Dark Matters

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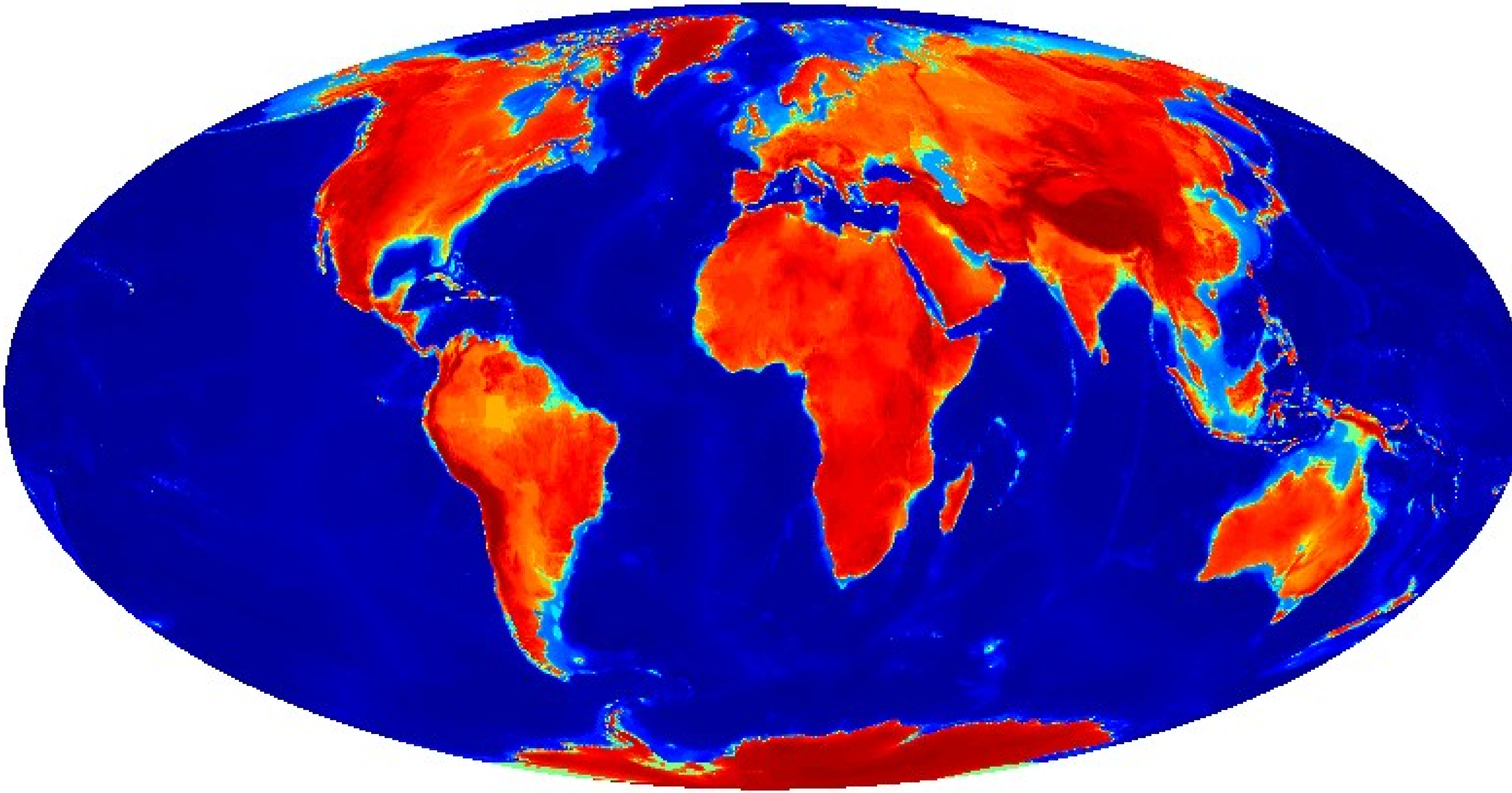
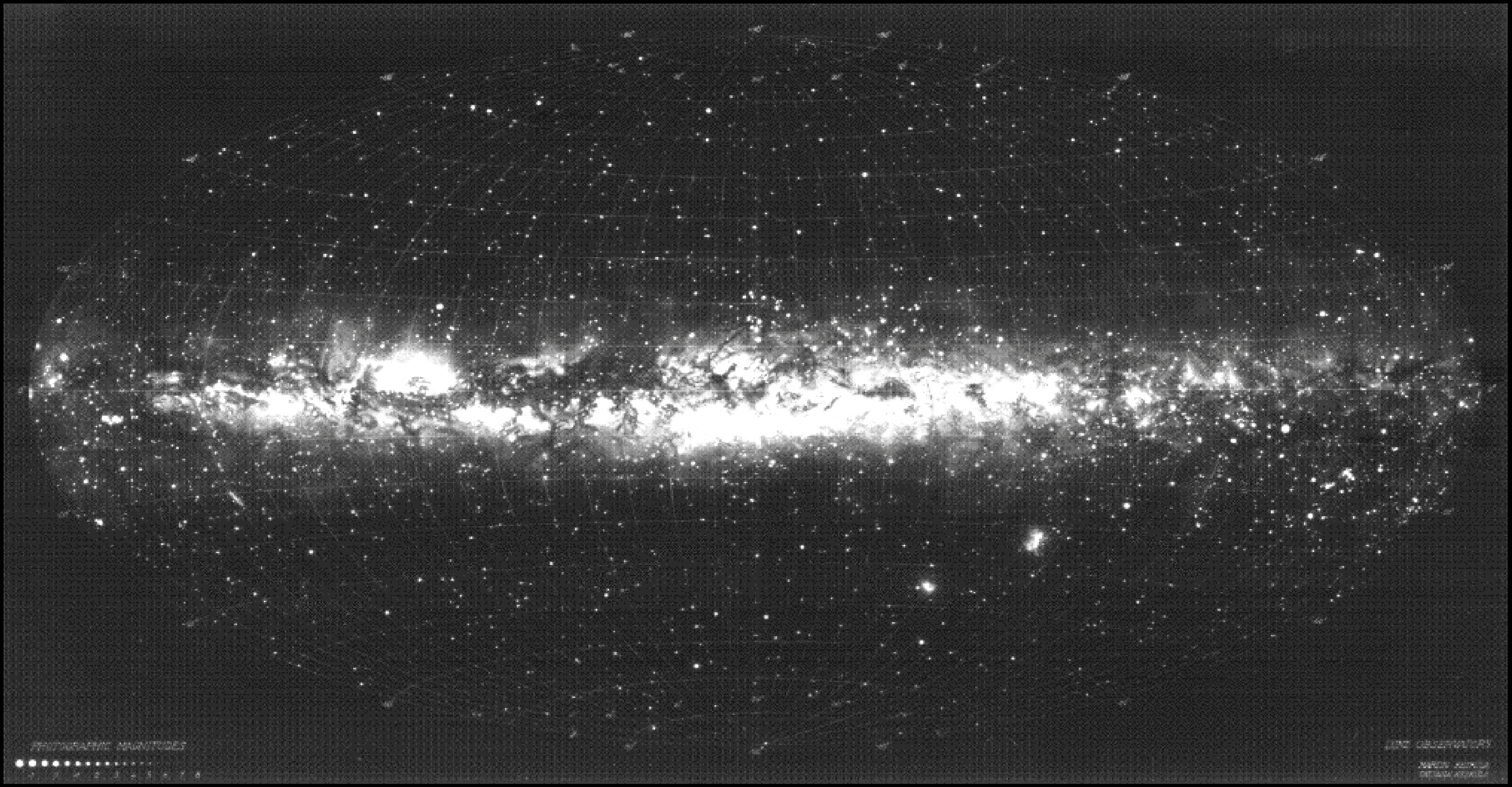
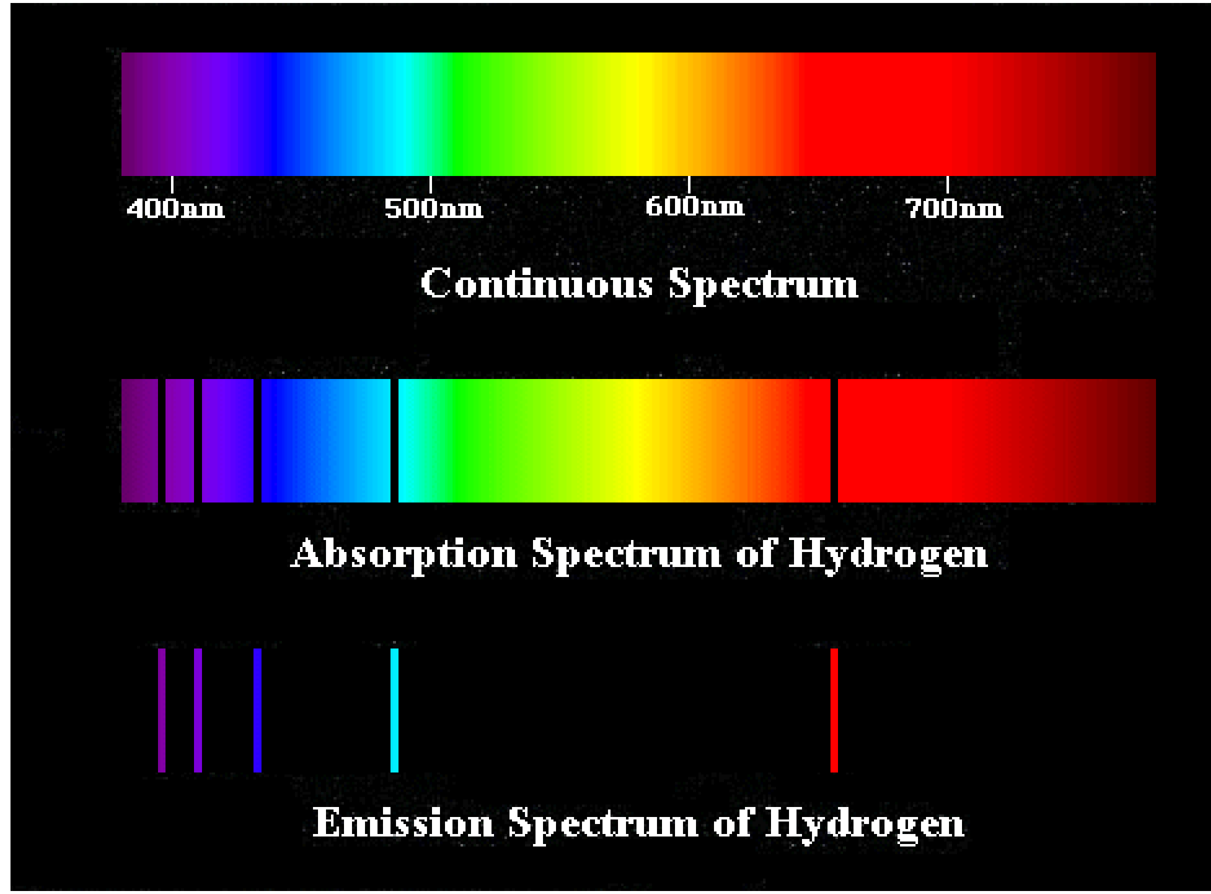
What can we know about things we cannot touch?

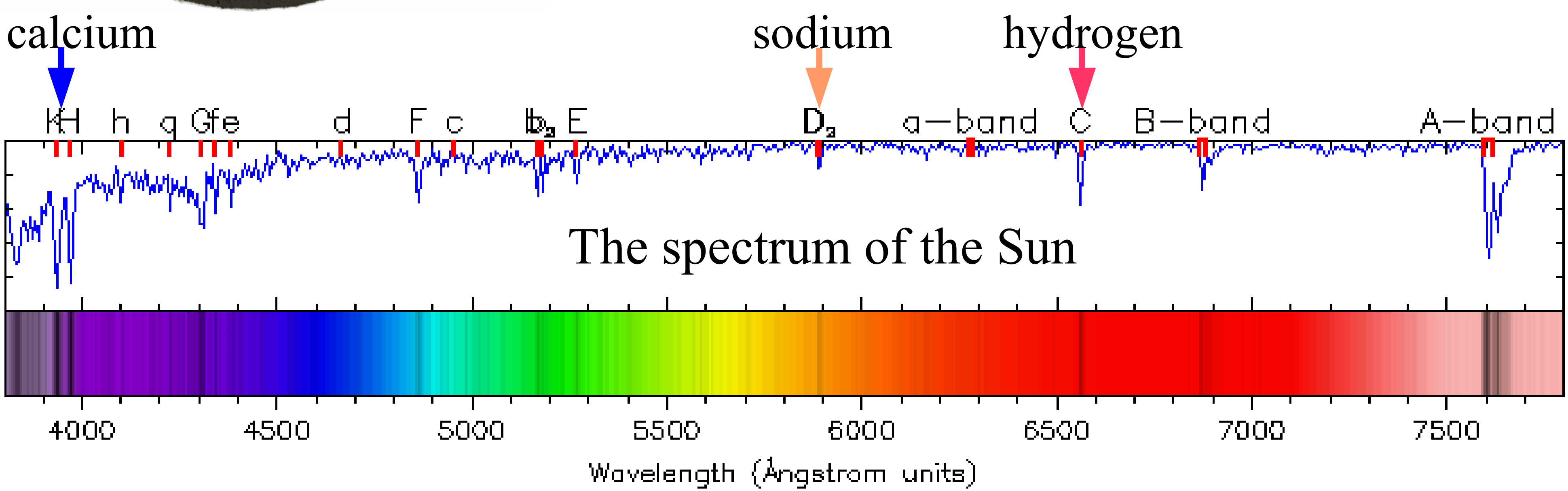


Star map of the whole sky

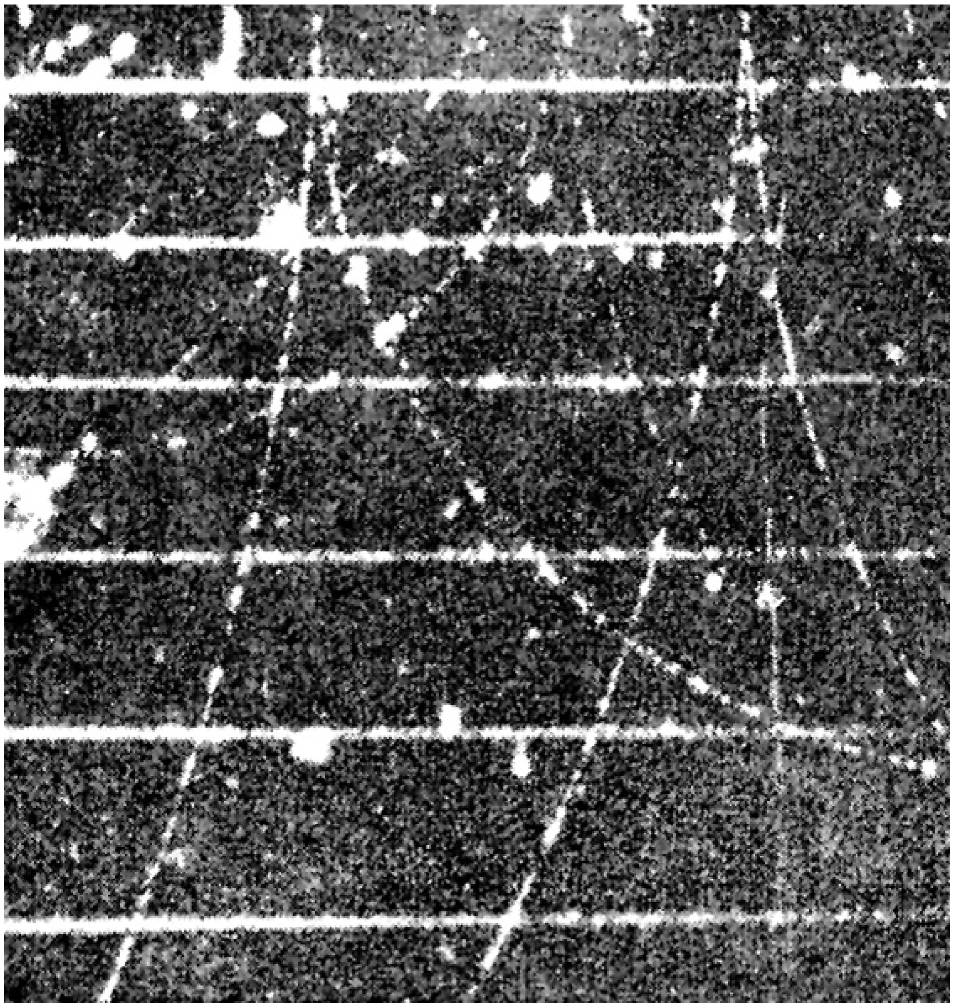



Joseph
von Fraunhofer


400nm
500nm
600nm
700nm
Continuous Spectrum
Absorption Spectrum of Hydrogen
Emission Spectrum of Hydrogen


calcium
sodium
hydrogen
K H
h
g
G
fe
d
F
c
b
E
D
a–band
C
B–band
A–band
The spectrum of the Sun
4000
4500
5000
5500
6000
6500
7000
7500
Wavelength (Ångstrom units)

