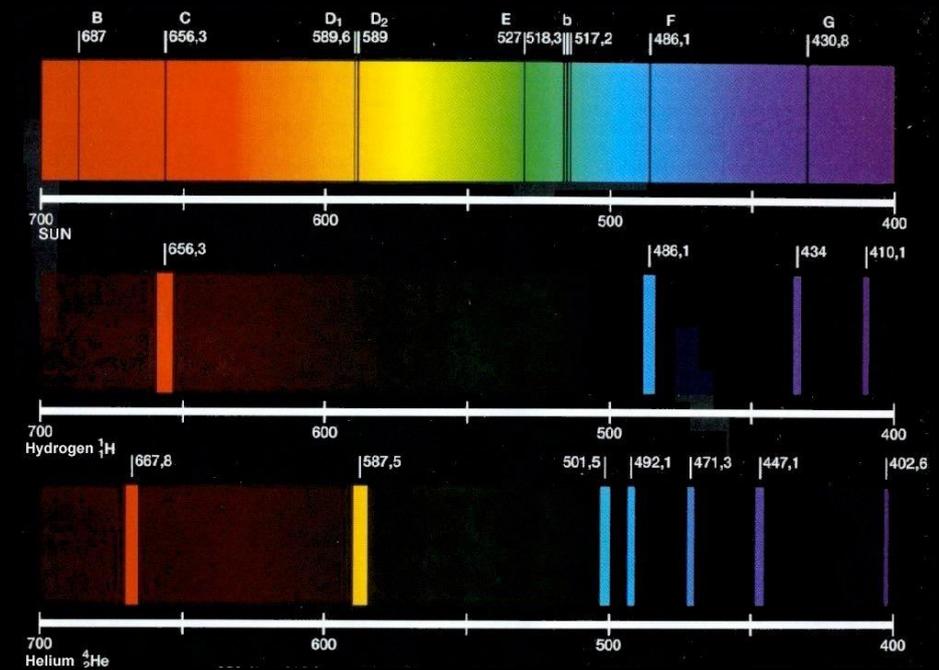
Looking at galaxies far away is like looking back in time

The visible Universe has the same composition



H and He

(~ 3:1)



Four basic, point-like constituents explain all visible matter

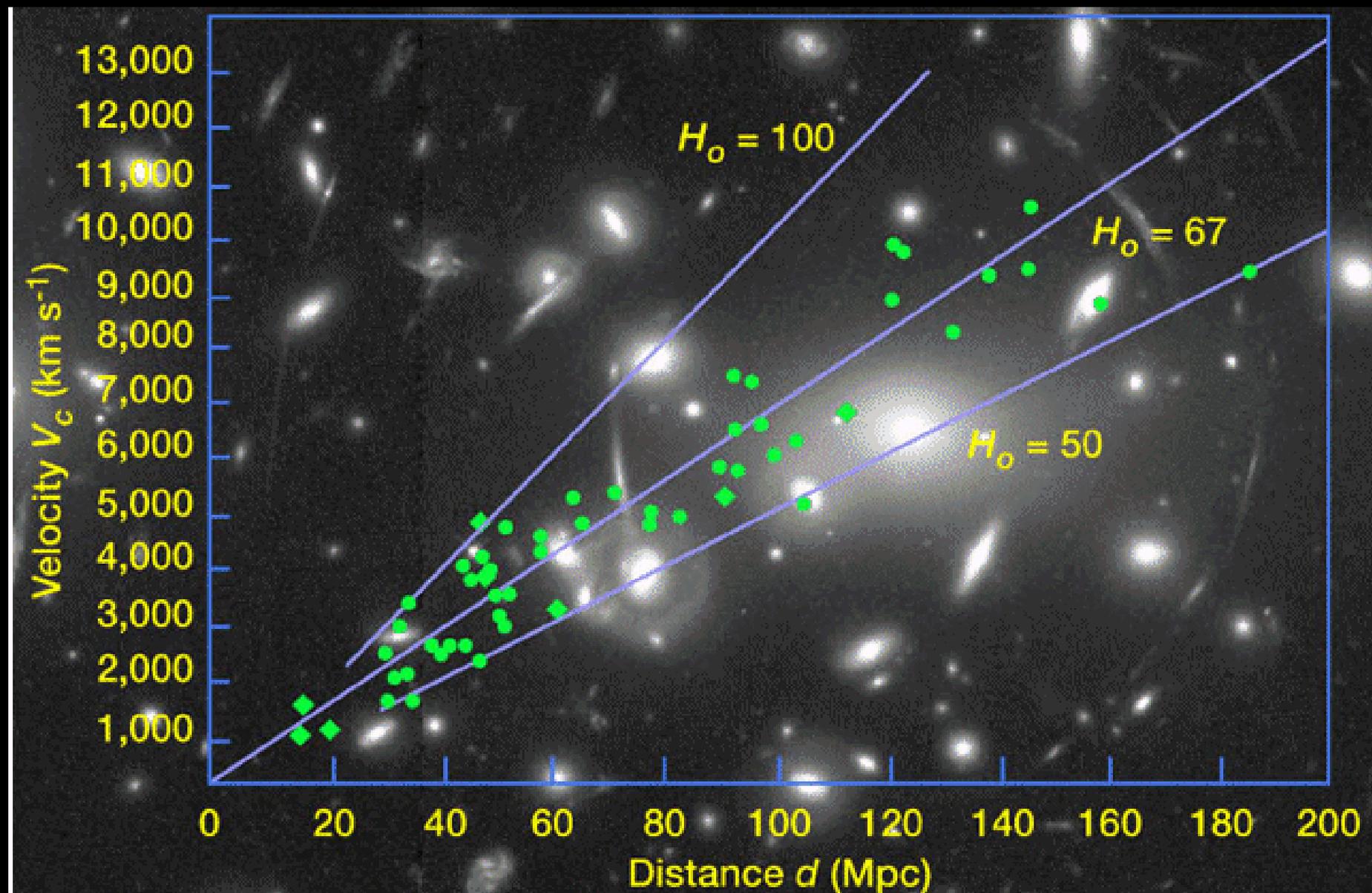
The Universe expands



Hubble (1929) - discovery of galaxies, redshift

Expansion of space: $v = H_0 d$

$$H_0 = 73 \pm 4 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad 1/H_0 = (13.4 \pm 0.7) \cdot 10^9 \text{ y}$$



