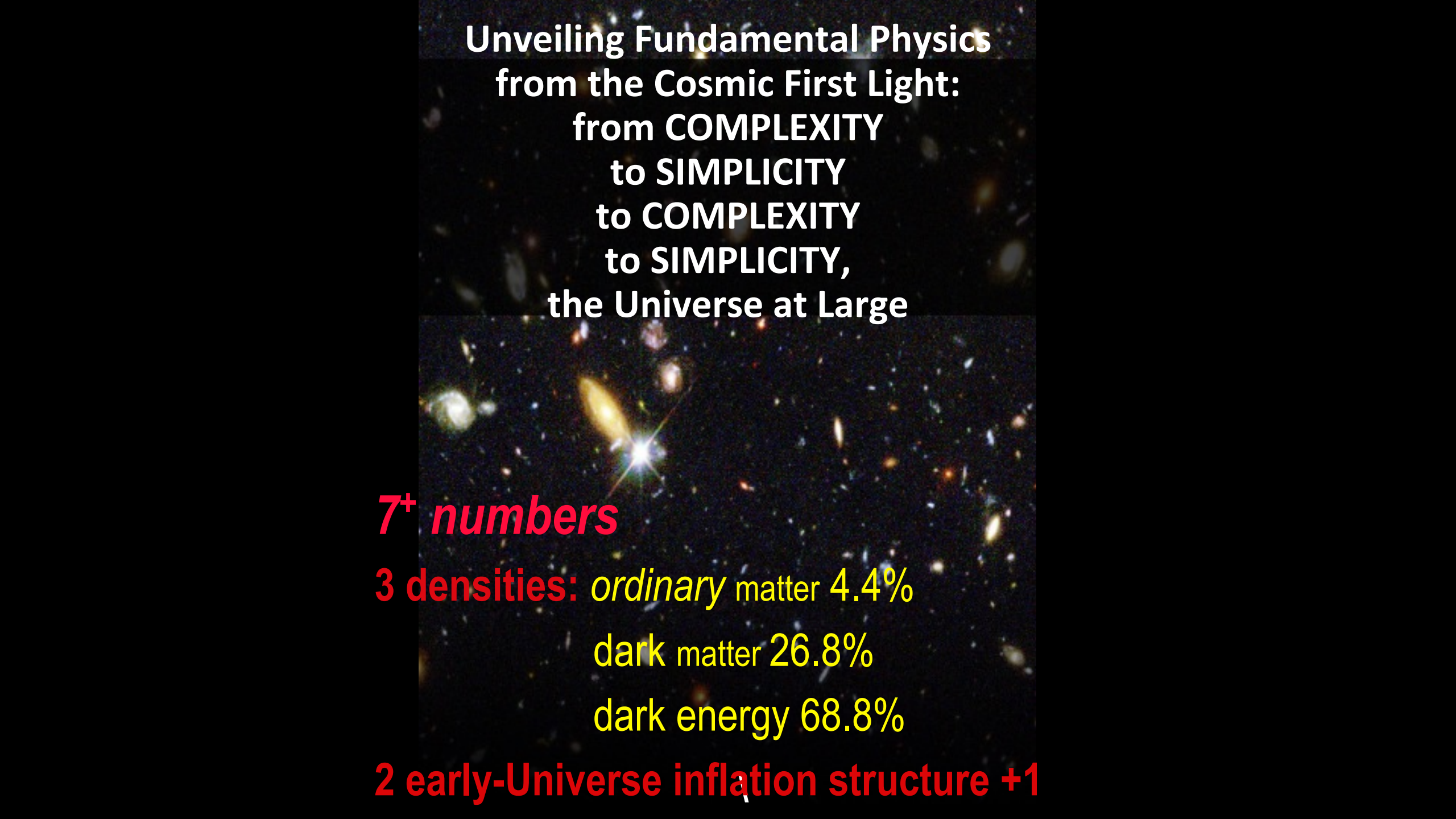


Unveiling Fundamental Physics from the Cosmic First Light

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CIFAR Fellow and Program Director, Cosmology & Gravity program;
University of Toronto, Canadian Institute for Theoretical Astrophysics

CIFAR | IDEAS
EXCHANGE



Unveiling Fundamental Physics
from the Cosmic First Light:
from COMPLEXITY
to SIMPLICITY
to COMPLEXITY
to SIMPLICITY,
the Universe at Large