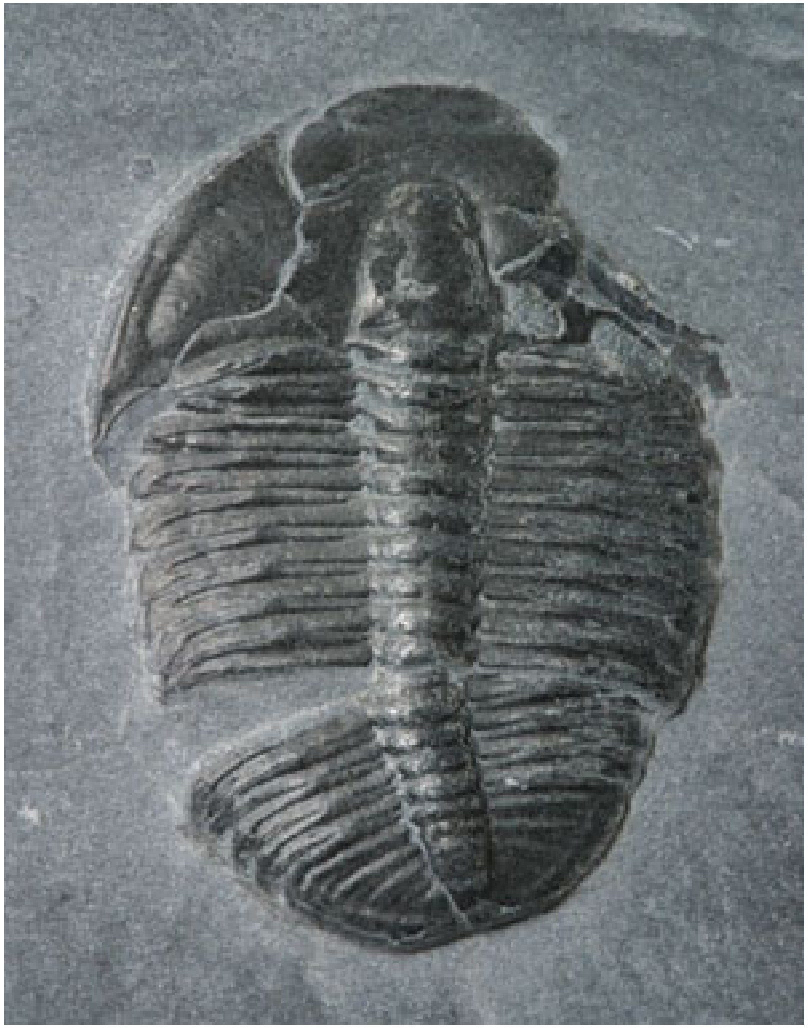
What can we know about things we cannot see?

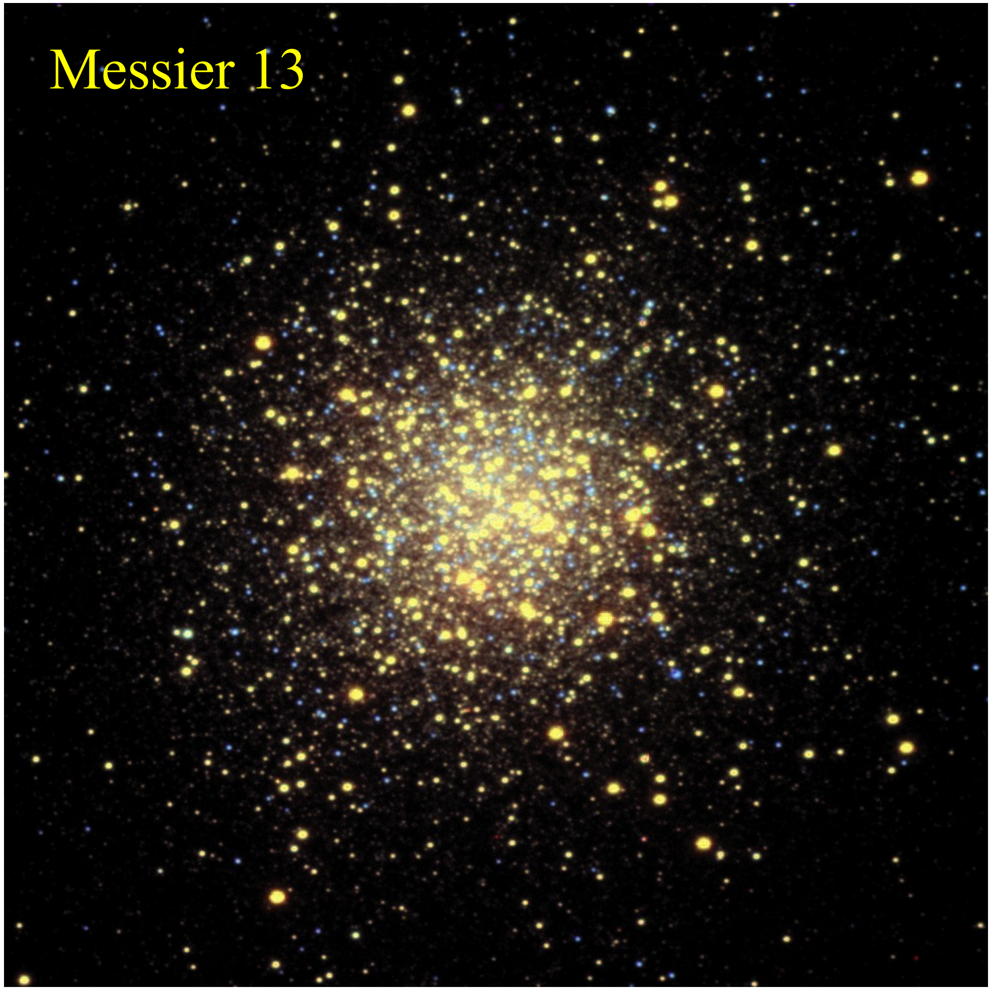

e⁻
e⁺
e⁻
e⁻

What can we know about things that affect nothing we can see or touch?

What can we know about processes which act over billions of years when we live for only three-score and ten?

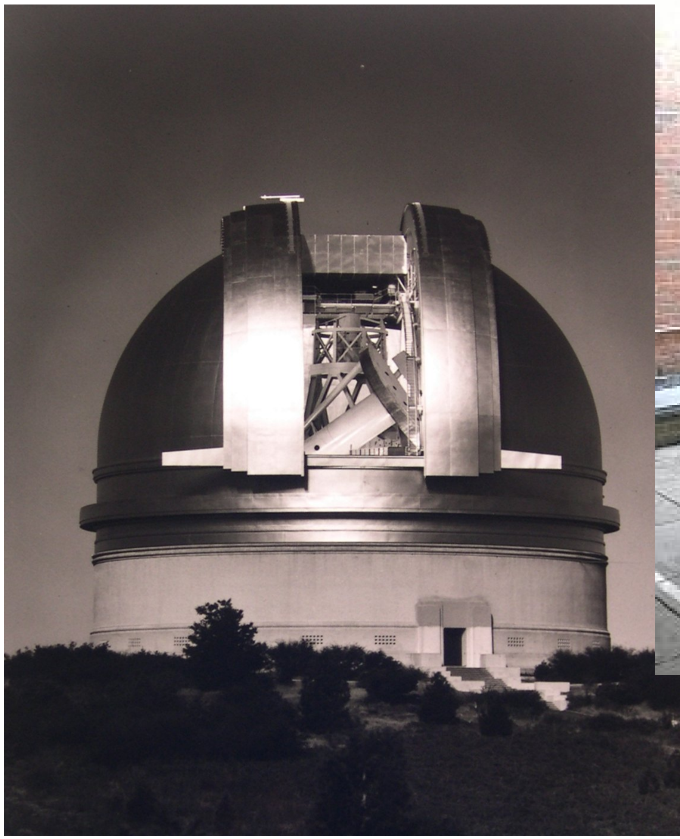
Do archaeology!





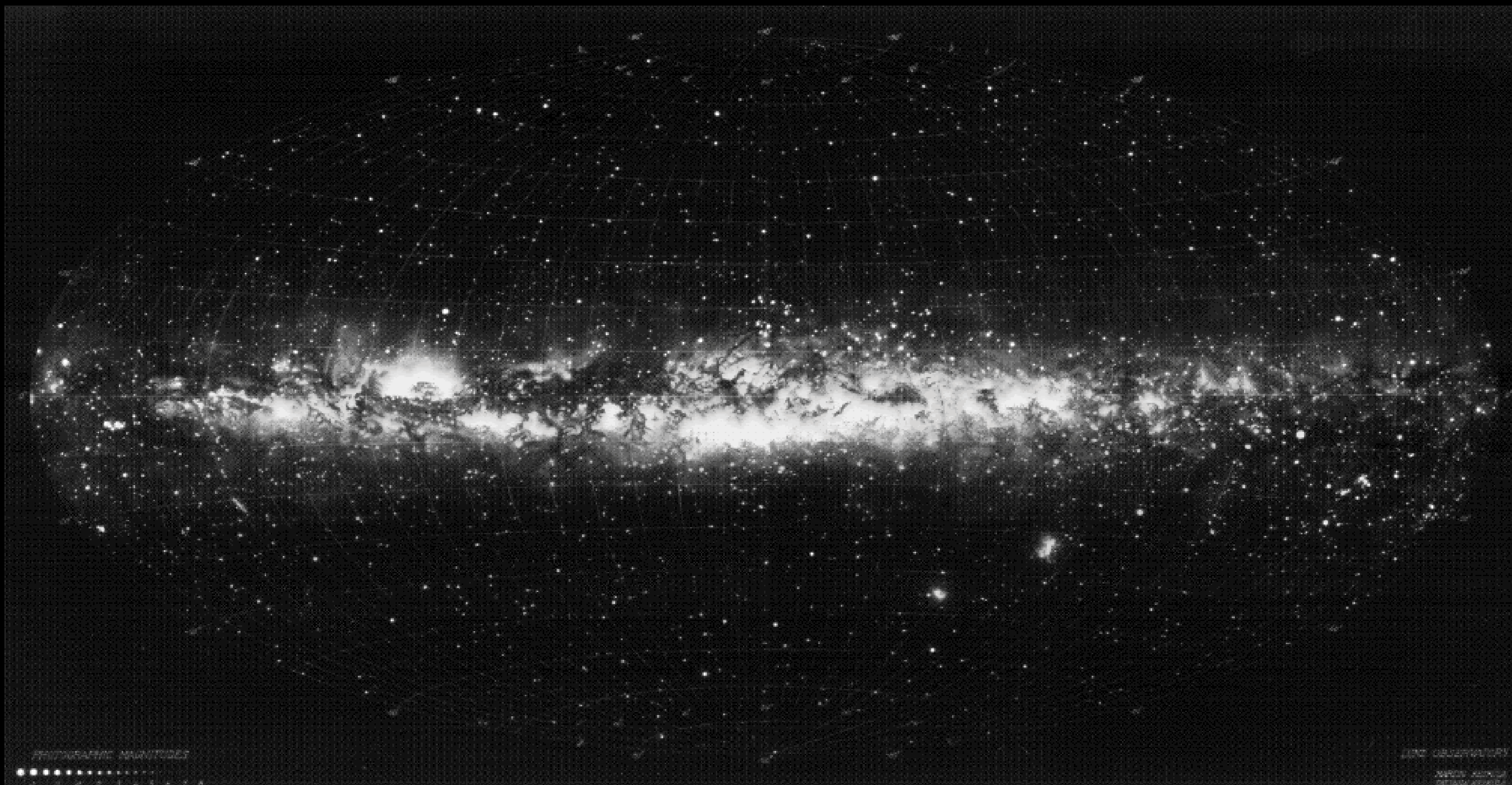
Use old objects to find out what the Universe was like when they were young.