The oldest stars are 13-14 billion years old

old

HD 140283 • AAO/UK Schmidt • POSS/DSS



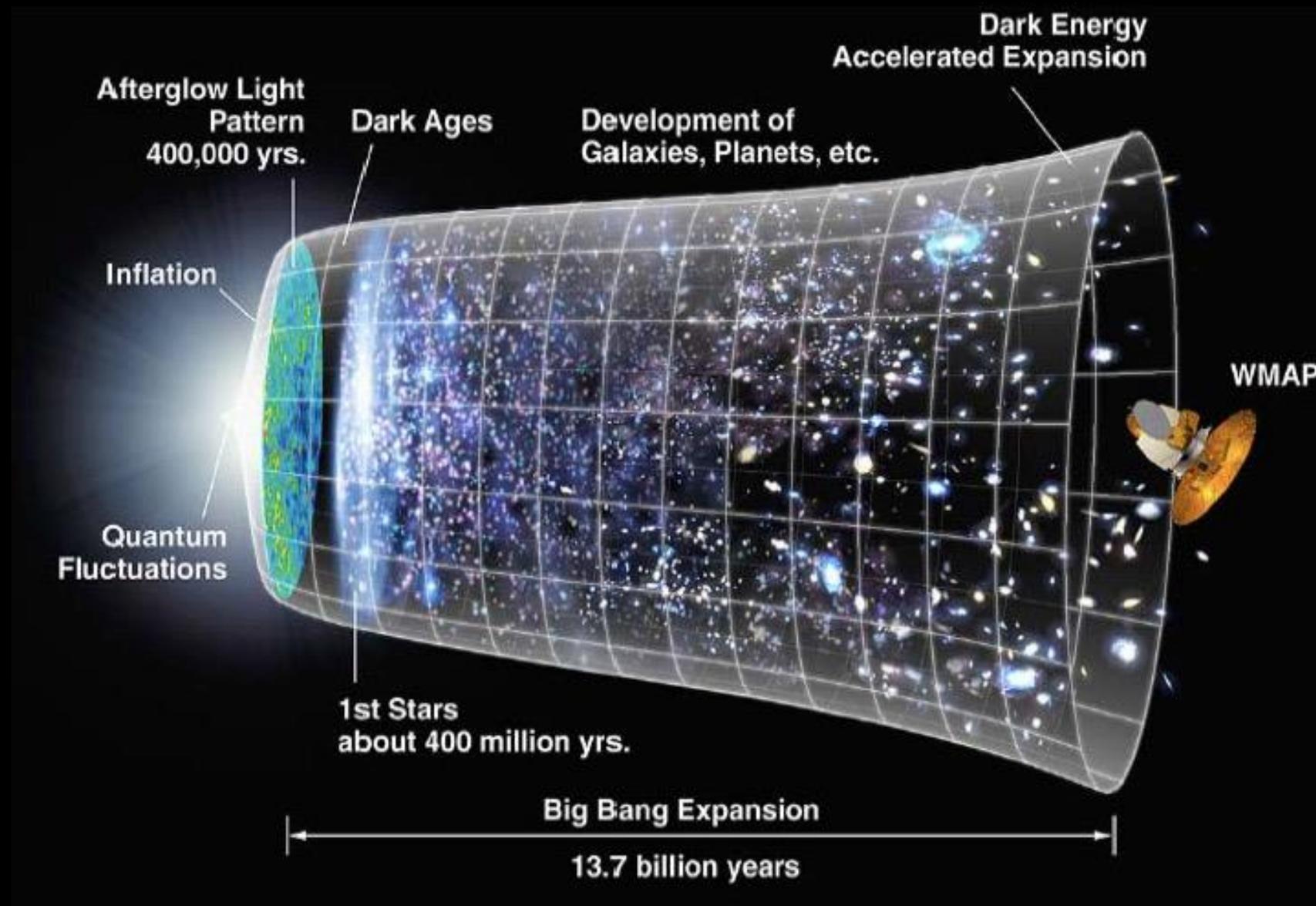
NASA and ESA

STScI-PRC13-08a

190 light years away from Earth

WHERE DO WE COME FROM ?

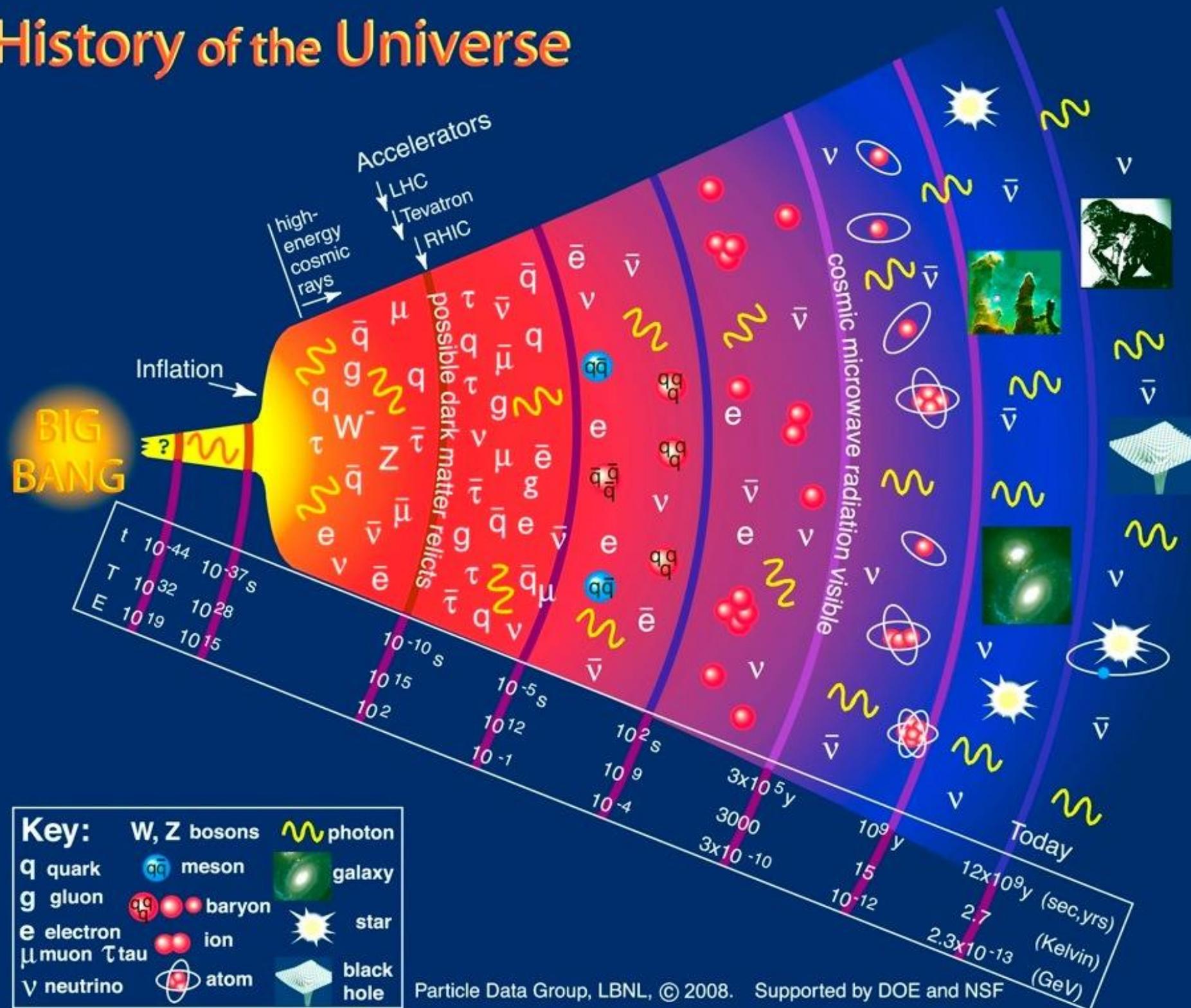
Simplest answer, compatible with all observations:
Big Bang - 13 800 Million Years ago



Mathematical model (General Relativity + Particle Physics):
Correlation between time and temperature (energy density)