7⁺ numbers

3 densities: *ordinary* matter 4.4%

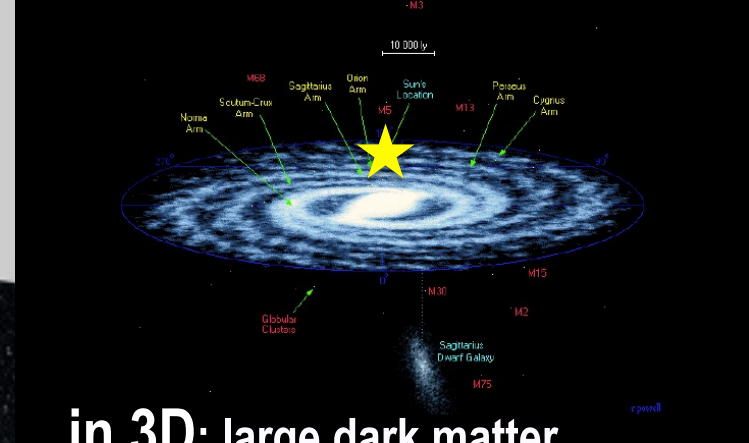
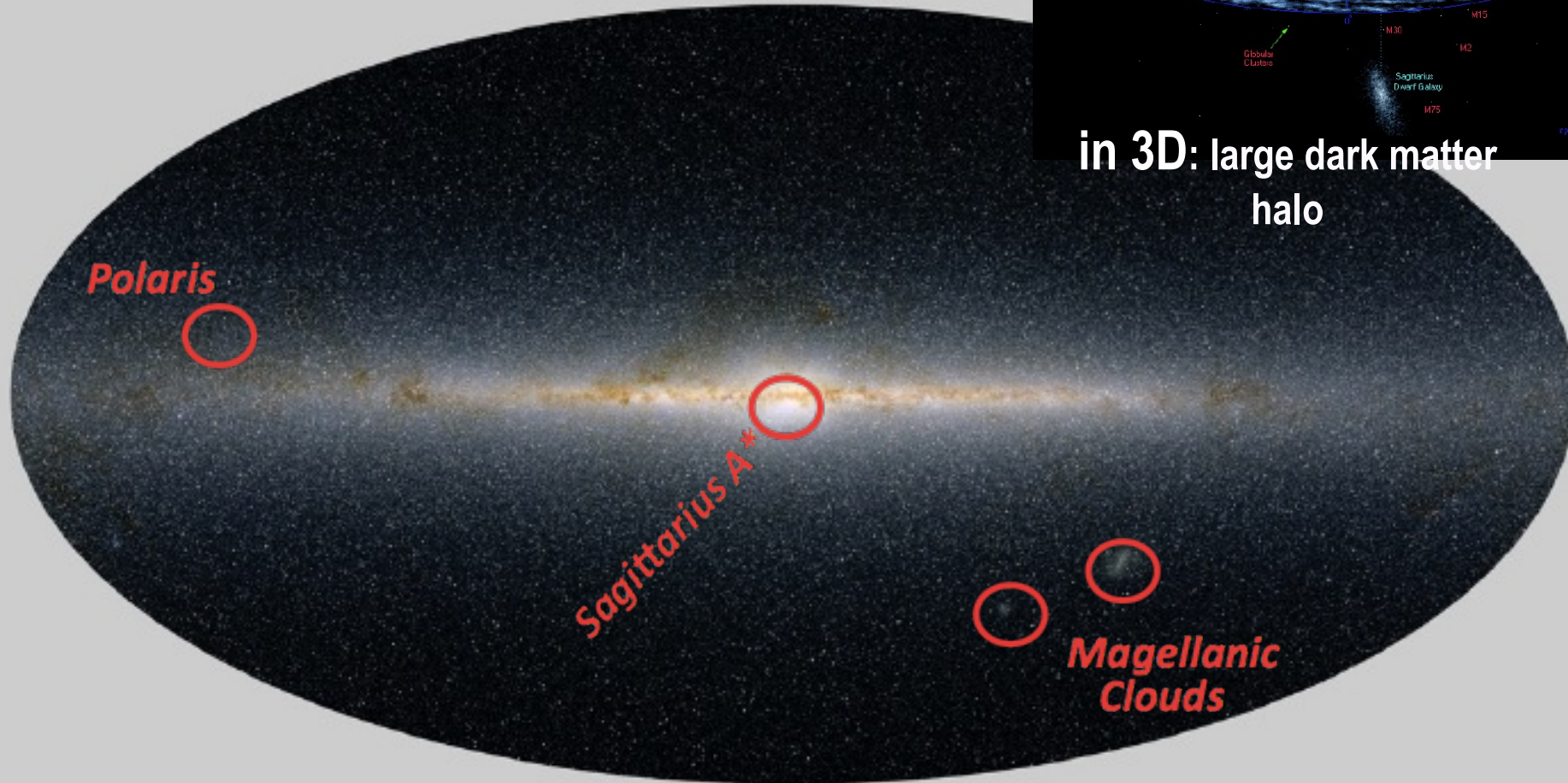
dark matter 26.8%