Use telescopes as time machines - look directly into the past

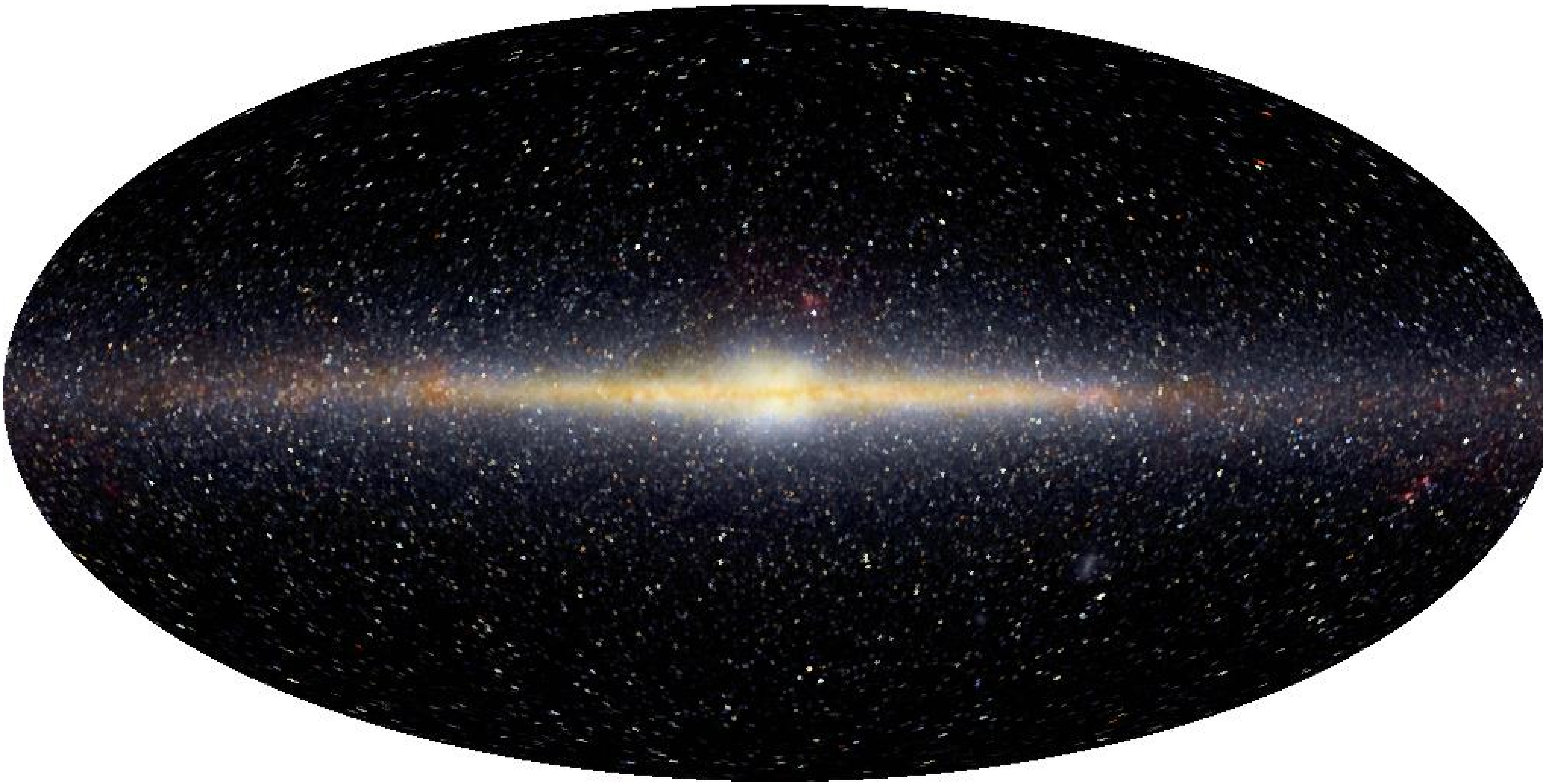


We see objects as they were when the light left them, not as they are today

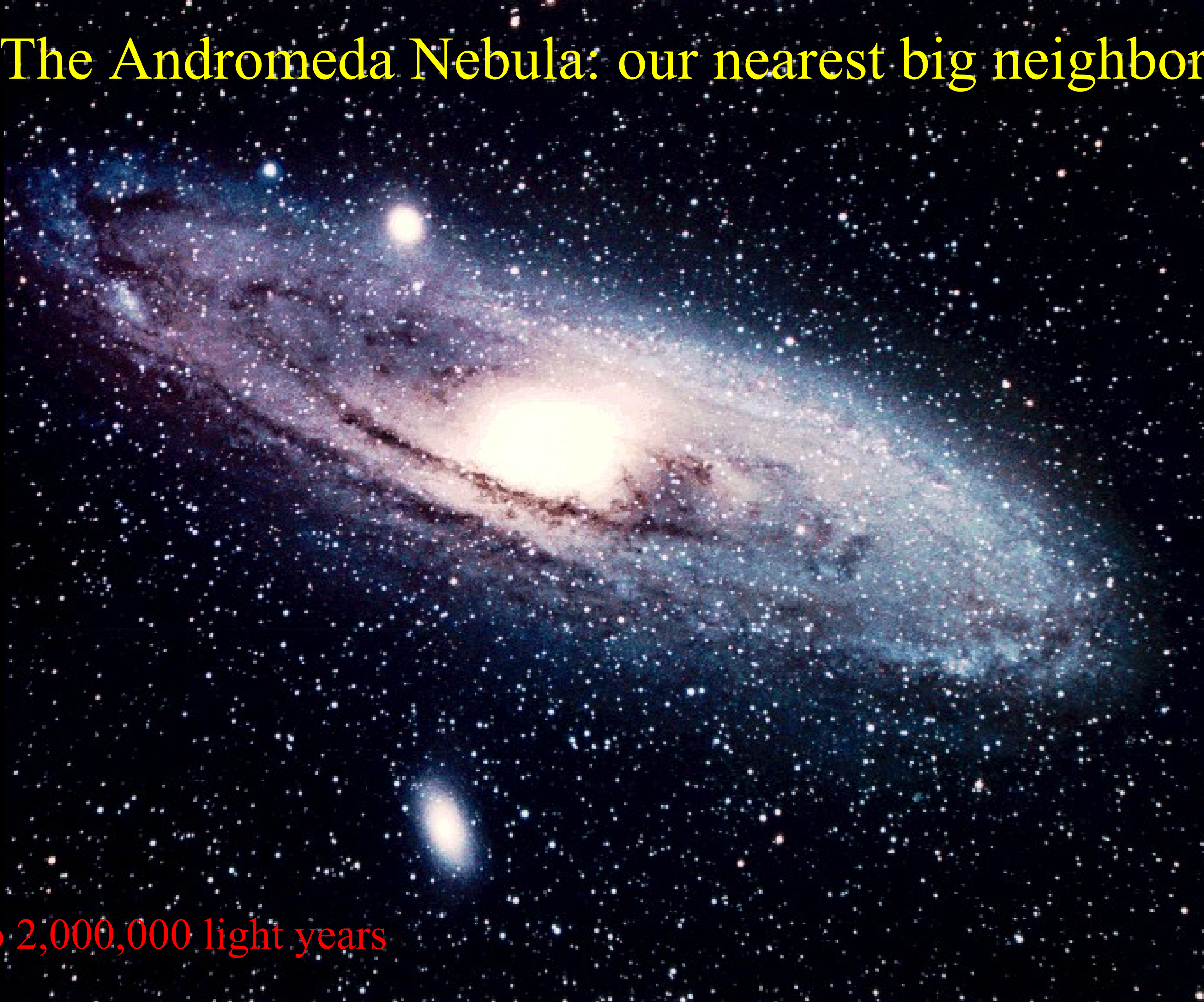
Star map of the whole sky



to 10,000 light years



to 30,000 light years

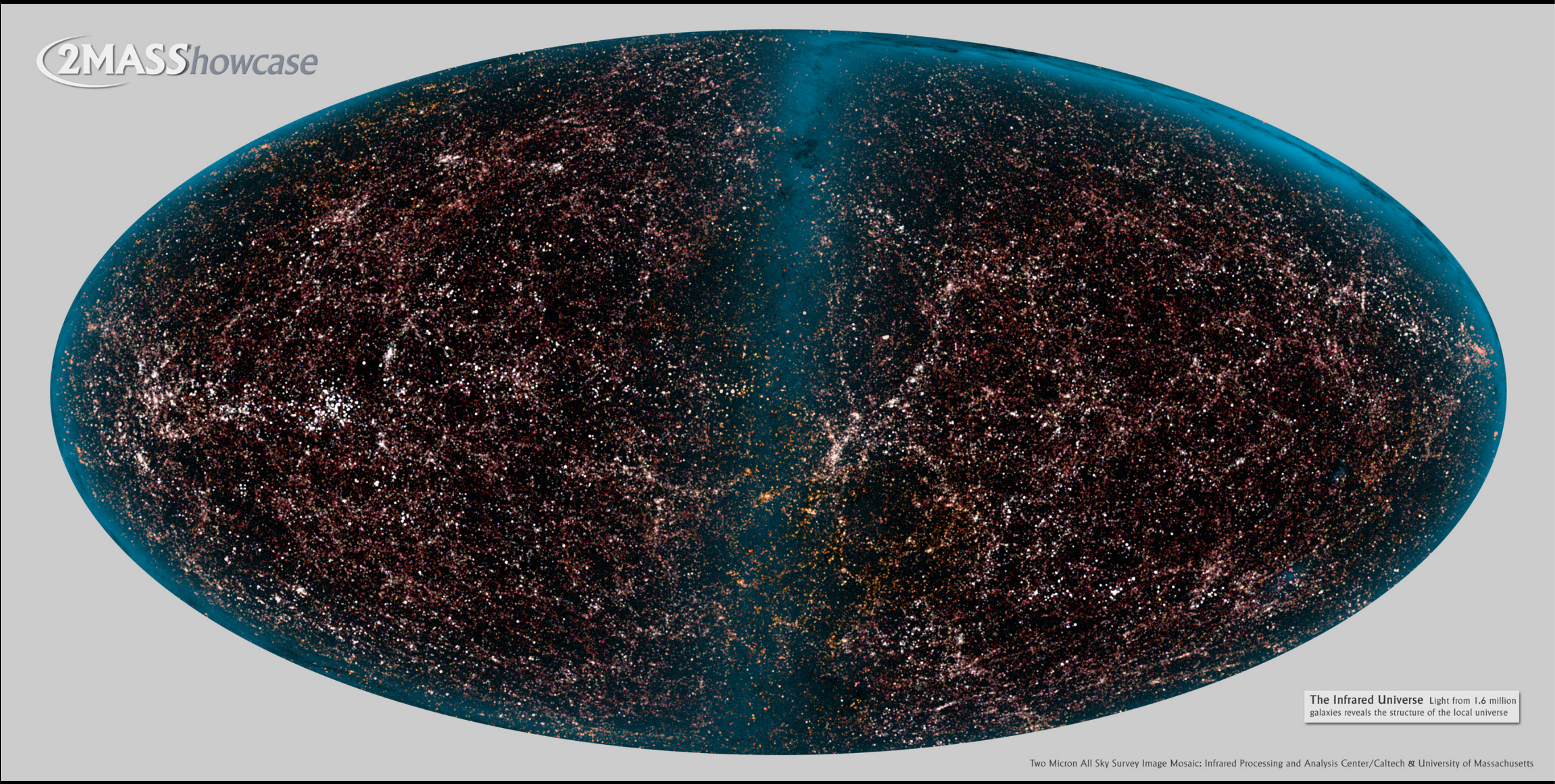

The Andromeda Nebula: our nearest big neighbor
to 2,000,000 light years

Spiral galaxies

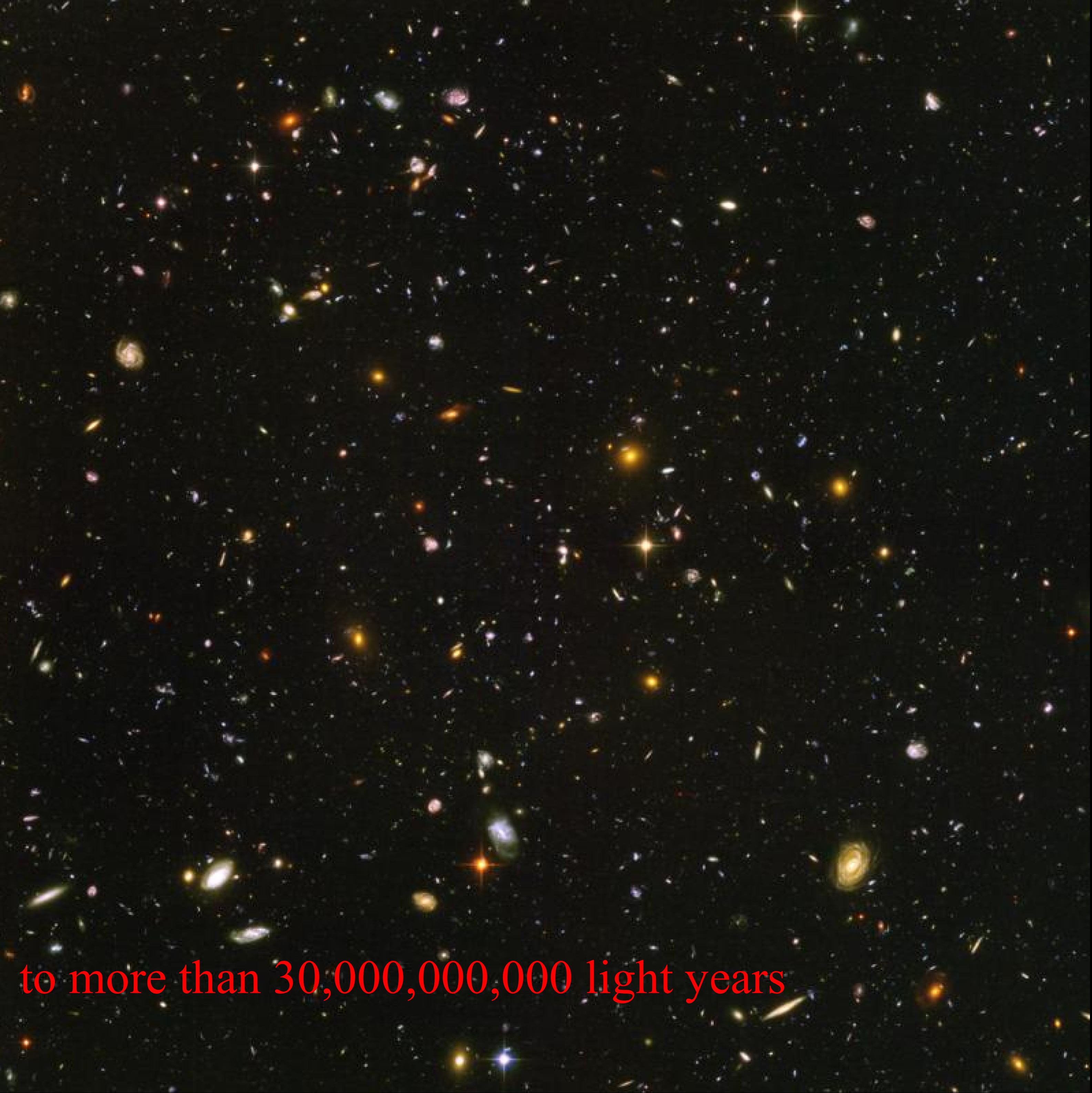
M101

NGC 5907

Map of galaxies across the whole sky



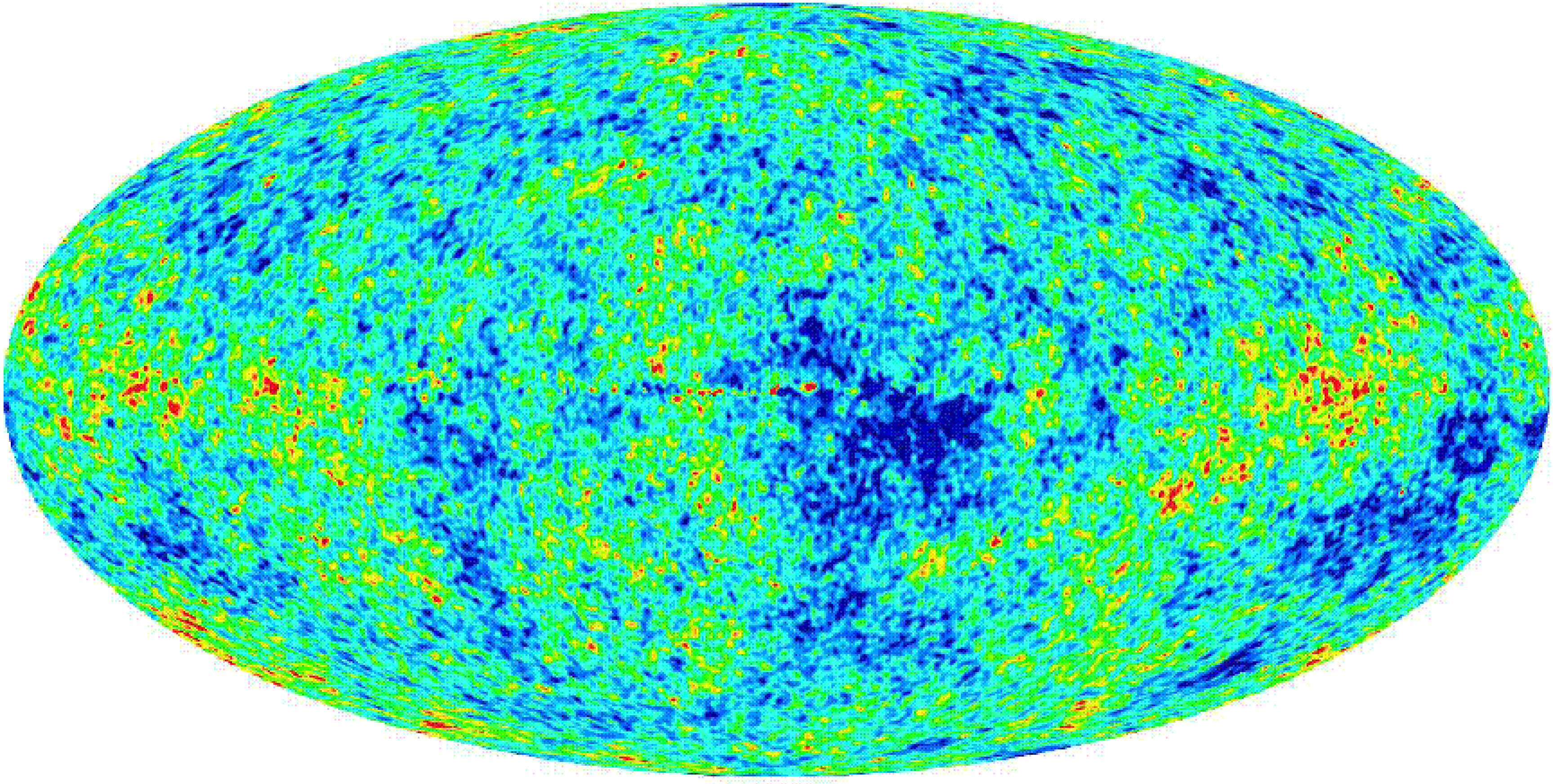
to 1,000,000,000 light years



The deepest photo ever made

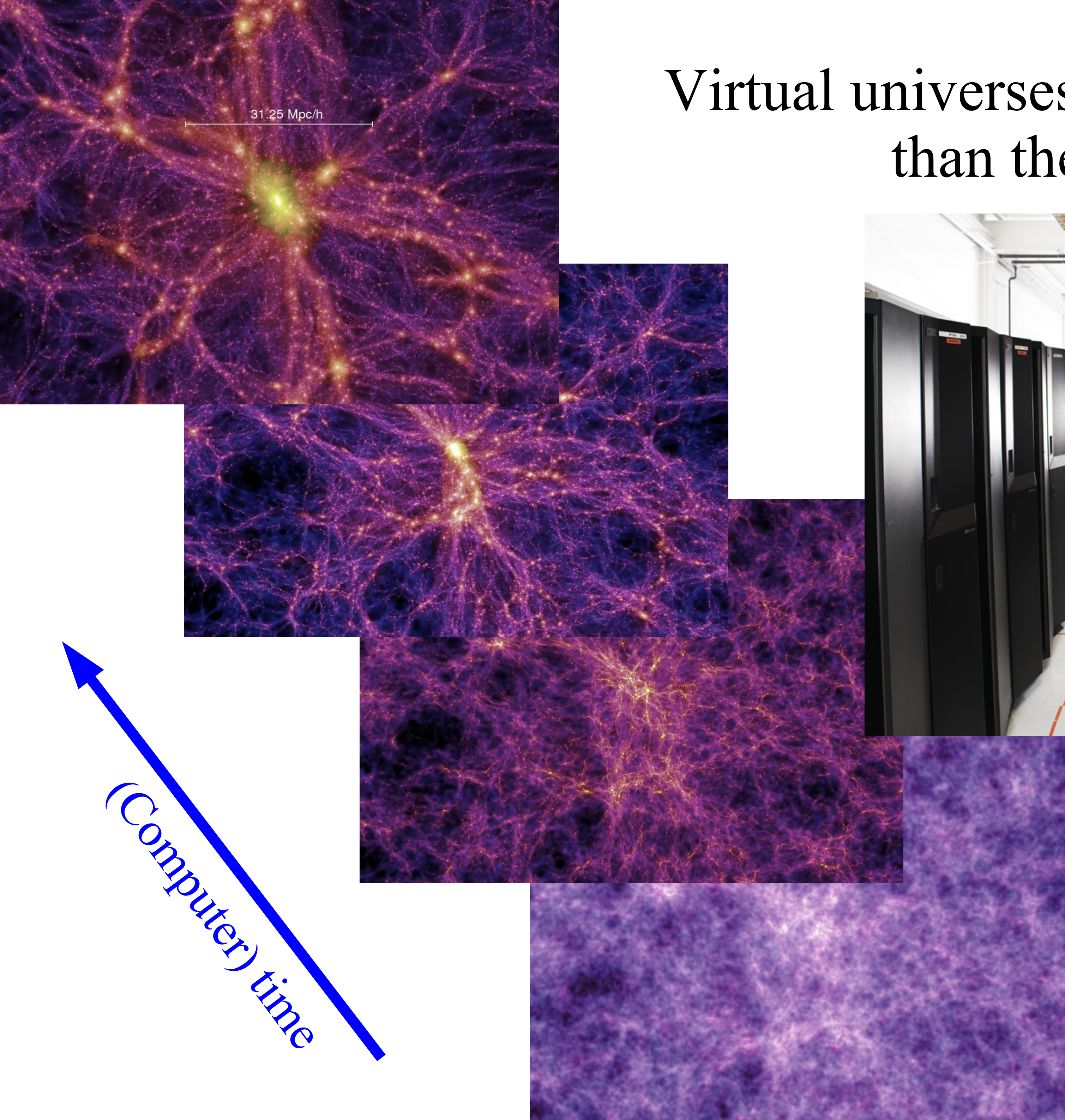
A 300 hour exposure with the Hubble Space Telescope