Geschichte des Universums

History of the Universe



Cosmic Microwave Background

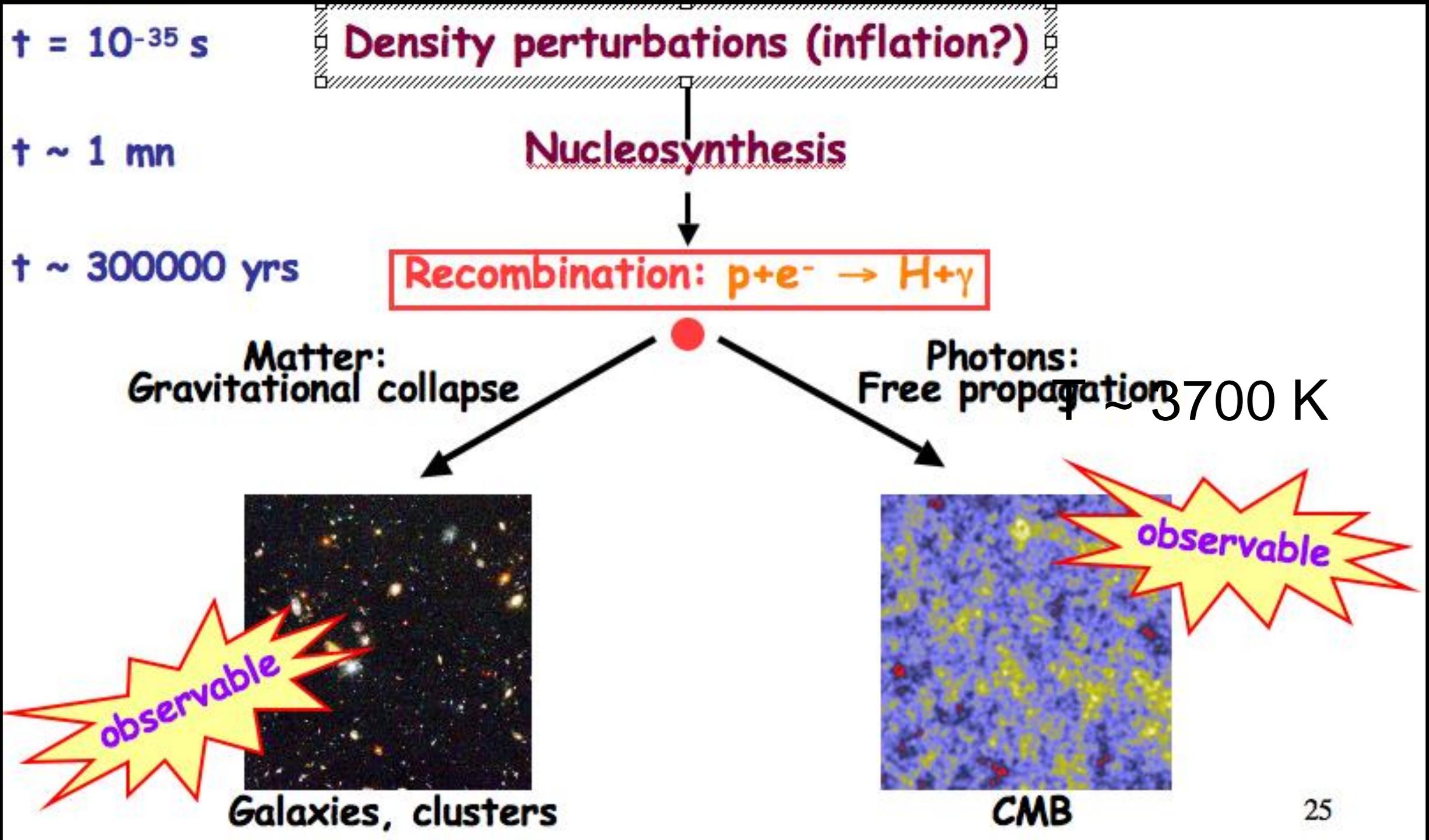
Black body radiation filling all of the Universe
homogeneously



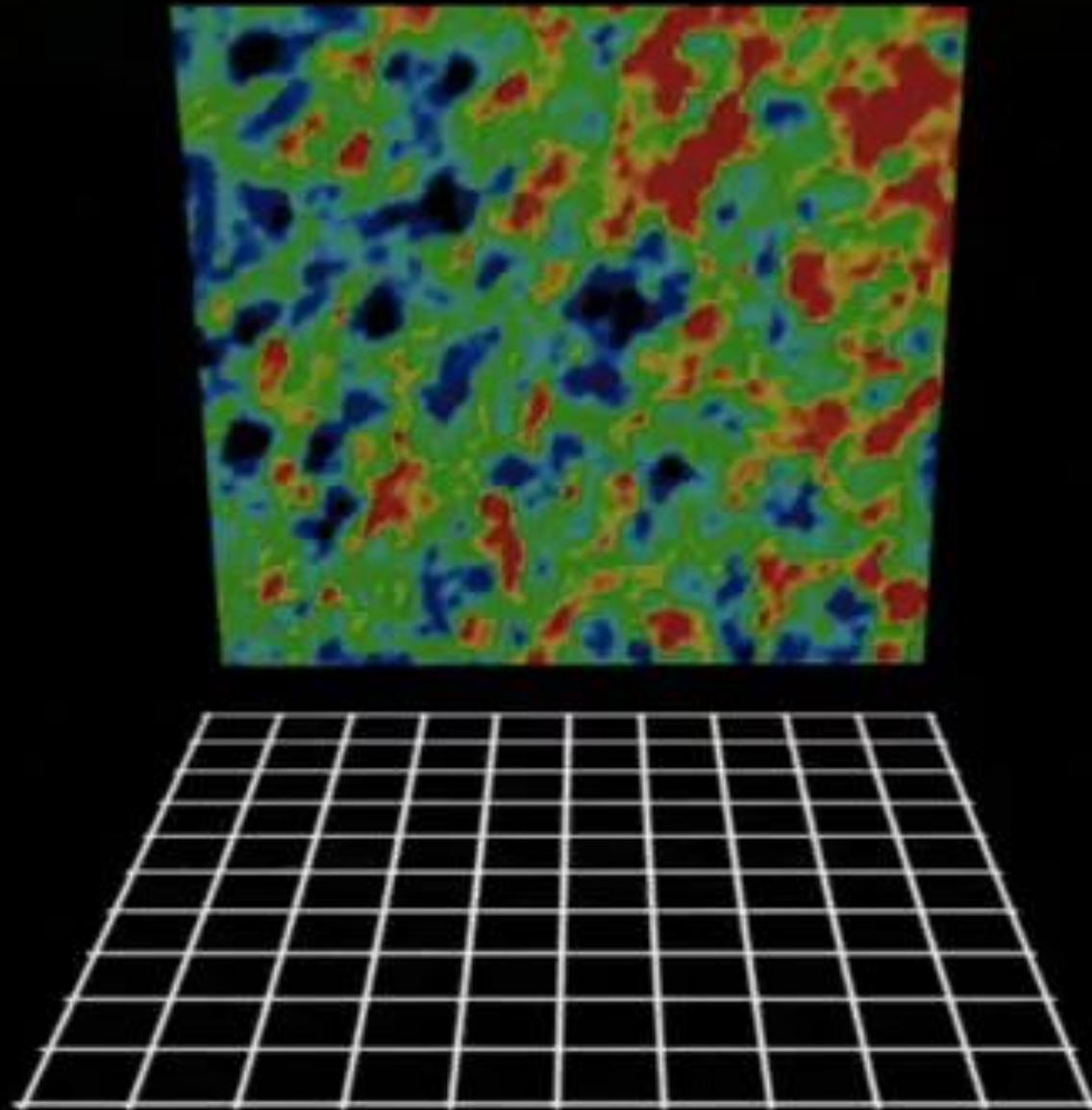
Copyright: WMAP/NASA

Precise analysis yields amazing results ...