dark energy 68.8%

2 early-Universe inflation structure +1

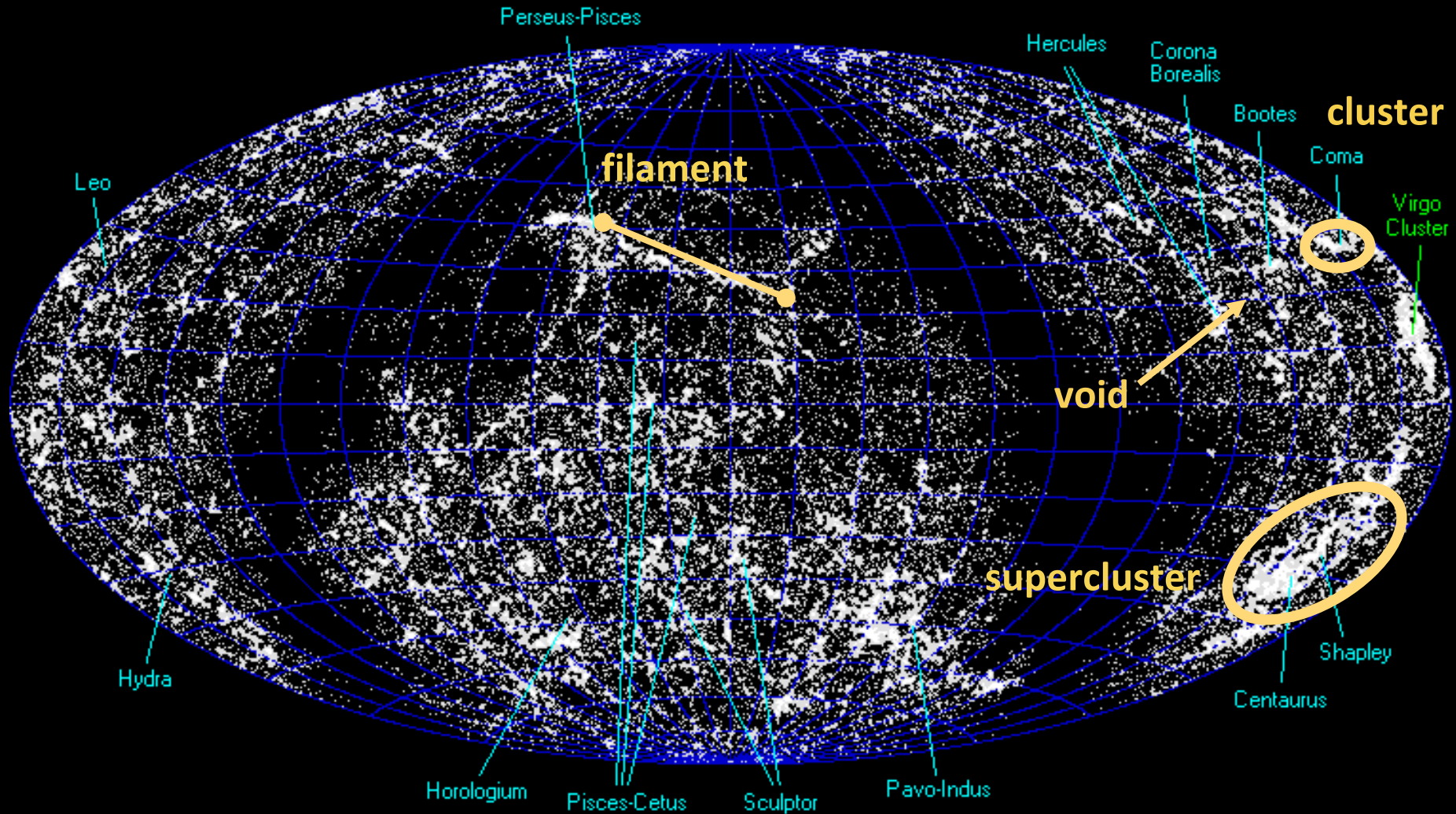


Milky Way in infra-red: half a billion stars, a disk galaxy



in 3D: large dark matter halo