Map of the Cosmic Microwave Background



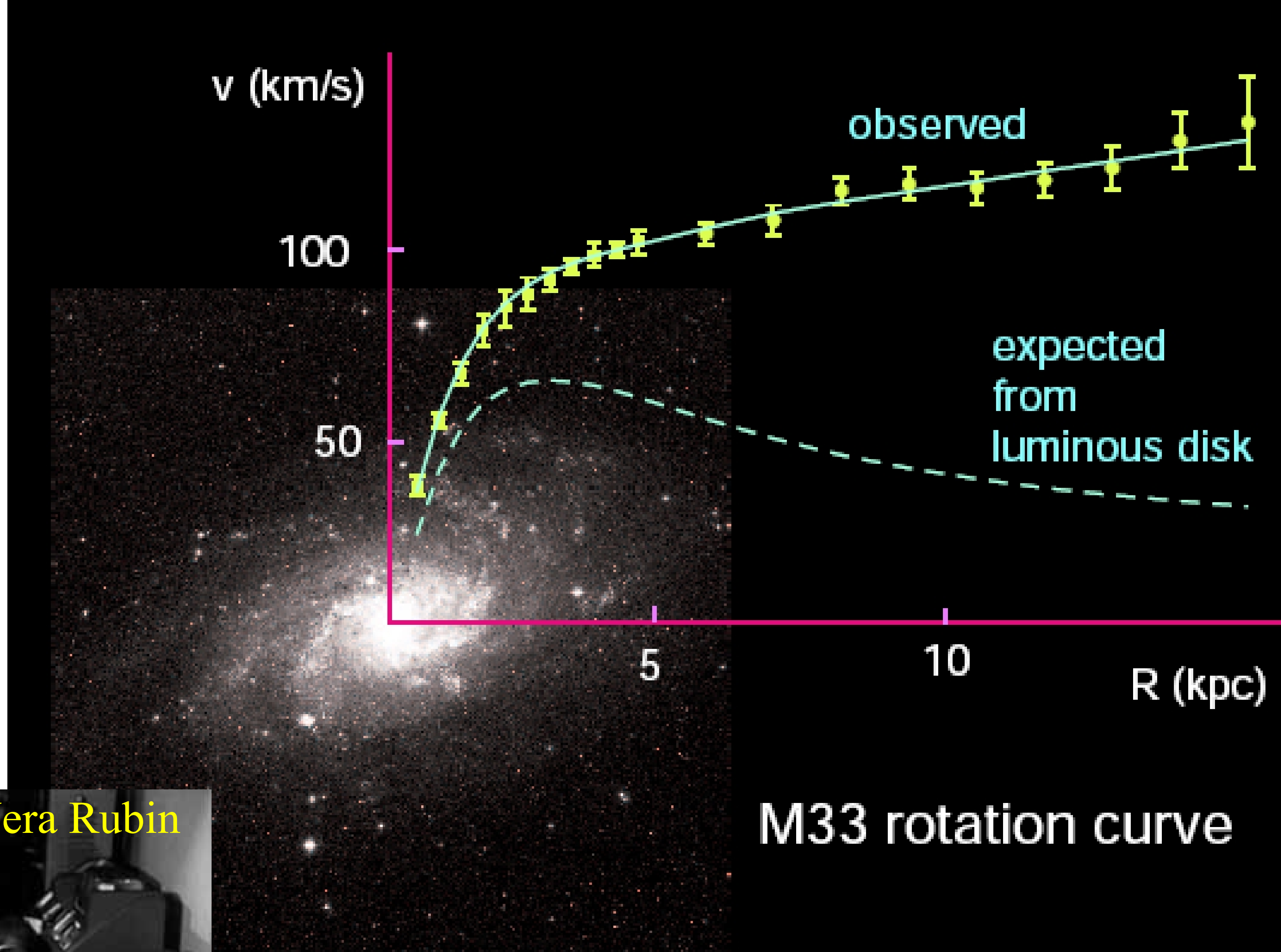
To 40 billion light-years, 400,000 years after the Big Bang

Virtual universes can run faster than the real Universe



The Coma Galaxy Cluster

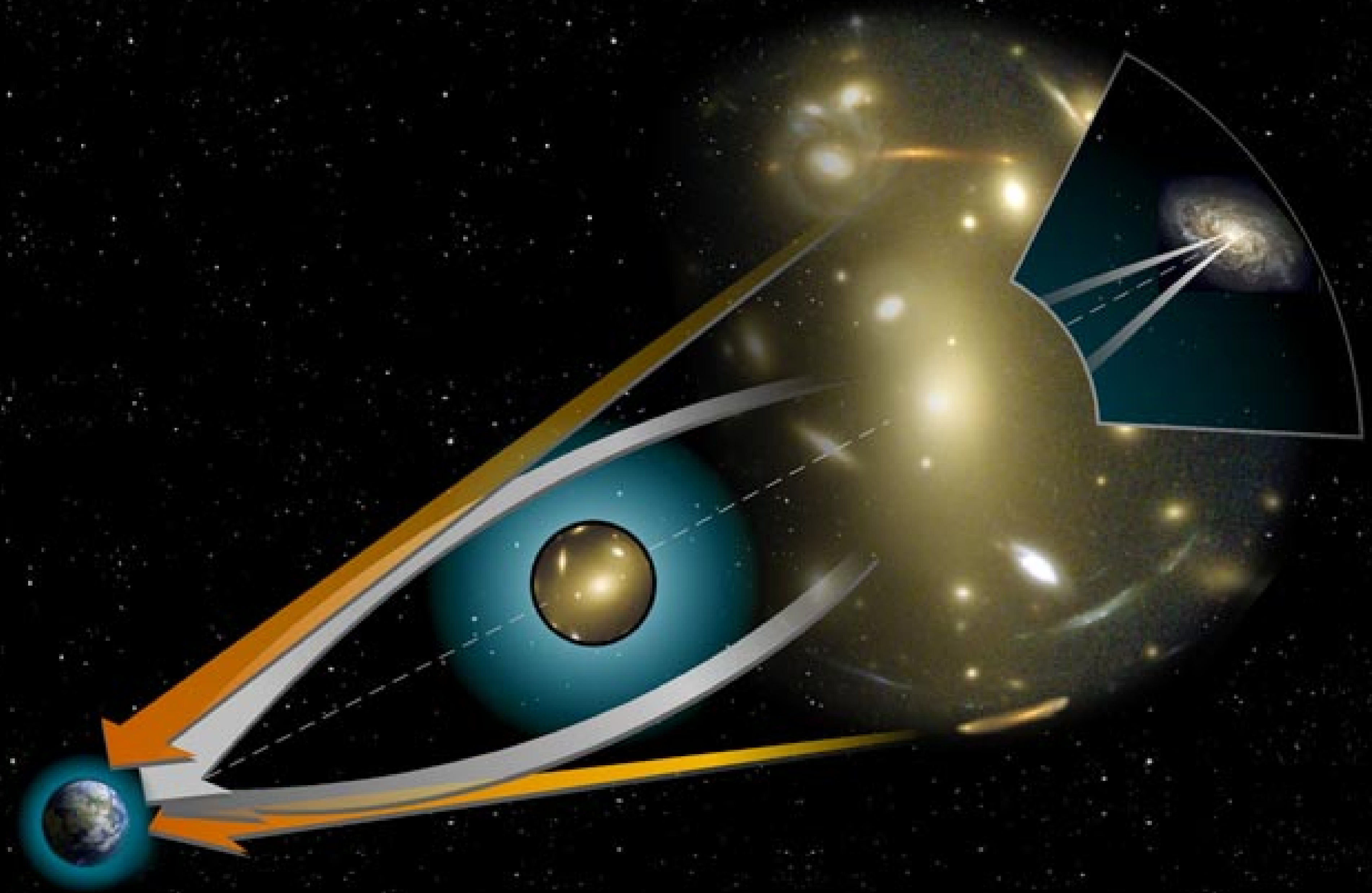
The Triangulum Nebula (M33)


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


Vera Rubin

The Galaxy Cluster, Abell 2218

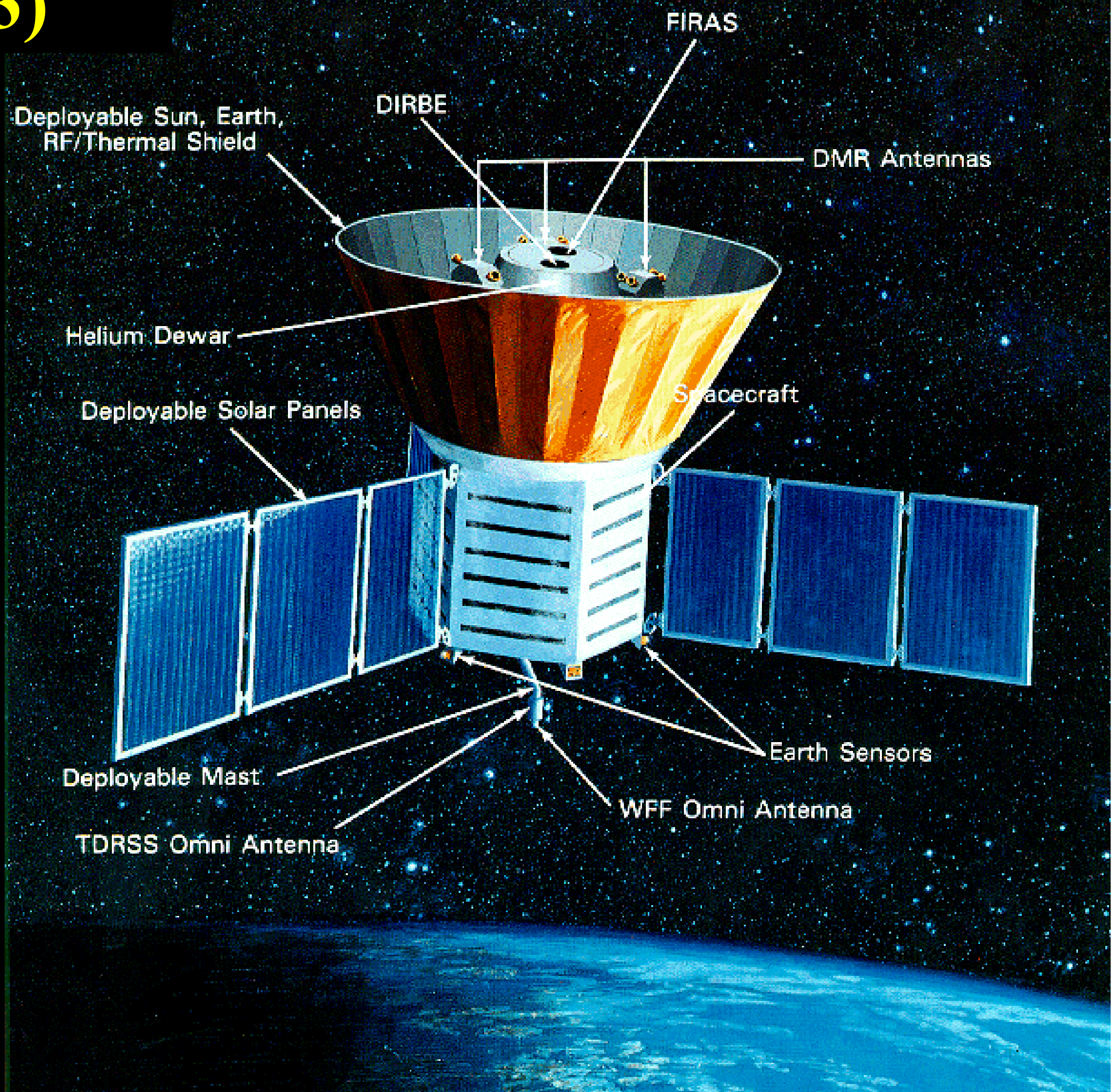
Galaxy clusters as gravitational telescopes



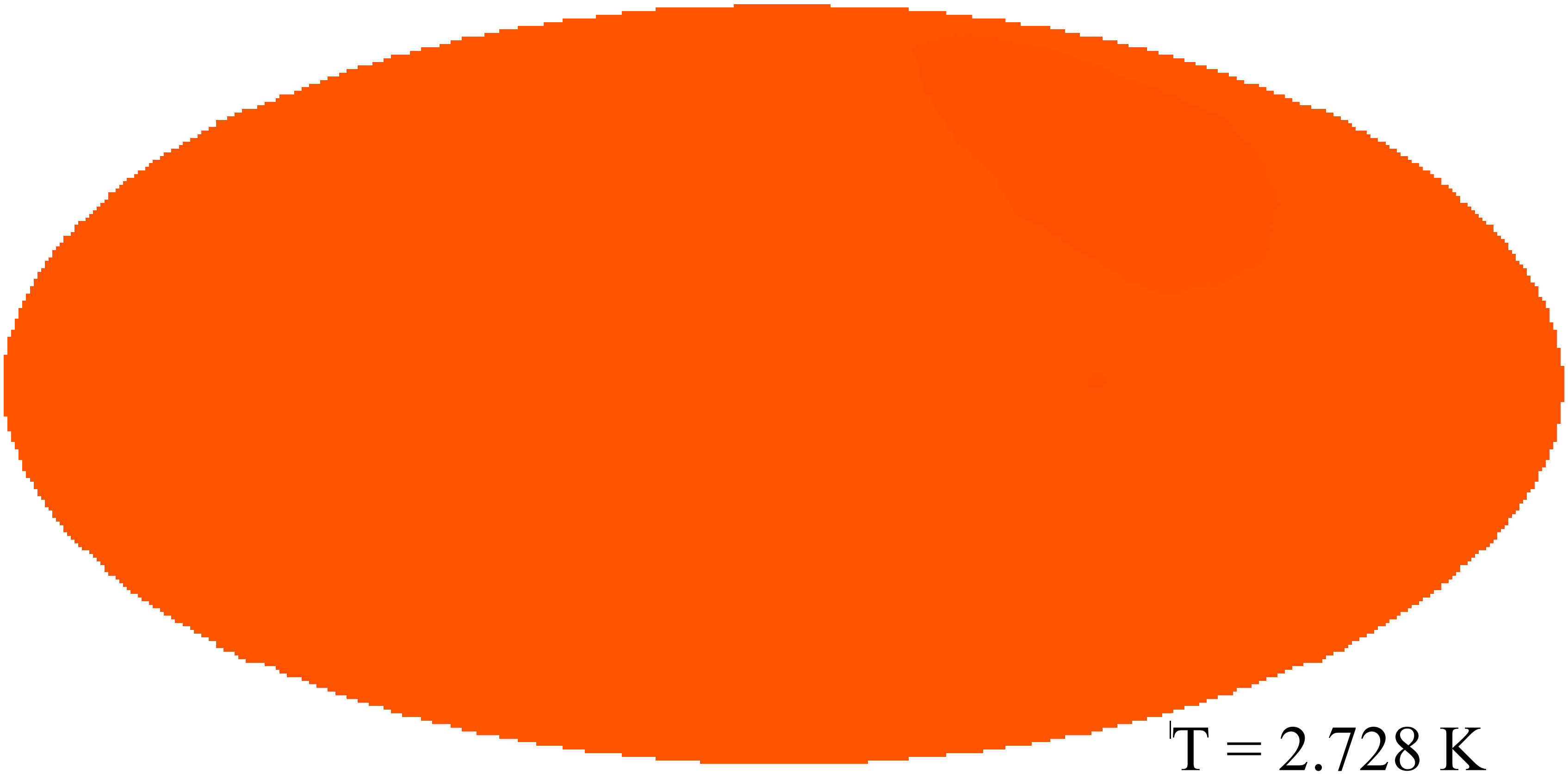
The strength of the lensing measures the total mass in the cluster