Origin of the Cosmic Microwave Background



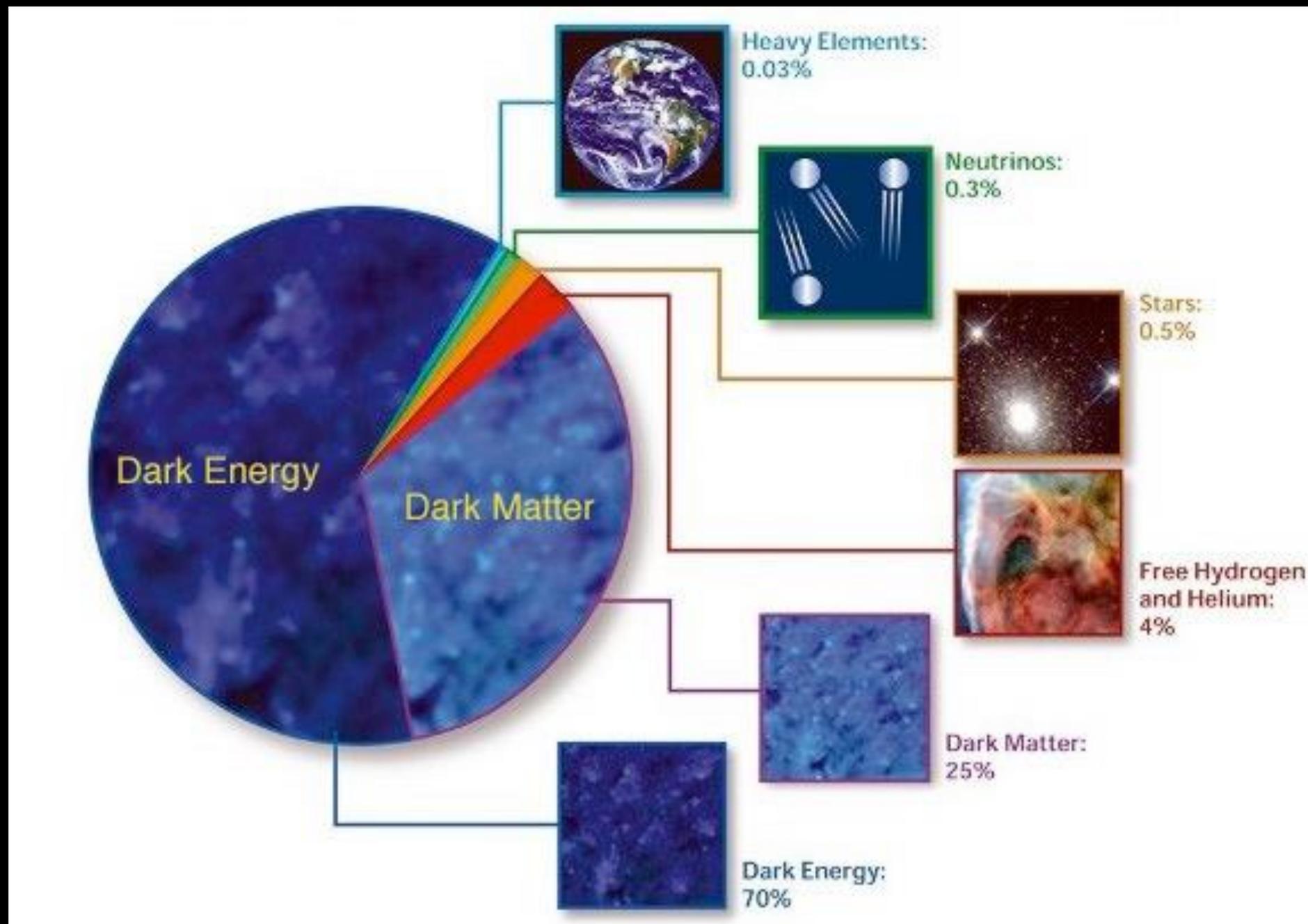
Finger print of the Big Bang



We are made of star dust

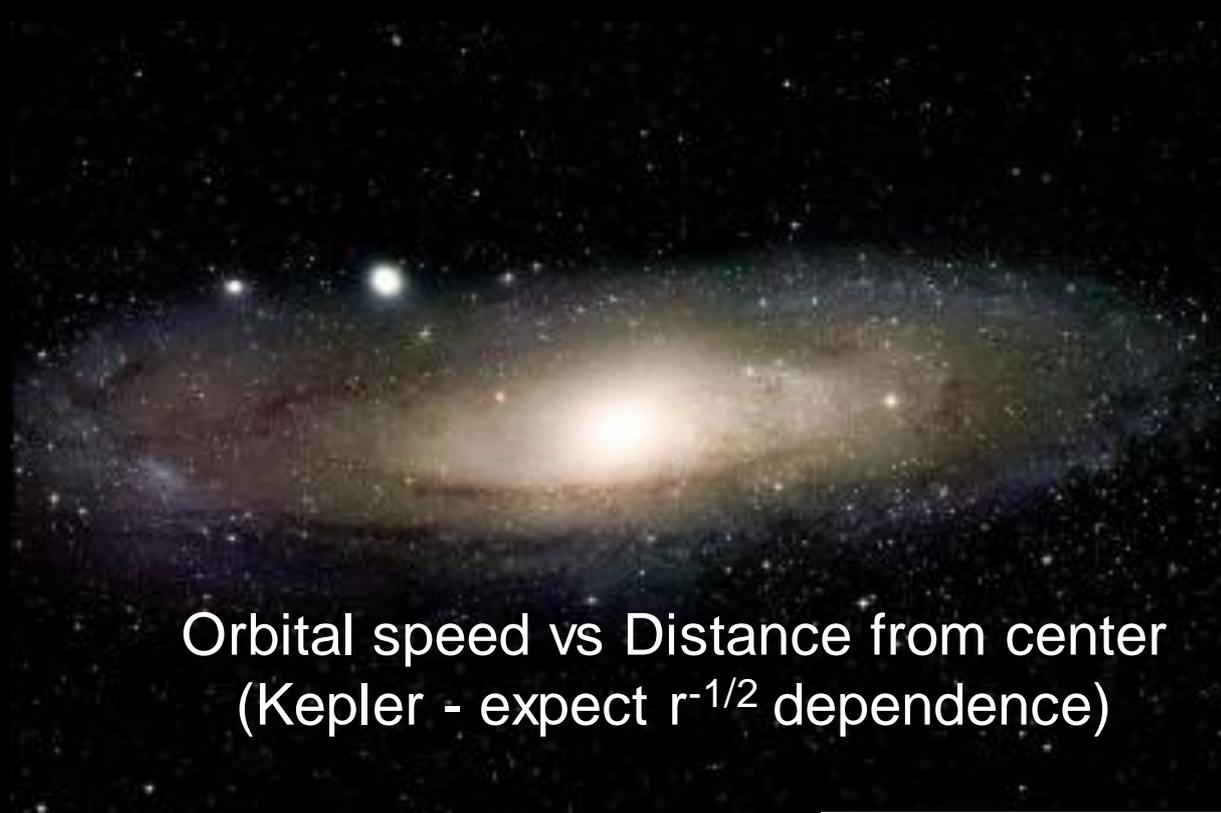


The Universe has a 'dark' side

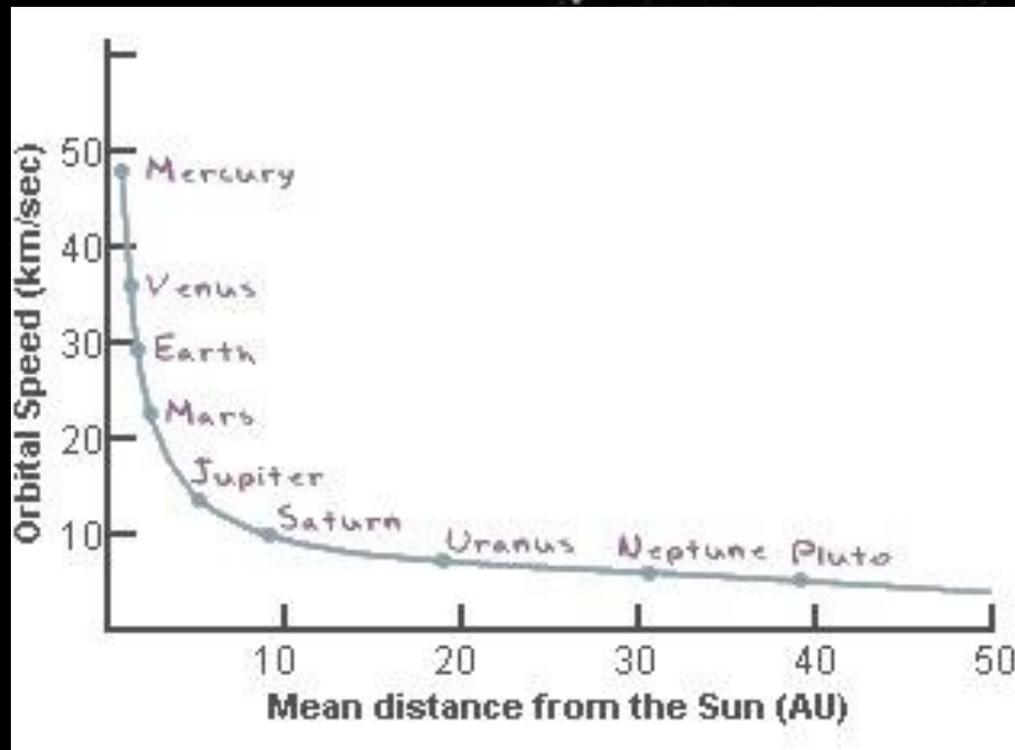


Quarks and Electrons only account for 4 % of the total energy of the Universe are filled with unknown 'dark' stuff