Cosmic Web of 60,000 nearby galaxies:
exhibits “local” **COMPLEXITY** ~1 billion *light yrs*



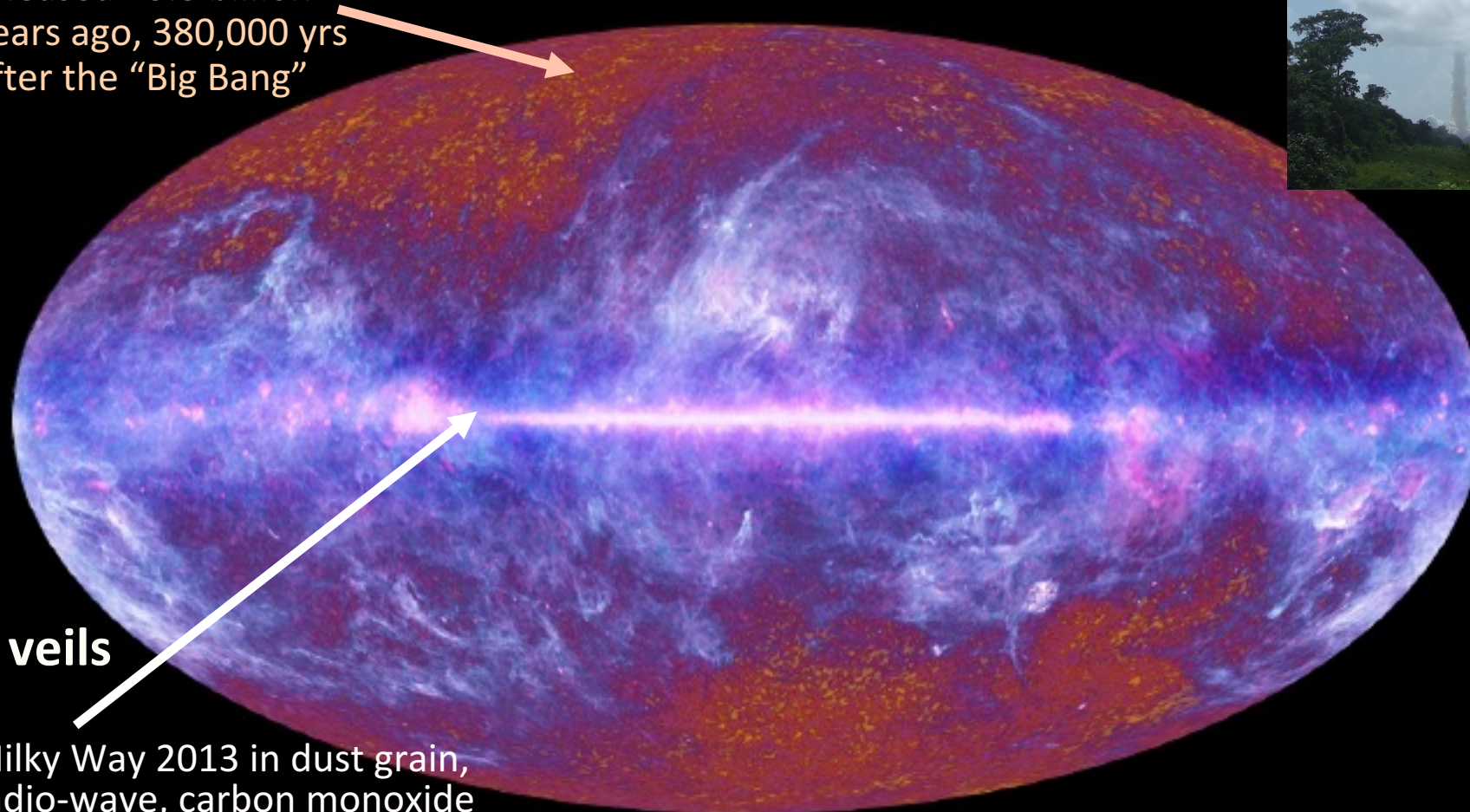
hard won observational emergence of the cosmic web of galaxies, clustered & interconnected