The COBE satellite (1989 - 1993)

- Two instruments made maps of the whole sky in microwaves and in infrared radiation
- One instrument took a precise spectrum of the sky in microwaves

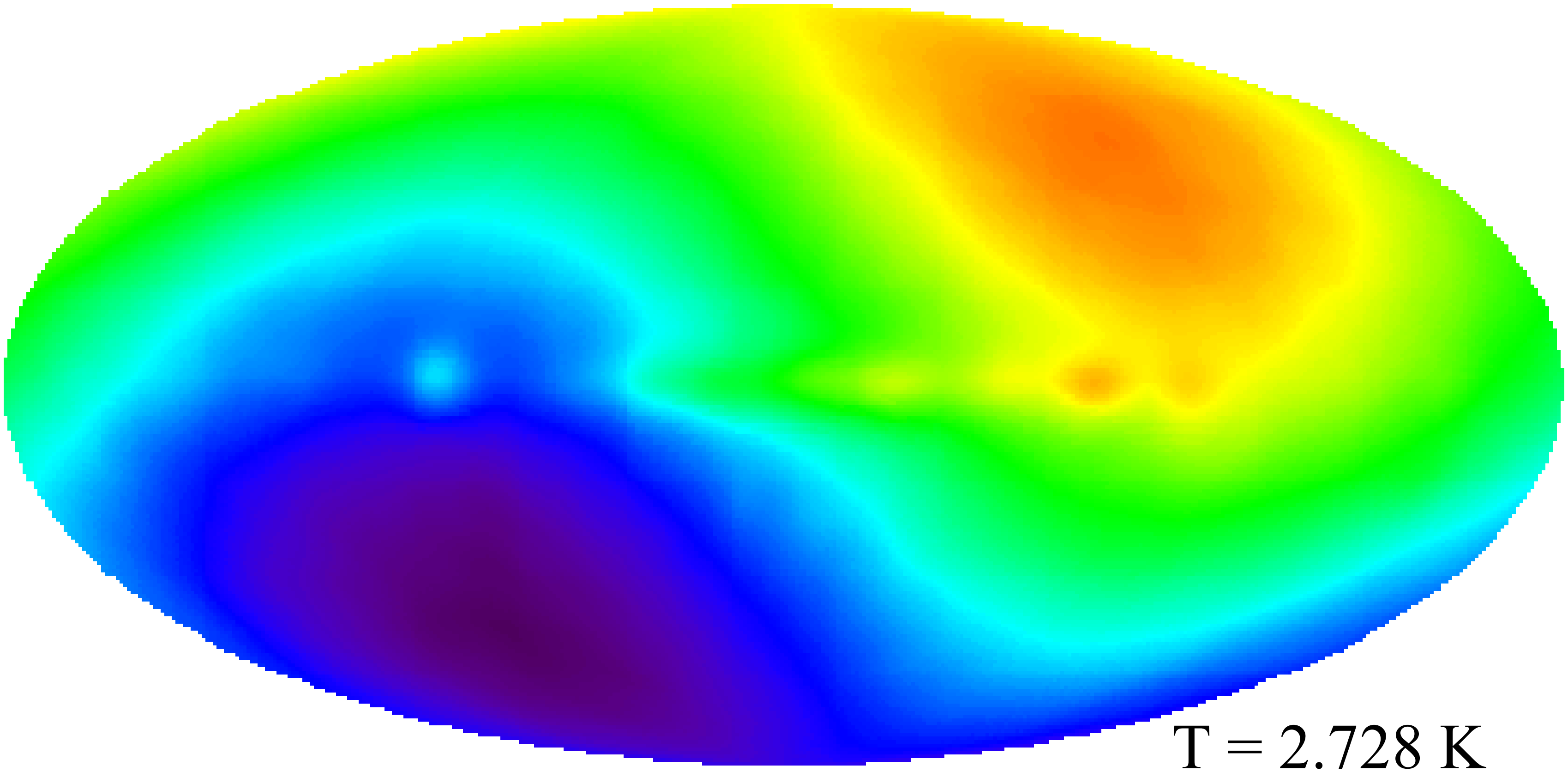


COBE's temperature map of the entire sky



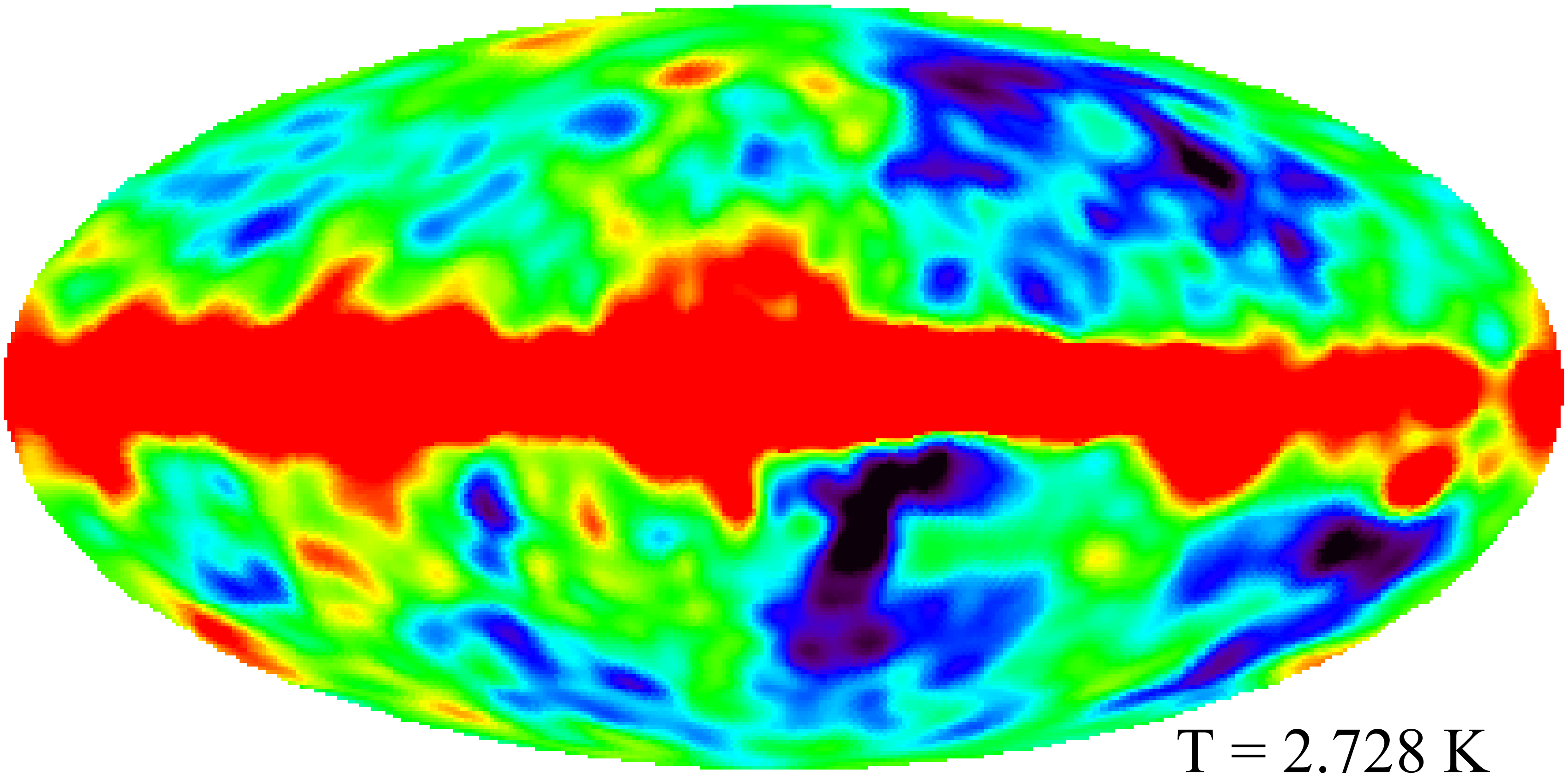
T = 2.728 K
ΔT = 0.1 K

COBE's temperature map of the entire sky



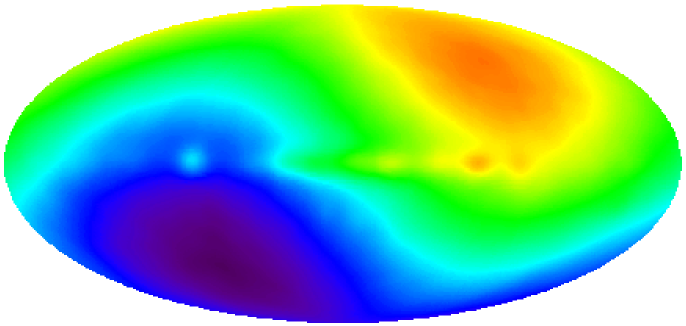
T = 2.728 K
ΔT = 0.0034 K

COBE's temperature map of the entire sky



T = 2.728 K
$\Delta T = 0.00002$ K

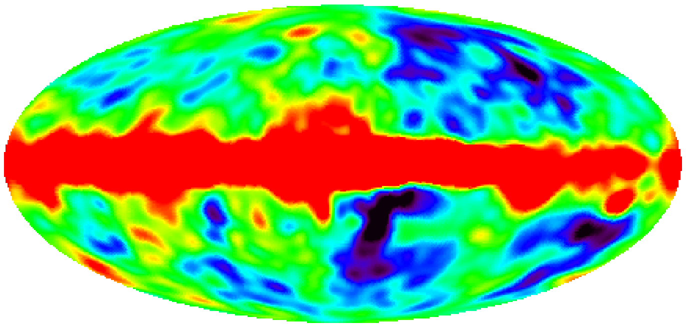
Structure in the COBE map



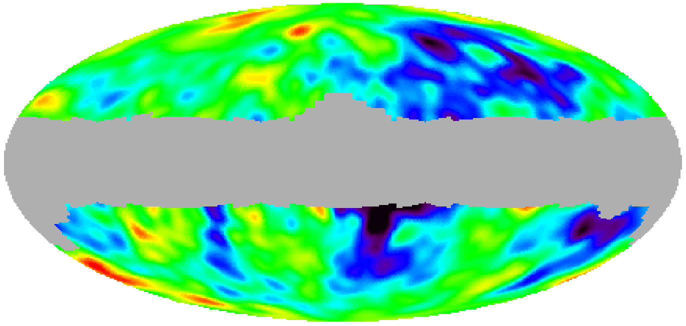
- One side of the sky is `hot', the other is `cold'

→ the Earth's motion through the Cosmos

$V_{\text{Milky Way}} = 600$ km/s



- Radiation from hot gas and dust in our own Milky Way



- Structure in the Microwave Background itself

Structure in the Microwave Background

- The structure lies in cosmic "clouds", ~ 4 10^{10} l-yrs away
- It reflects weak "sound" waves, A ~ 10^{-4}, in the clouds
- At the time the Universe was only 400,000 years old, and was 1,000 times smaller and 1,000 times hotter than today