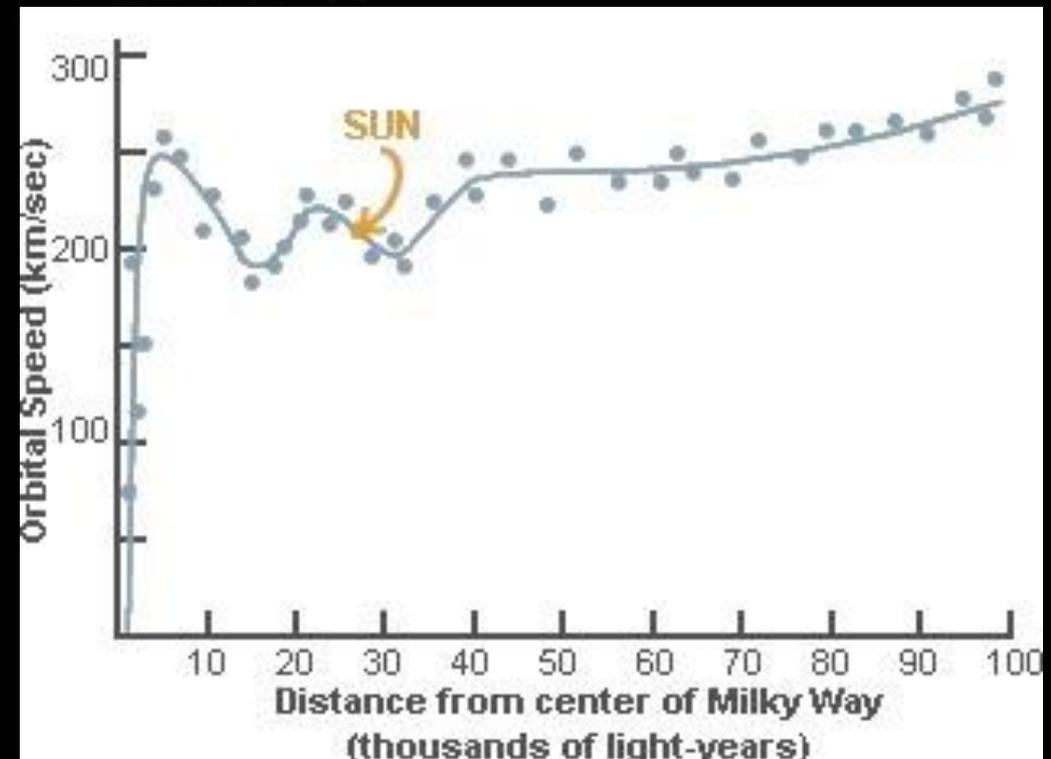
EVIDENCE FOR "DARK MATTER"



Orbital speed vs Distance from center
(Kepler - expect $r^{-1/2}$ dependence)



One central mass (Sun)



Milky Way

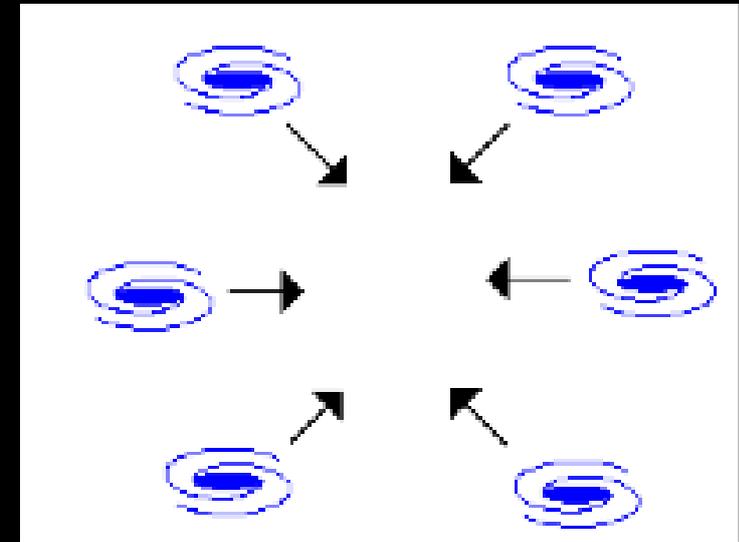
AND EVEN MORE EVIDENCE FOR “DARK MATTER”