May 14, 2009
French Guiana



COMPLEXITY of here & now

the primordial light,
released 13.8 billion
years ago, 380,000 yrs
after the "Big Bang"

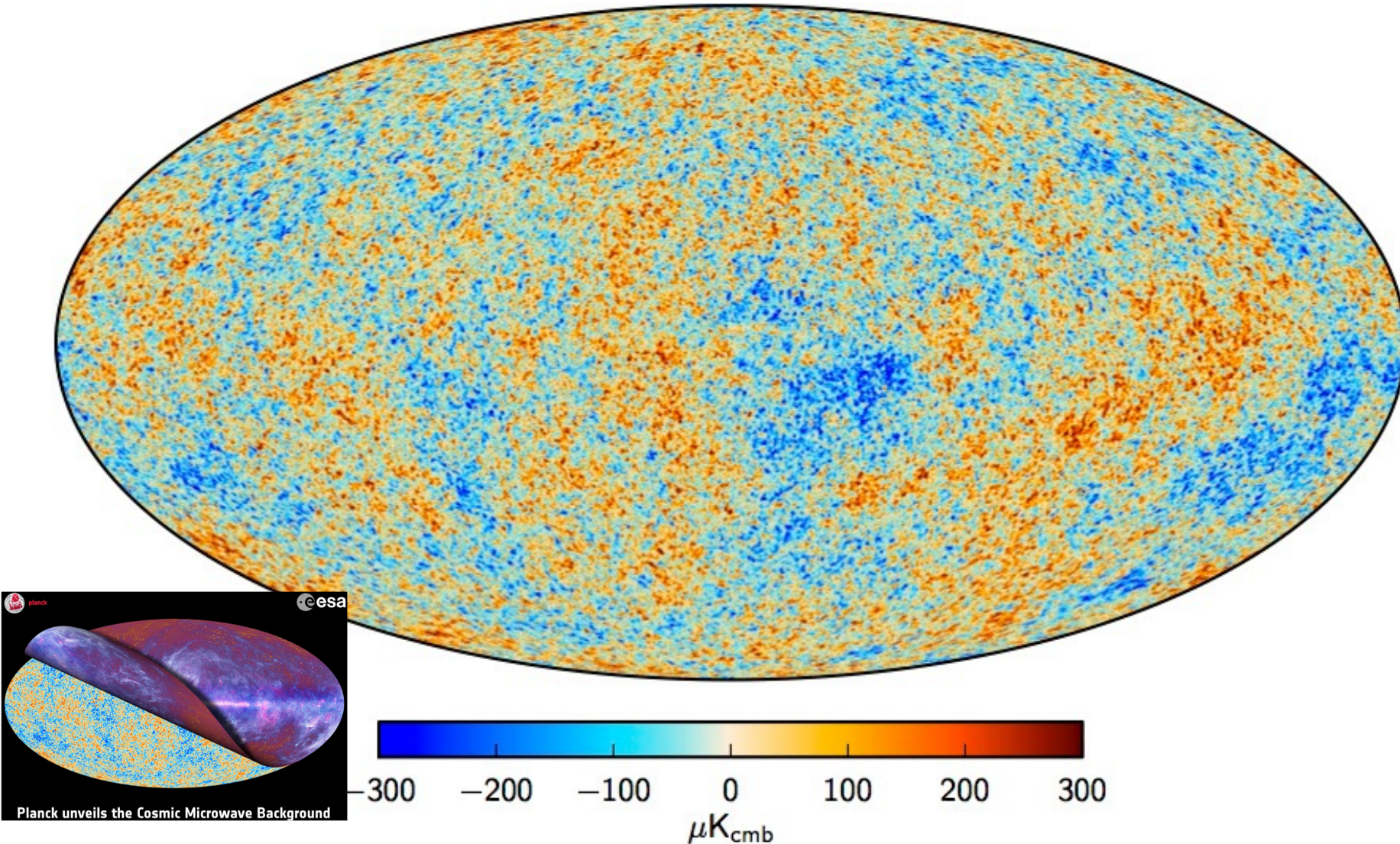


7 veils

Milky Way 2013 in dust grain,
radio-wave, carbon monoxide
emissions; plus stellar, X-ray,
gamma ray, cosmic ray emissions

...

Planck's primordial light unveiled