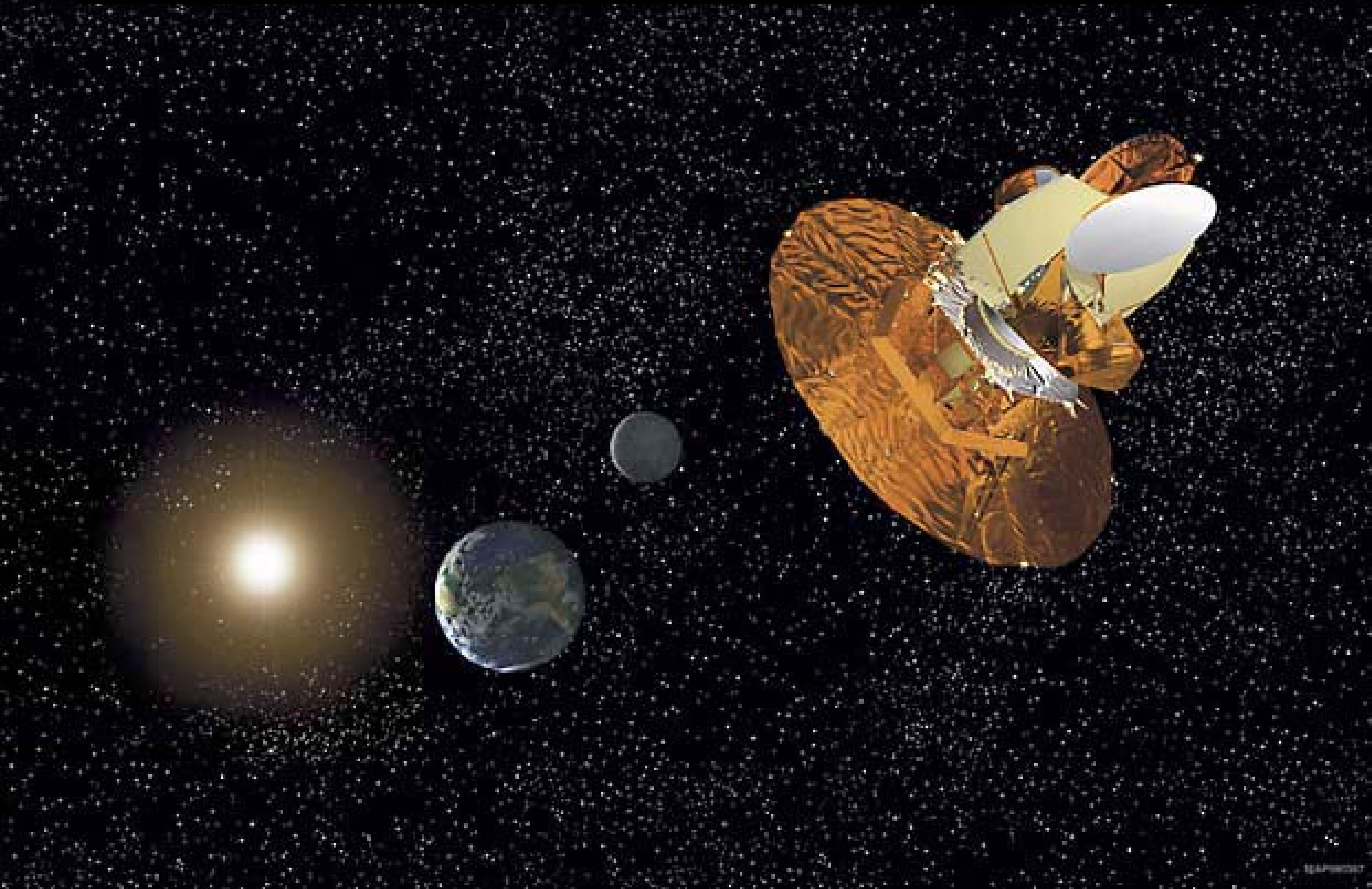
The *pattern* of structure reflects

A: The global geometry and topology of the Universe

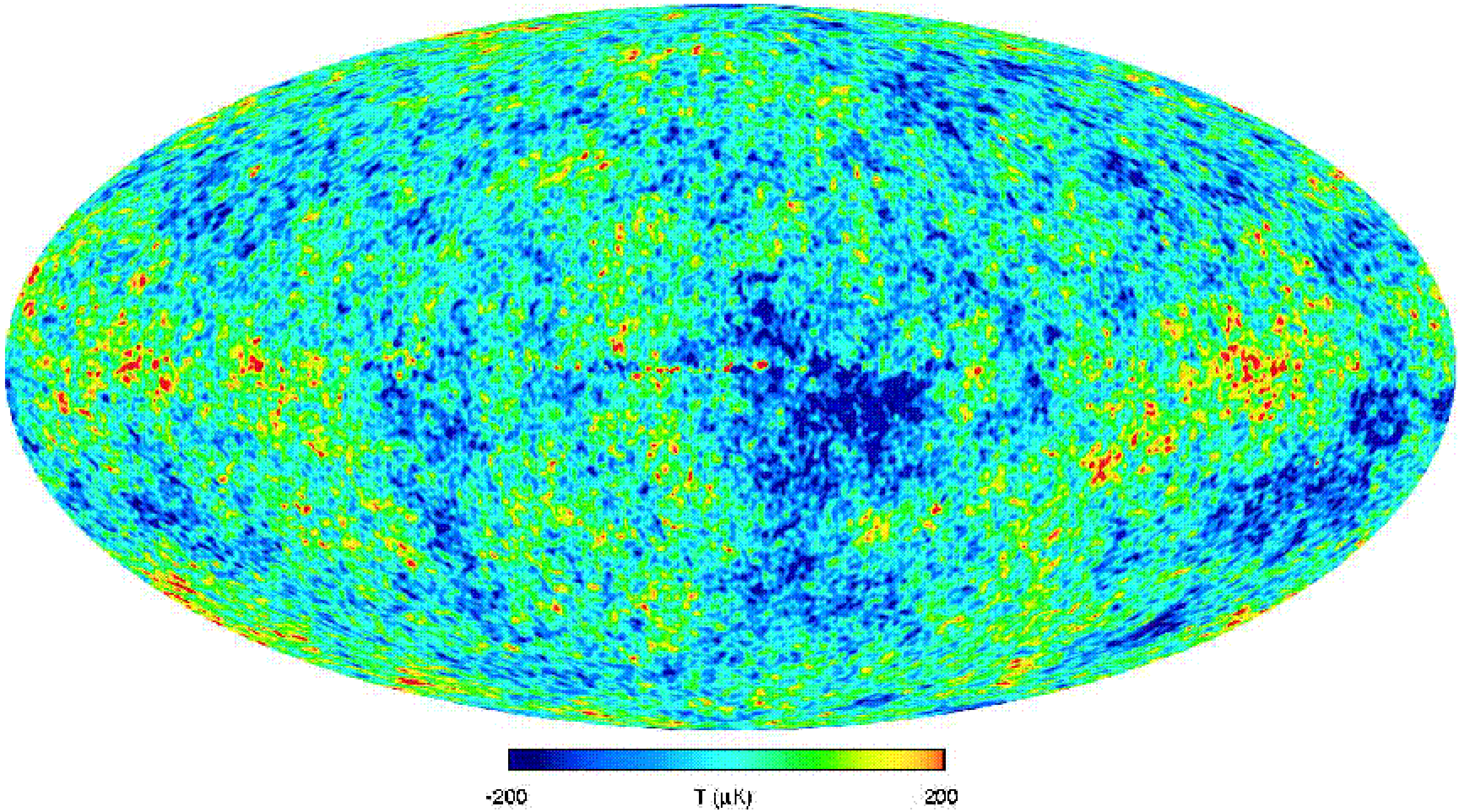
B: The constituents and thermal evolution of the Universe

C: The process which generated the structure

The *WMAP* Satellite at Lagrange-Point L2



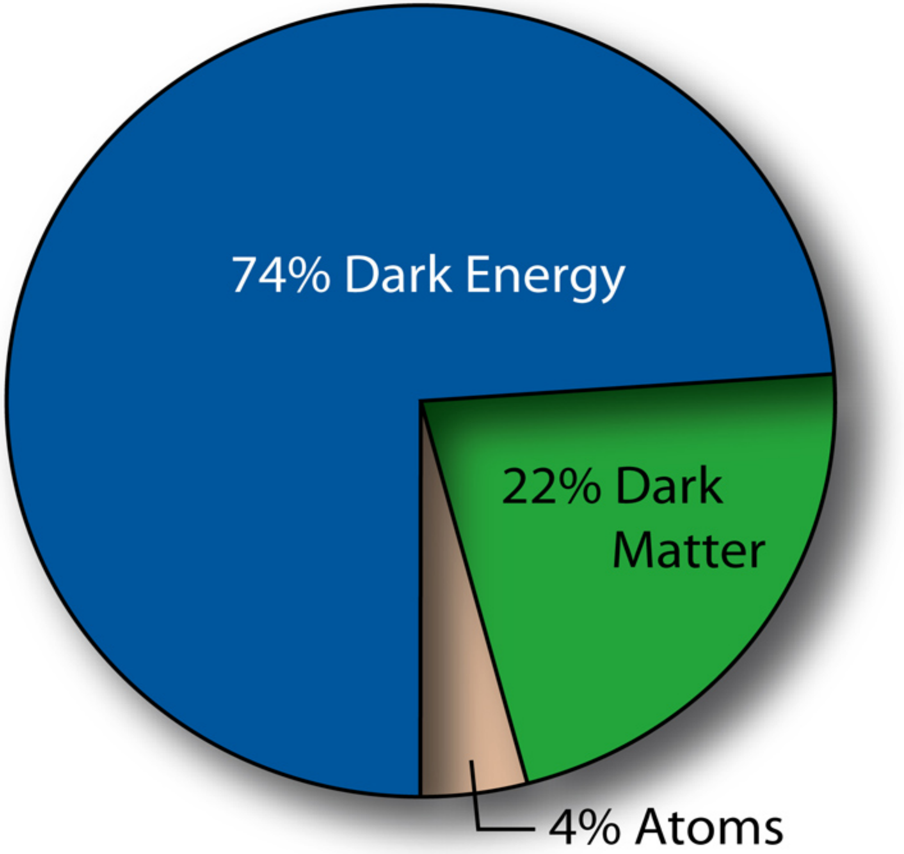
The *WMAP* of the whole CMB sky



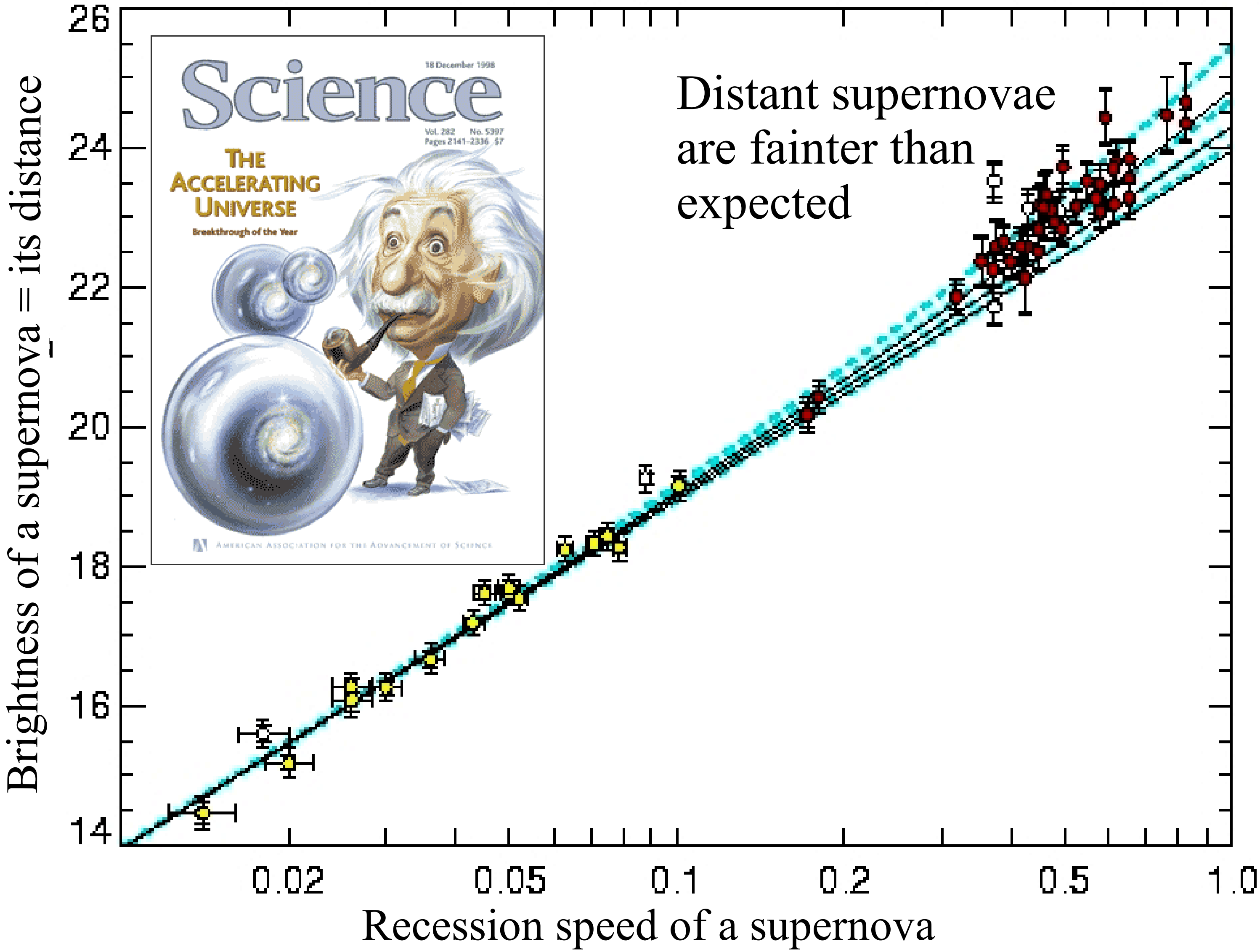
Bennett et al 2003

What has WMAP taught us?

- Our Universe is flat -- its geometry is that imagined by Euclid
- Only a small fraction is made of ordinary matter -- about 4% today
- About 21% of today's Universe is <u>non-baryonic</u> dark matter
- About 75% is Dark Energy
- All structure was apparently produced by quantum fluctuations in the <u>vacuum</u> at a very early time

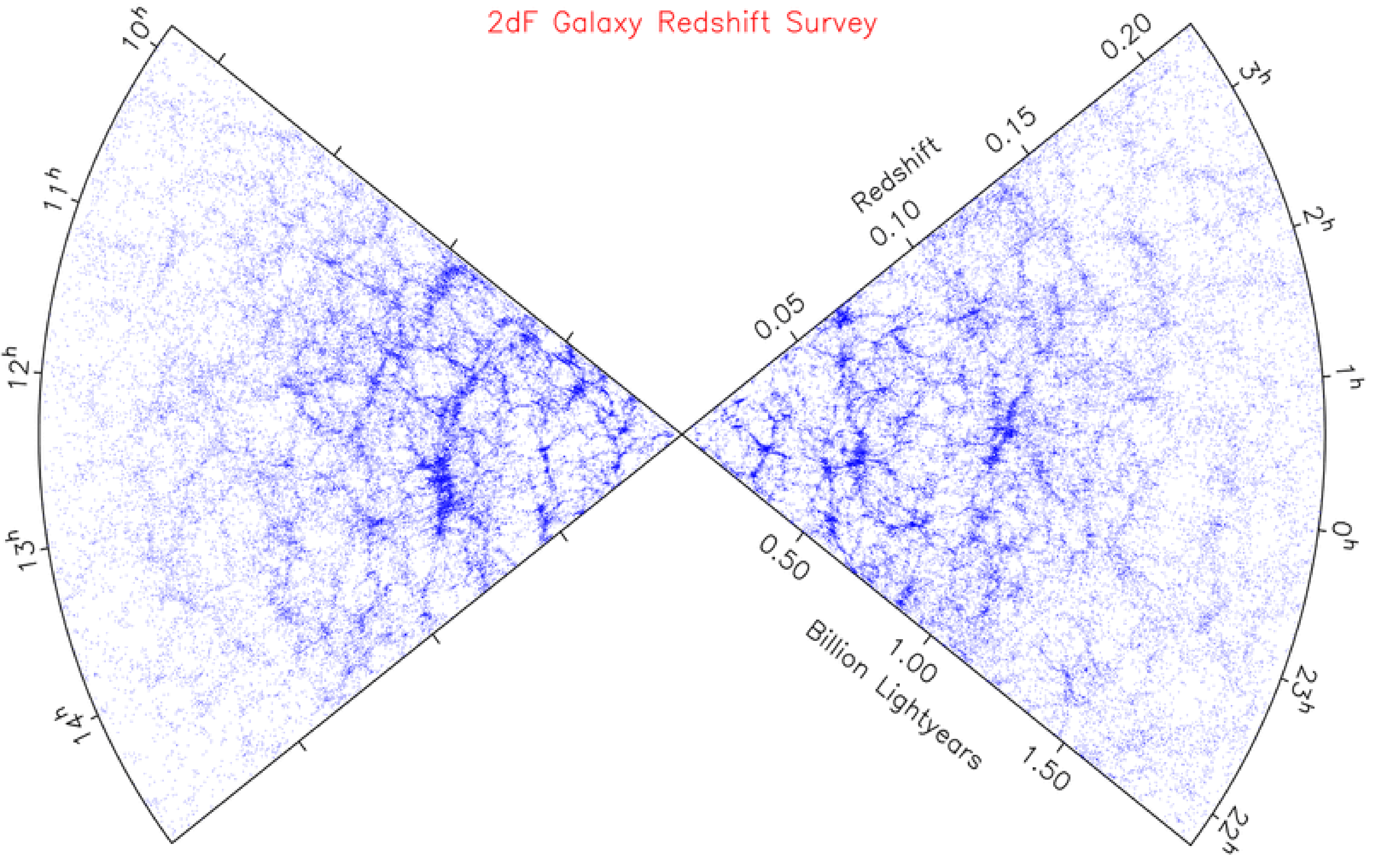


The Universe expands faster today than in the past!

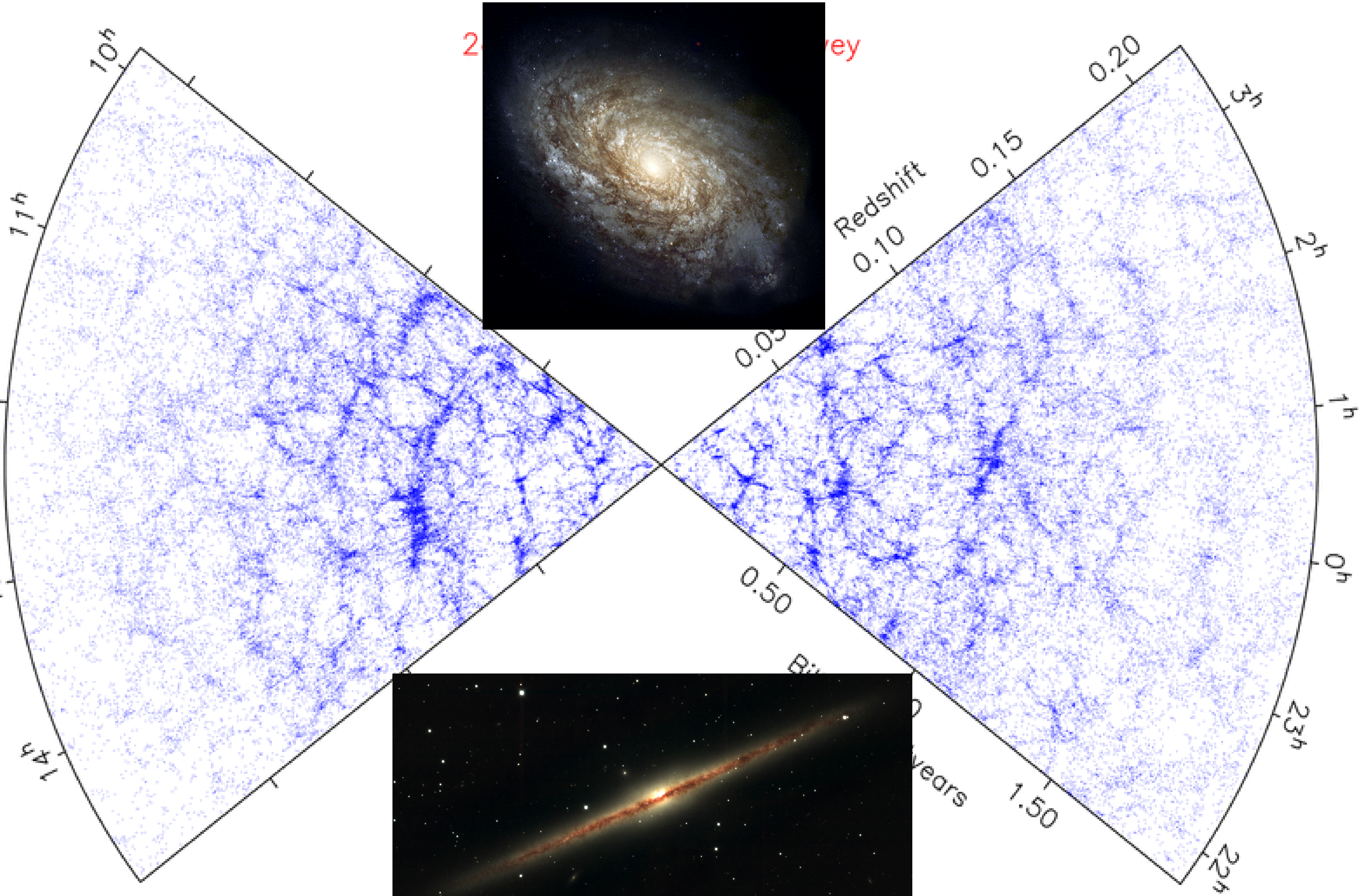


An accelerating Universe? The return of Einstein's "Eselei" or the discovery of a new form of mass/energy -- the Dark Energy?