Gravitational Lens in Abell 2218

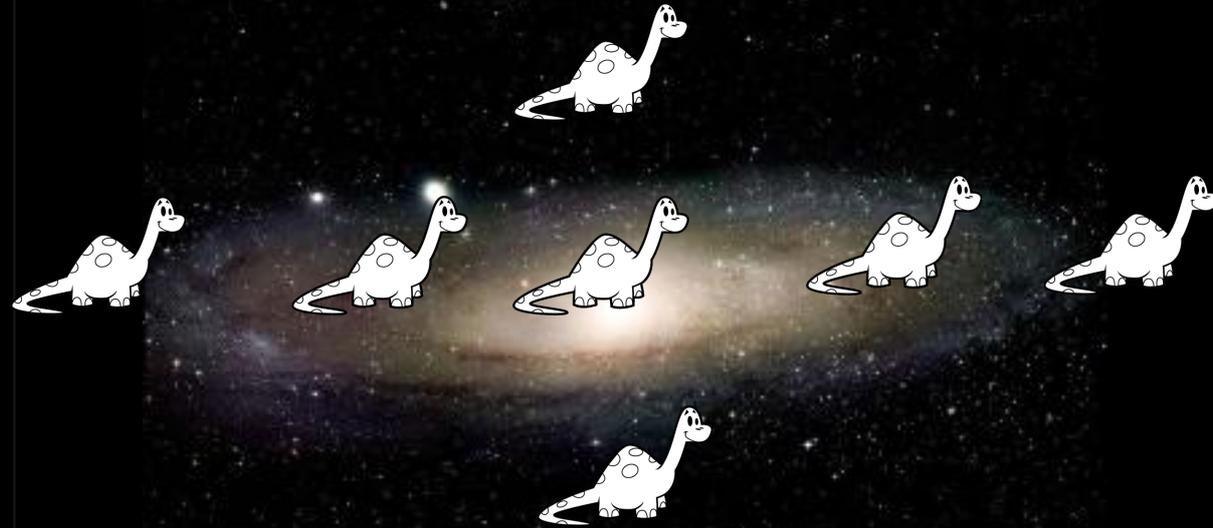
HST • WFPC2

PF95-14 • ST ScI OPO • April 5, 1995 • W. Couch (UNSW), NASA

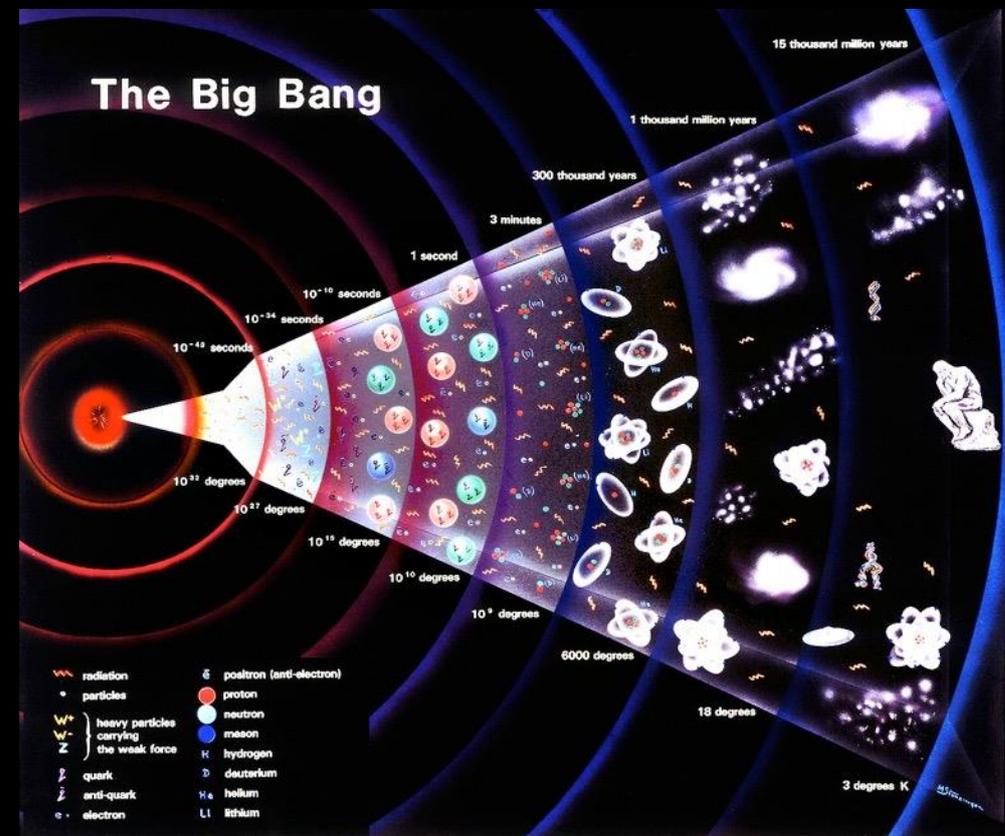


GRAVITATIONAL LENSING

SUSY particles = Dark Matter?



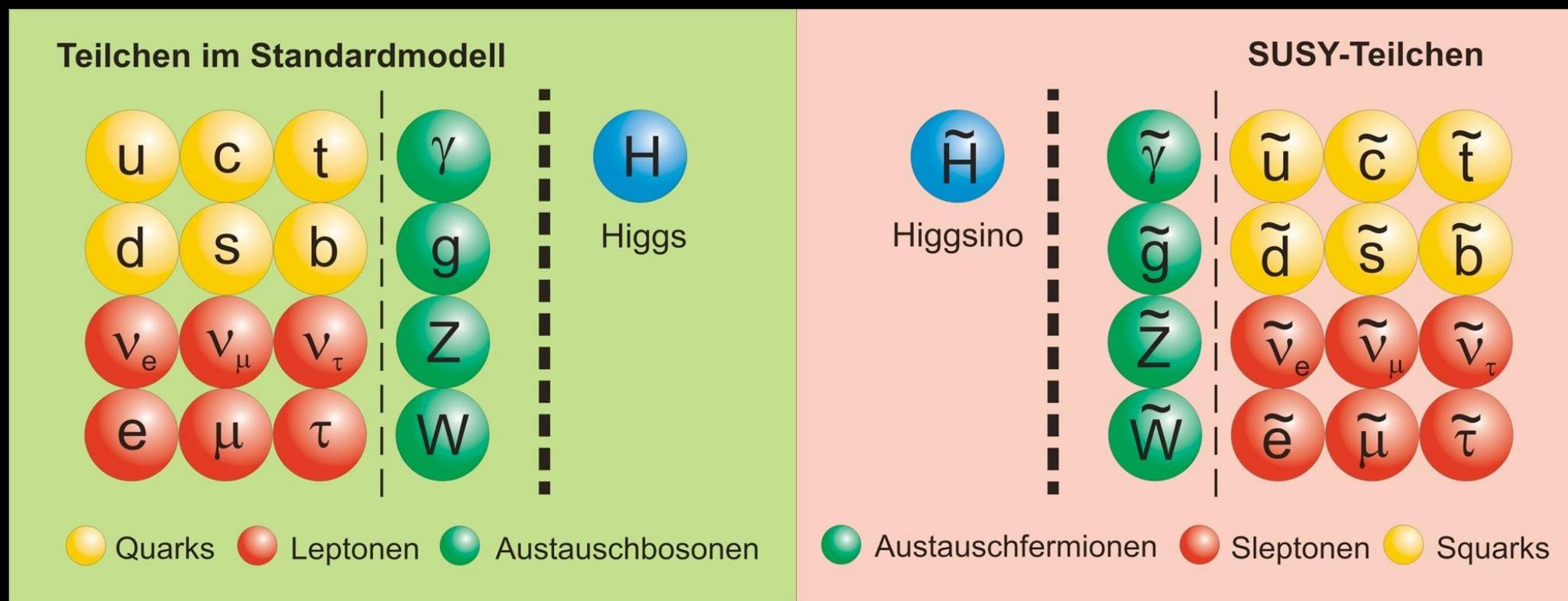
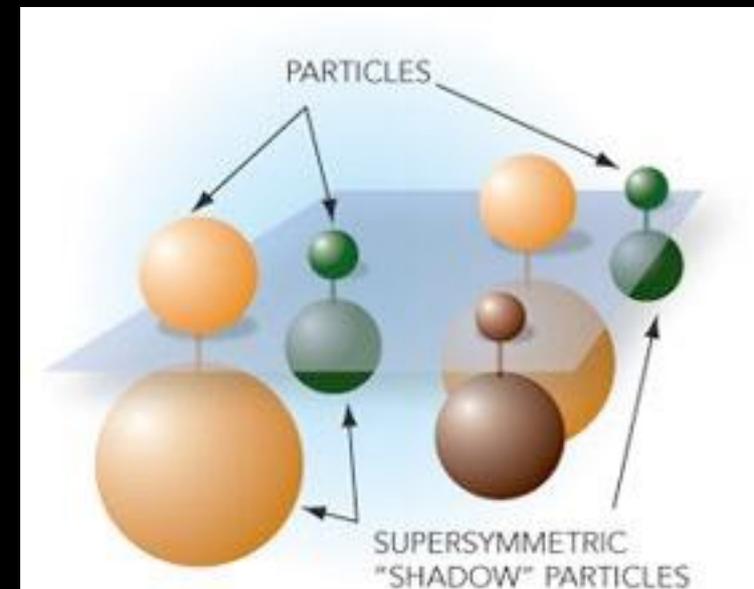
SUSY = Dark matter particles left over from Big Bang?



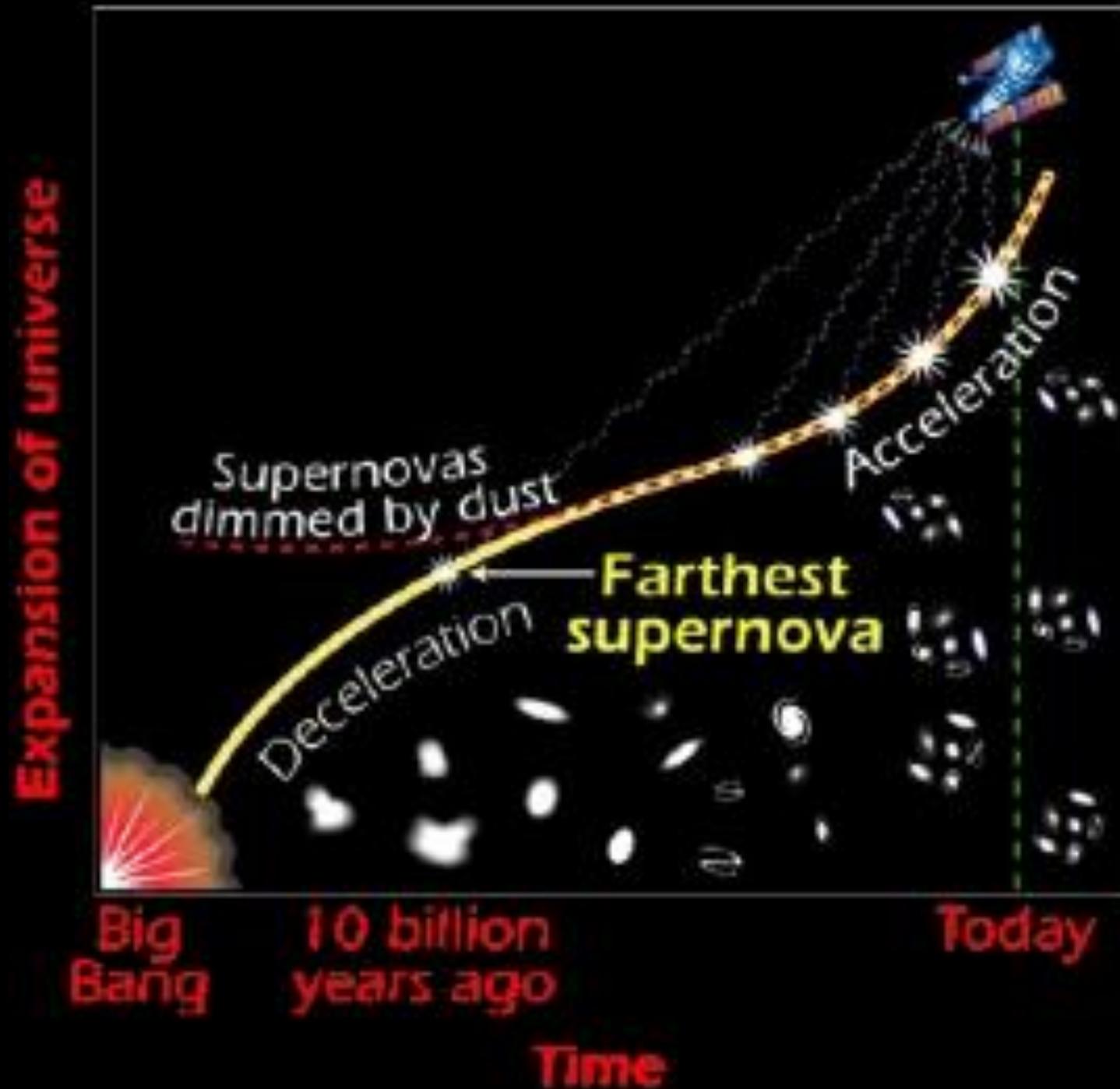
Supersymmetry ?

Is there a deeper **SUPERSYMMETRY** between matter and fields?

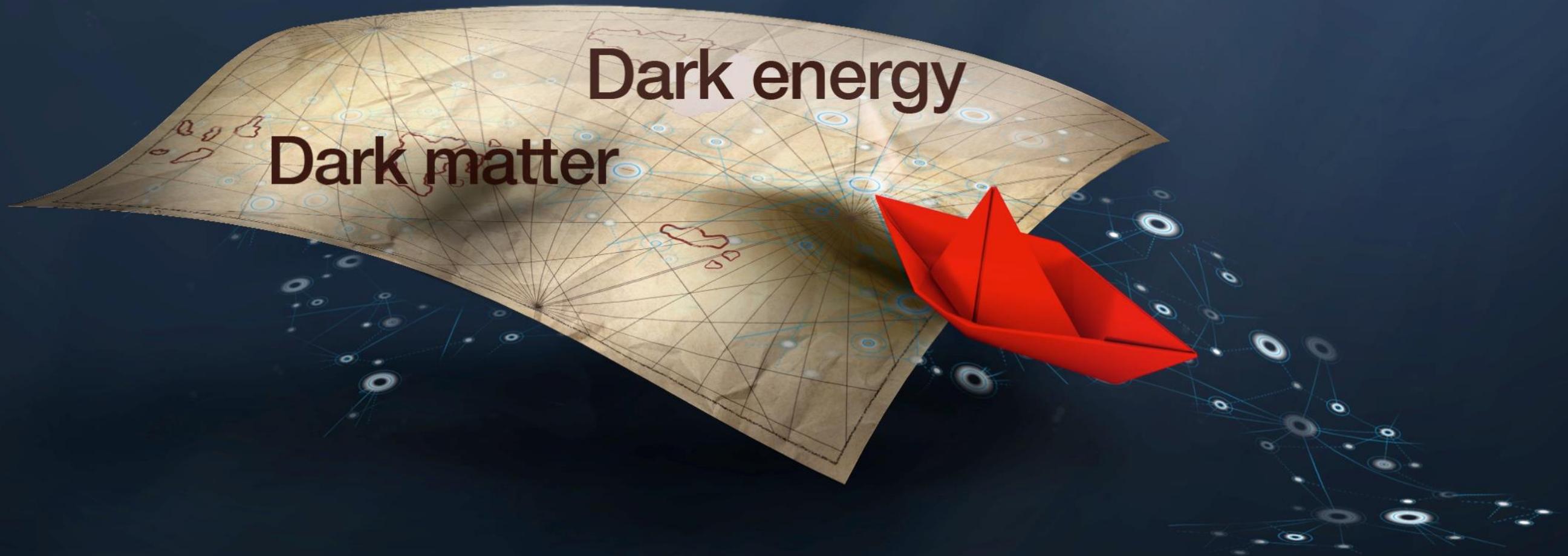
all matter particles have a field partner
all field particles have a matter partner