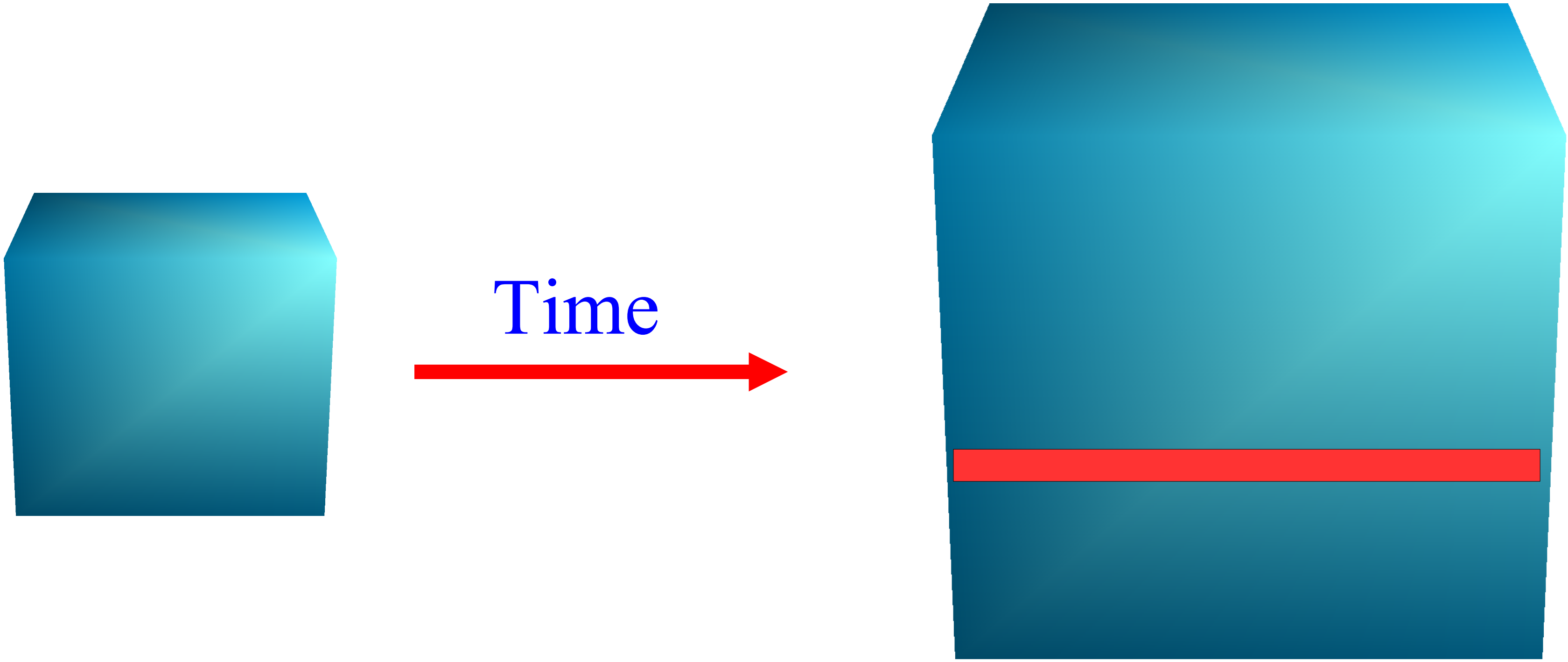
Nearby large-scale structure



Nearby large-scale structure



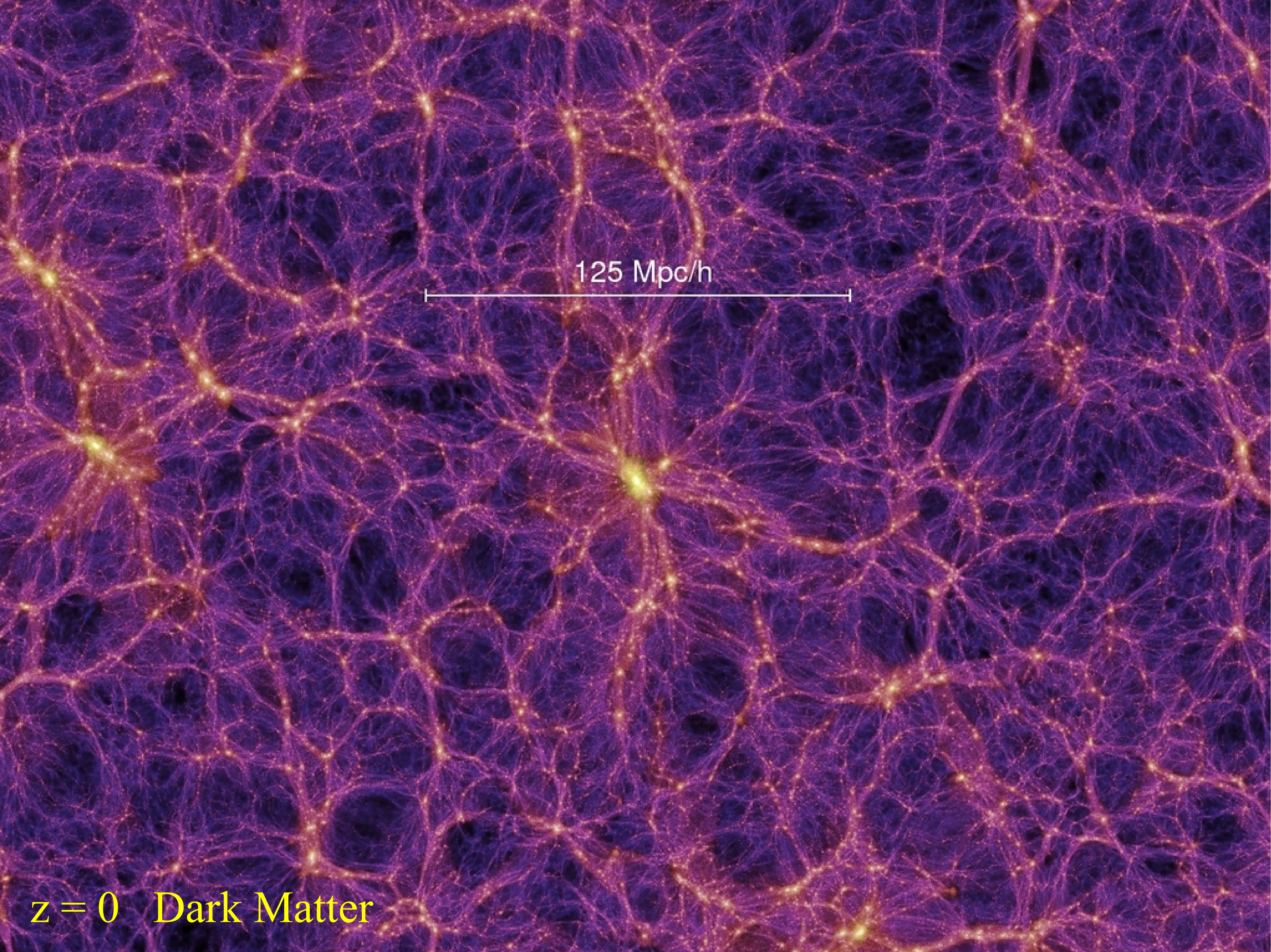
Evolving the Universe in a computer

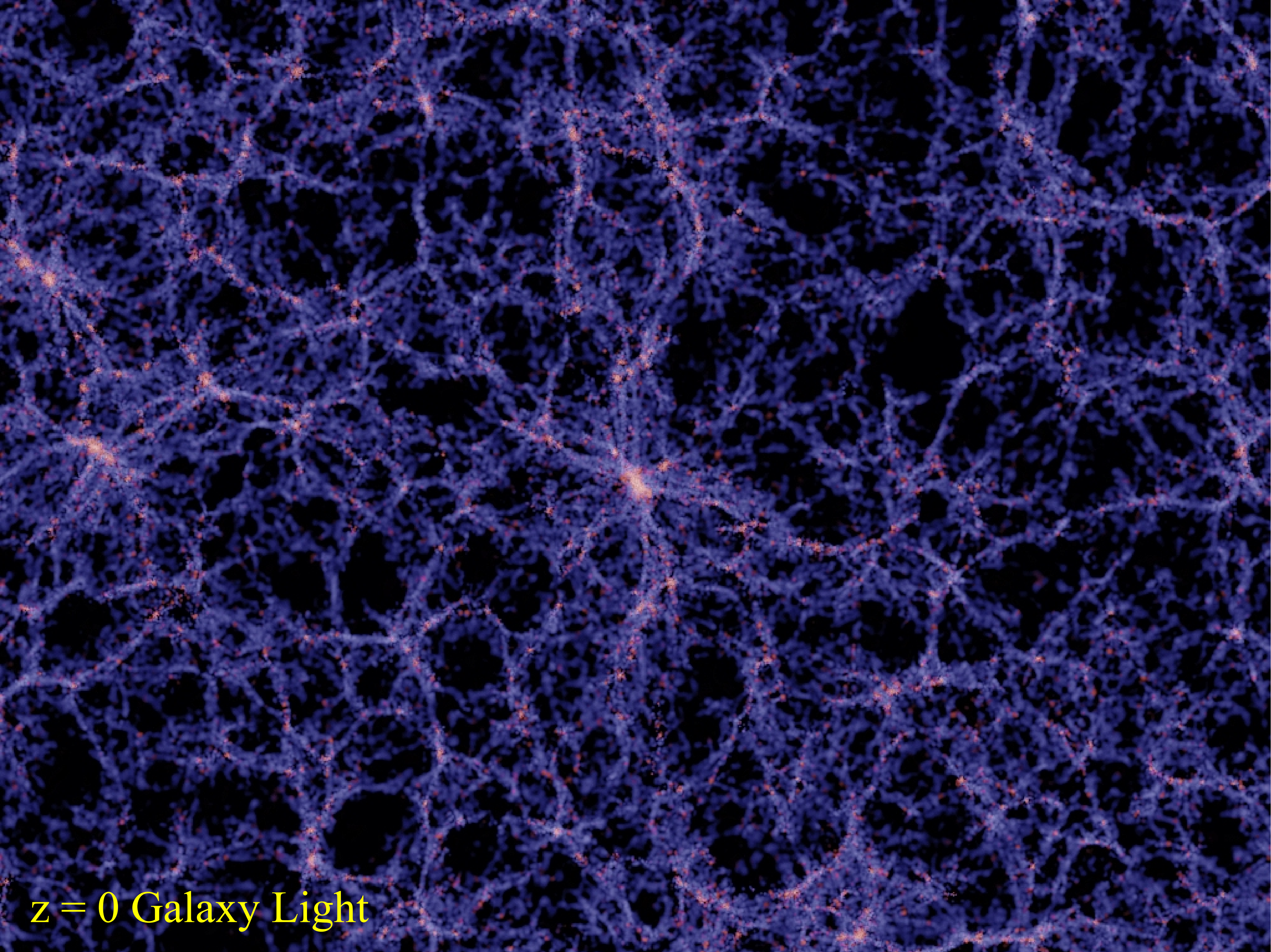


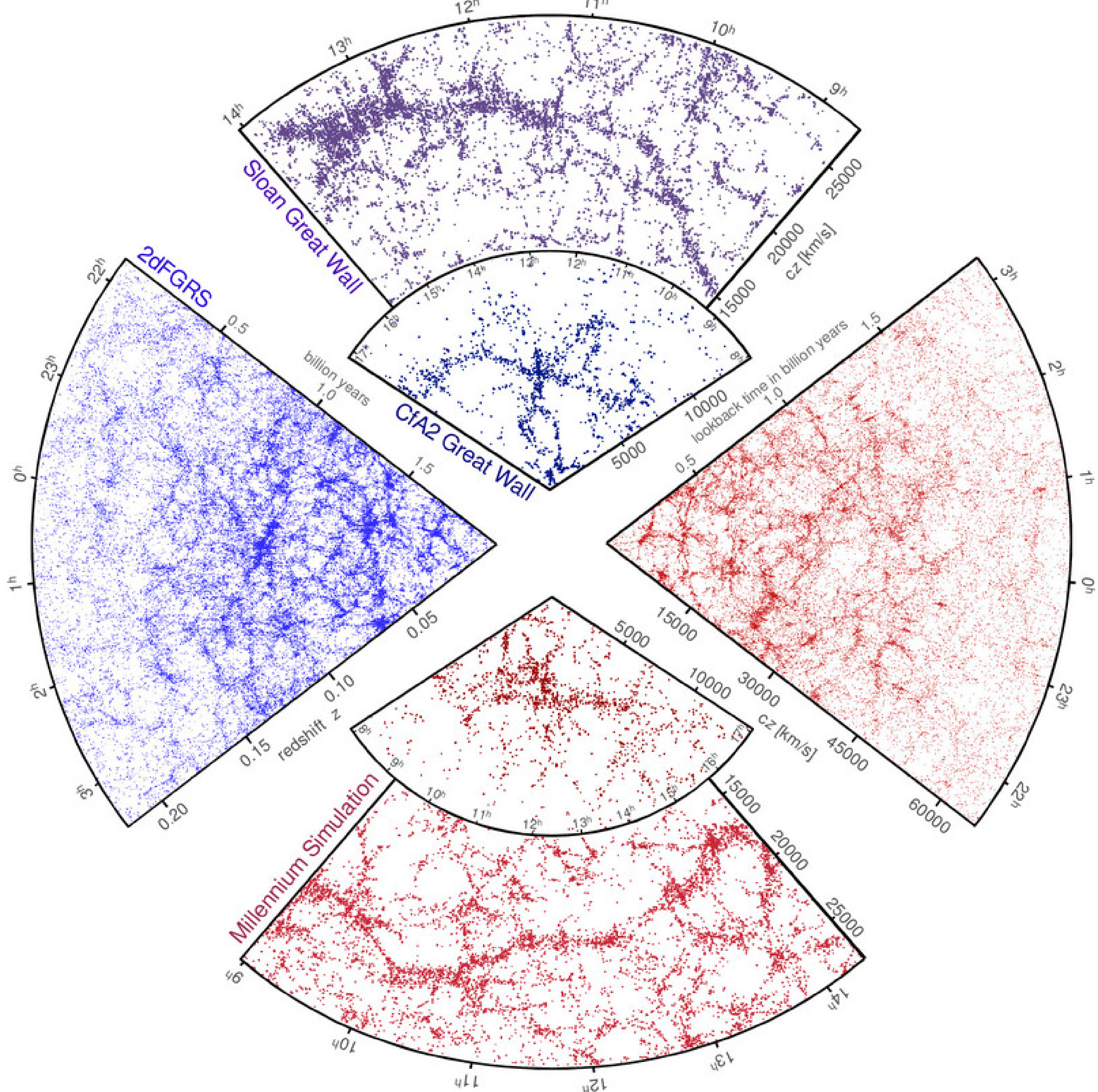
- Follow the matter in an expanding cubic region
- Start 300,000 years after the Big Bang
- Match initial conditions to the observed Microwave Background
- Calculate evolution forward to the present day

Views of the dark matter in a Virtual Universe

- The growth of dark matter structures in a thin slice
- A flight through the dark matter distribution
- The assembly of the Milky Way's halo

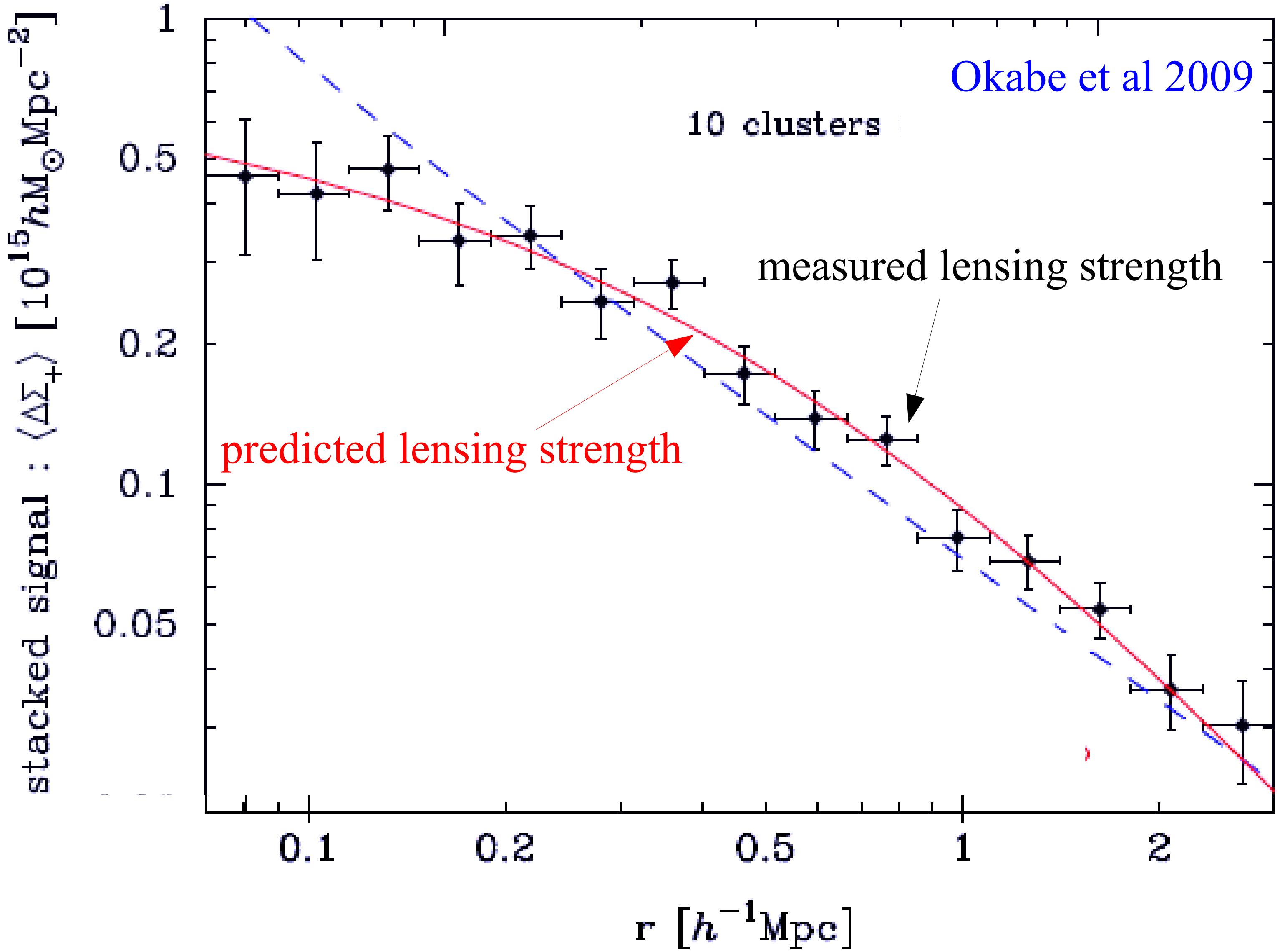

125 Mpc/h
z = 0 Dark Matter

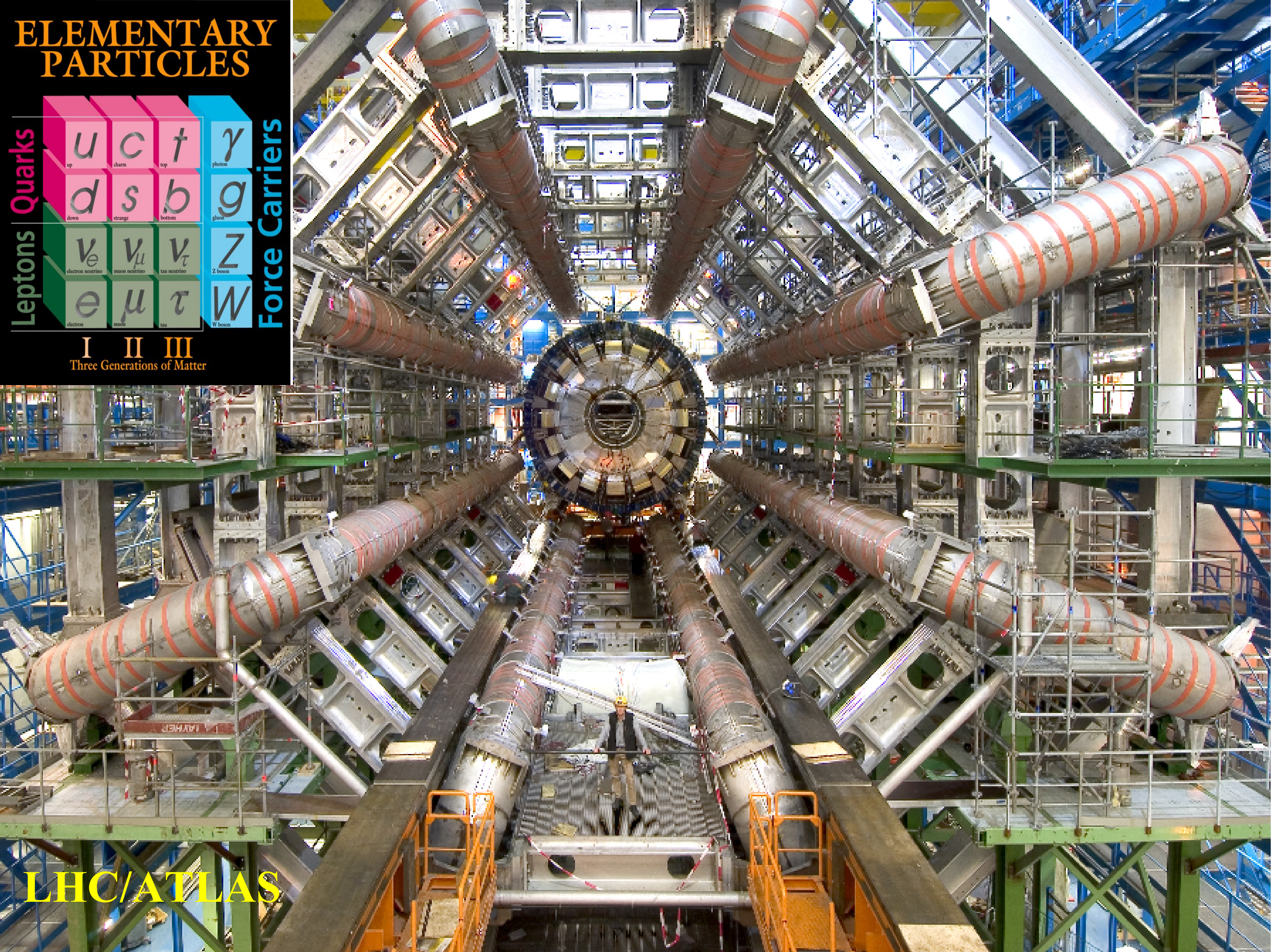

z = 0 Galaxy Light



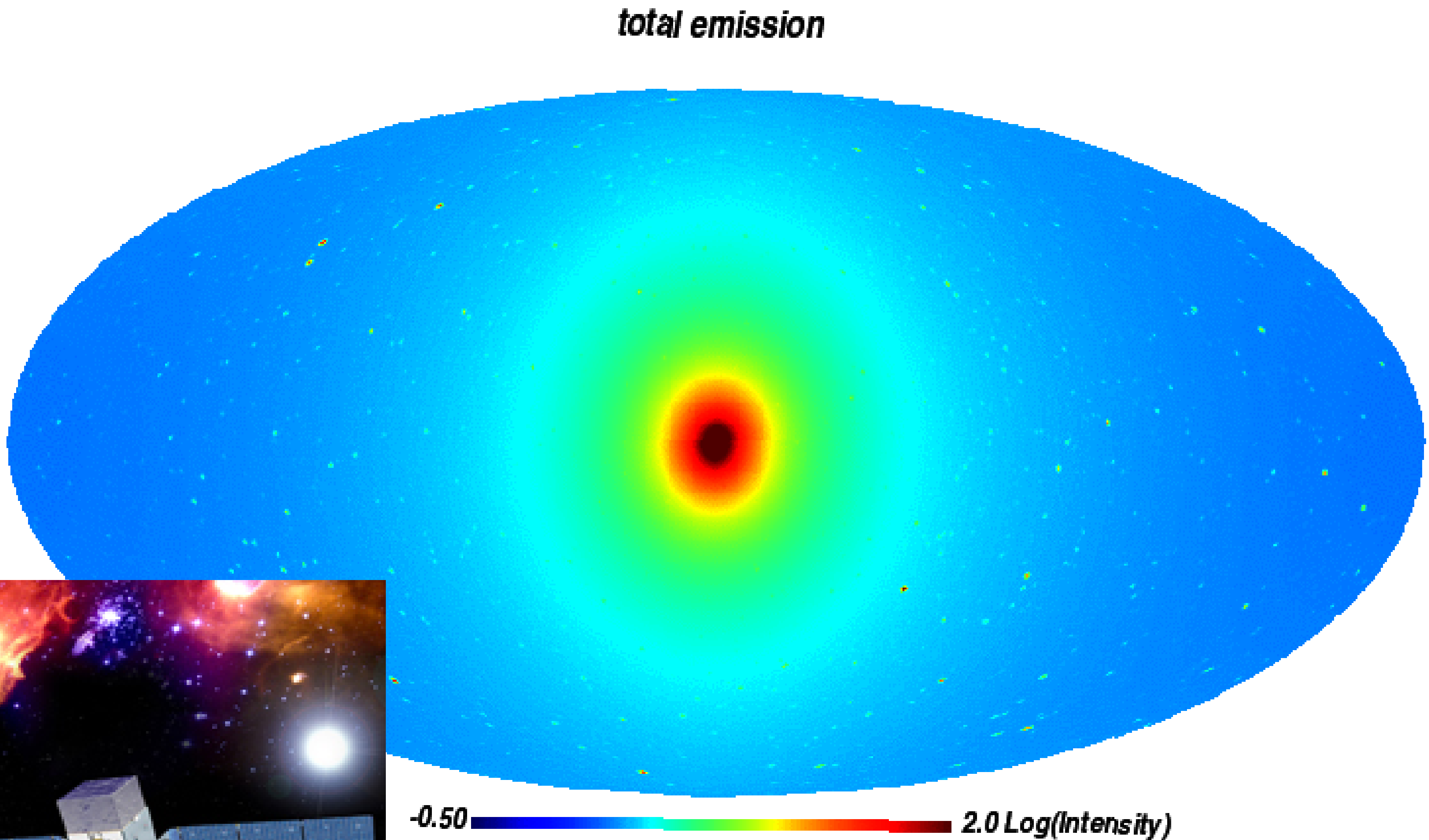
Sloan Great Wall
2dFGRS
CfA2 Great Wall
Millennium Simulation
cz [km/s]
billion years
lookback time in billion years
redshift z

Comparison of lensing strength measured around real galaxy clusters to that predicted by simulations of structure formation



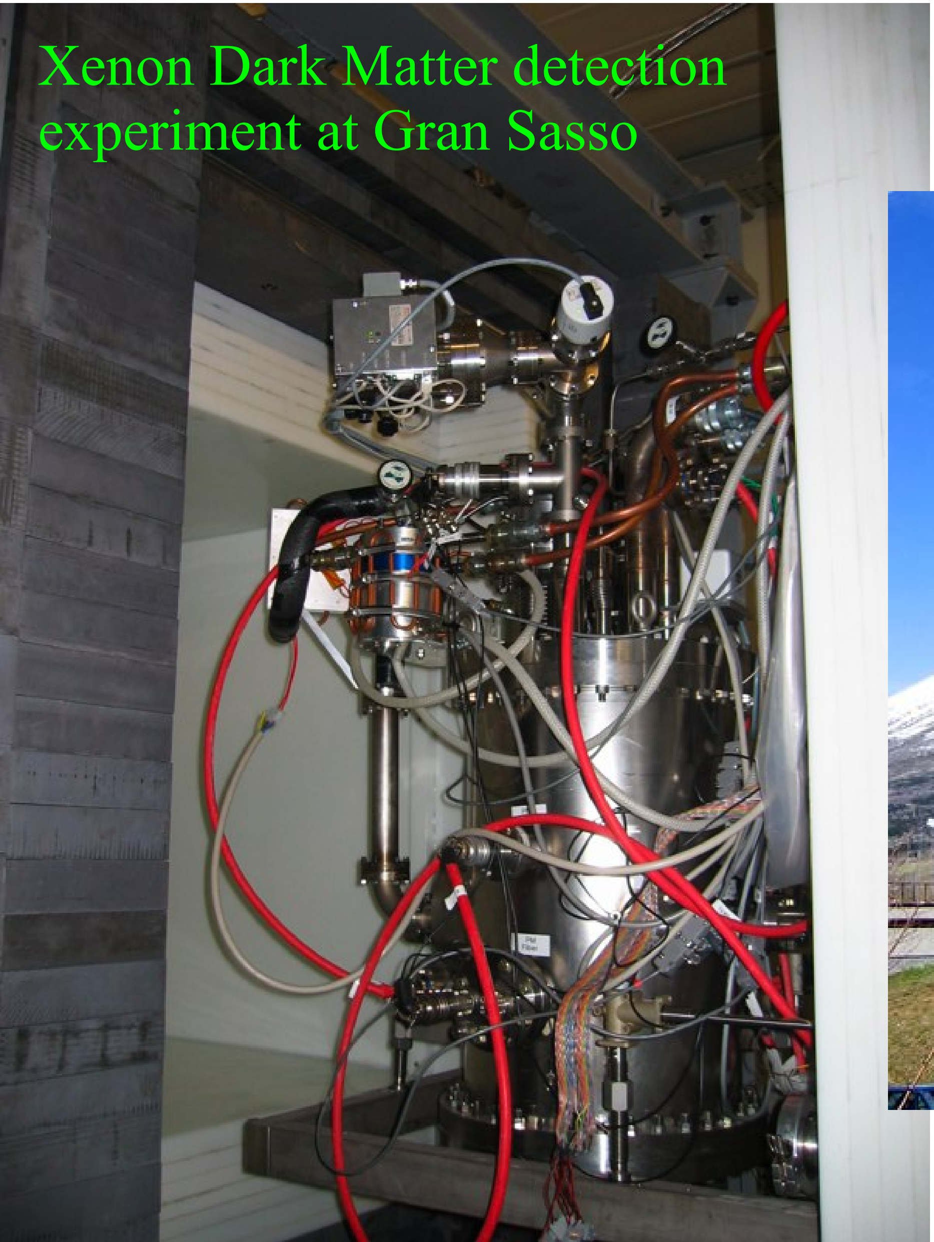

ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u up
c charm
t top
γ photon
d down
s strange
b bottom
g gluon
ν_e electron neutrino
ν_μ muon neutrino
ν_τ tau neutrino
Z Z boson
e electron
μ muon
τ tau
W W boson
I II III
Three Generations of Matter
LHC/ATLAS


Dark Matter around the Milky Way?



Maybe the annihilation of Dark Matter will be seen by Fermi?

Maybe Dark Matter can be detected in a laboratory



- Dark Matter appears to account for more than 80% of all the material in and around galaxies and galaxy clusters
- It is also needed to explain how today's cosmic structure grew from that seen in the microwave background
- It cannot be made of “ordinary” baryonic matter
- It is currently only detected by its gravitational effects
- It might be possible to see its annihilation radiation or to detect it in a laboratory on Earth

- Dark Energy is needed to explain the accelerated expansion of today's universe

- Observed structure in the Cosmic Microwave Background implies that the Universe is flat but that only 25% of the necessary mass-energy can be in baryons+dark matter The other 75% must be Dark Energy

- Dark Energy does not clump and is apparently detectable <u>only</u> by its effects on the cosmic expansion

- We don't have a clue what it is or how it is related to the rest of physics.   It appears to behave like the "cosmological constant" in Einstein's theory of gravity