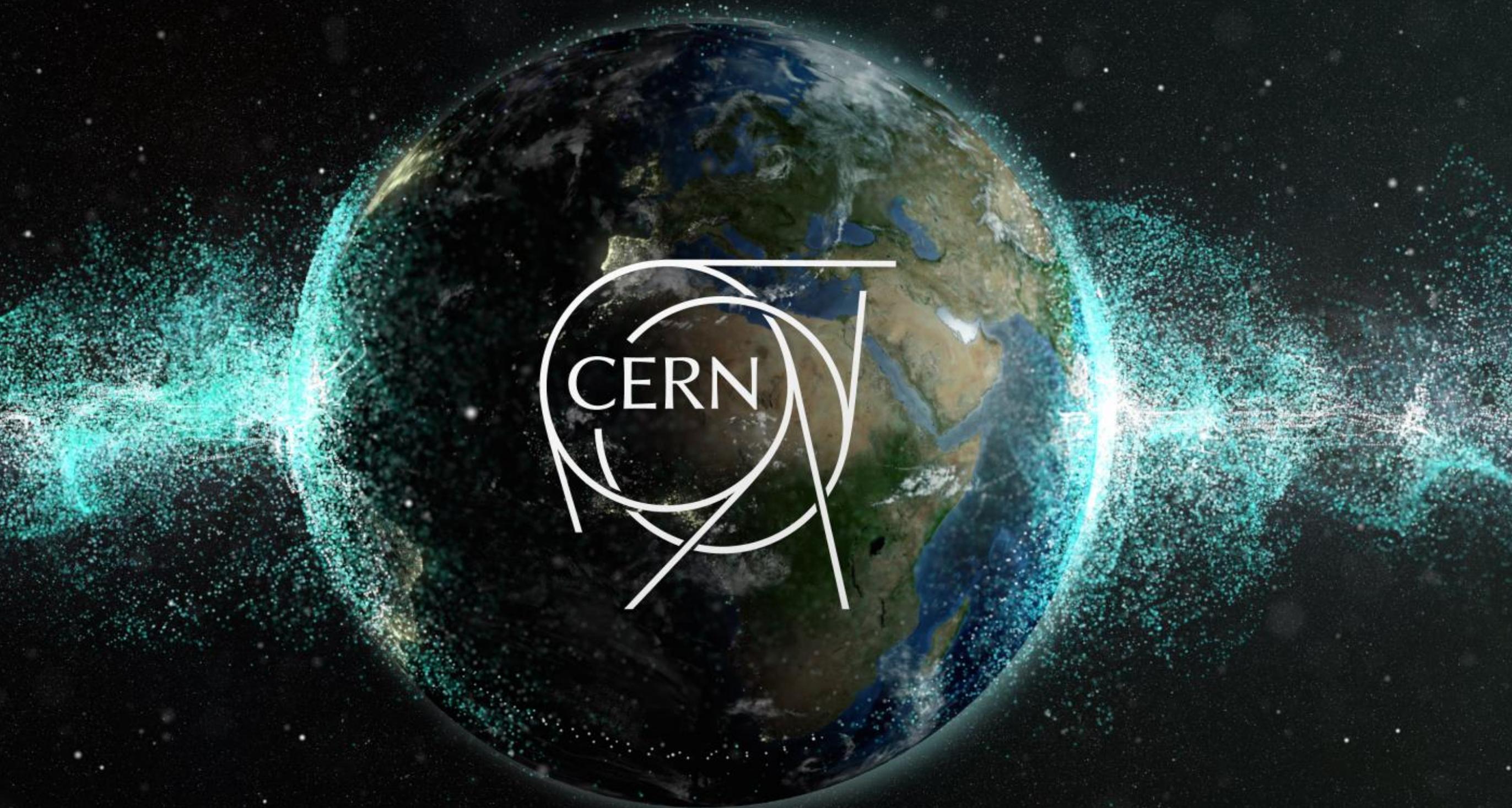
Evidence for Dark Energy



Voyage into the 'dark Universe'



CERN: Collaboration of mankind

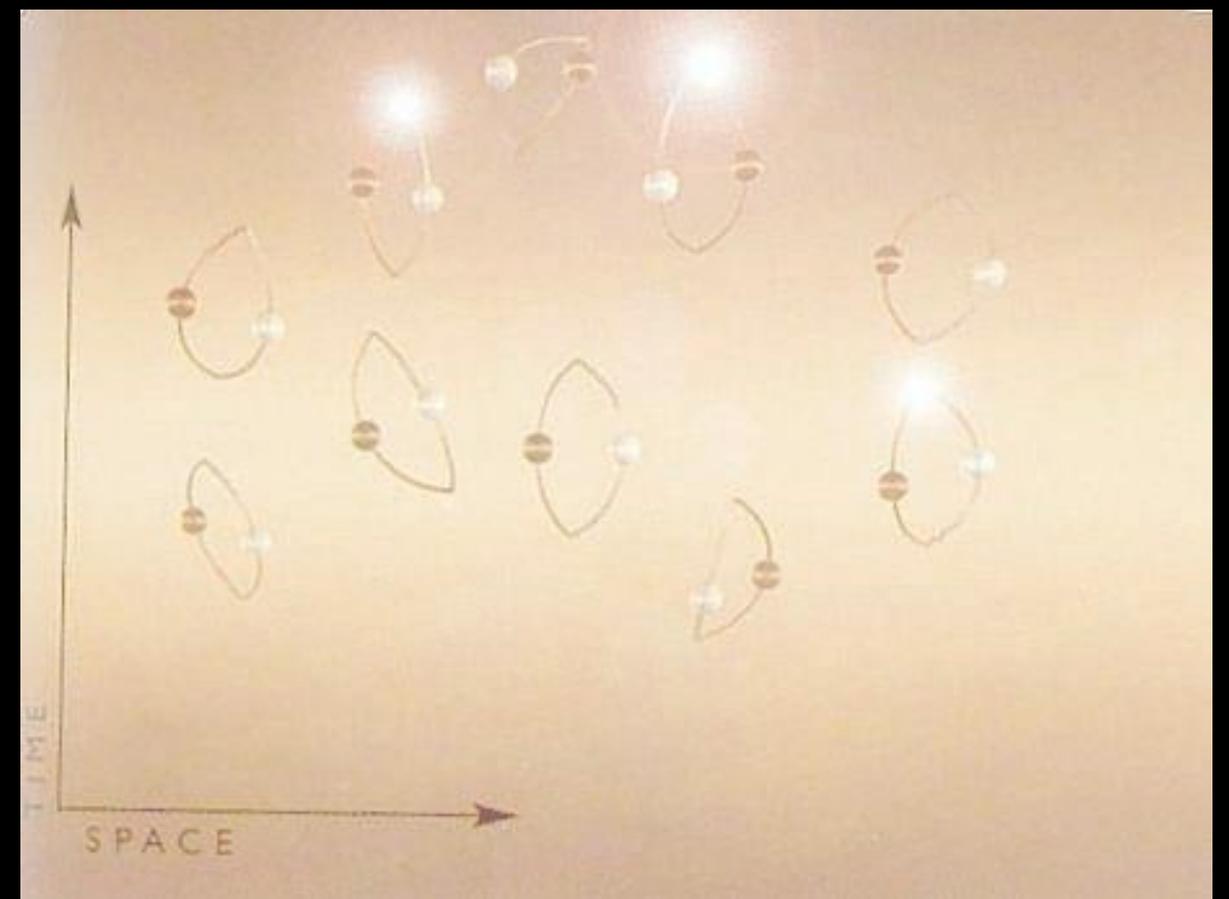


SOMETHING OUT OF NOTHING

Real particle pairs
($E \geq 2m$)



Virtual particle pairs
($\Delta E \Delta t \sim h$)

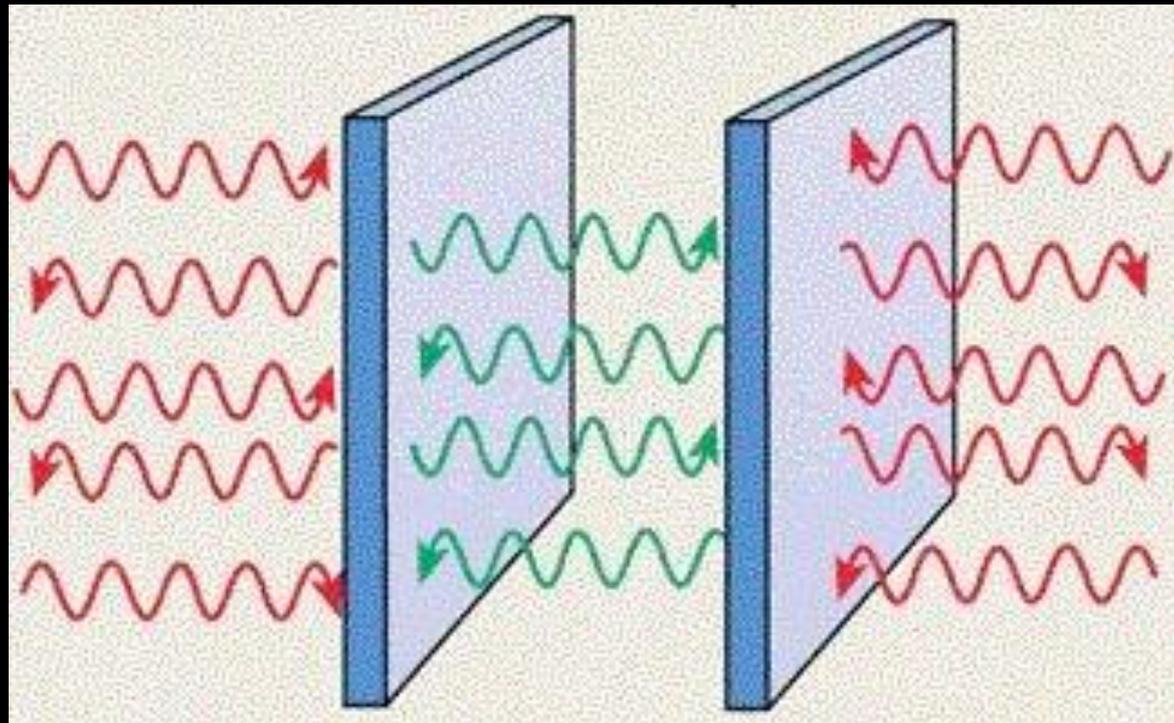


An old philosophical question ...
and the key to understanding the Big Bang.

Vacuum Fluctuations

Fields have a 'hyperactivity syndrome', too

Casimir (1948)



Vacuum exerts force on two uncharged metal plates

“Empty space” is not empty