reveals **primordial sound waves**
=> the inharmonious '*music of the spheres*'
in 7+ numbers

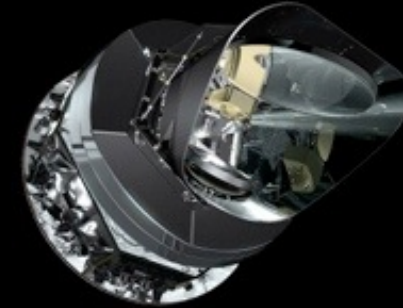


Comparison of CMB Space Experiments: Increasing Resolution

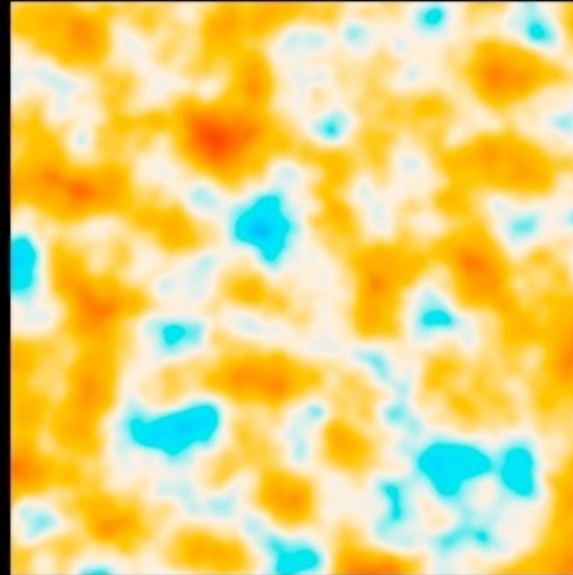
COBE
launch

WMAP
launch

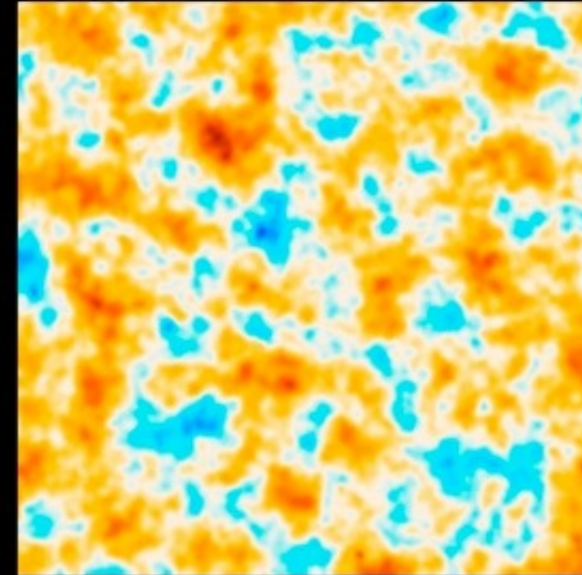
Planck
launch



COBE



WMAP

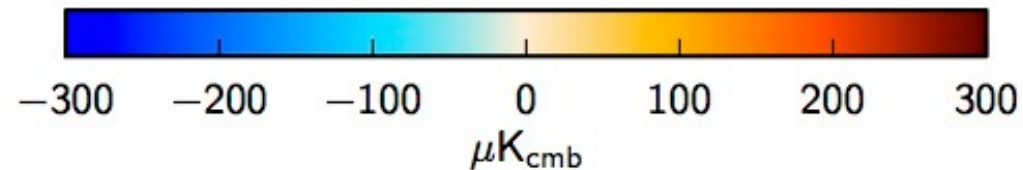
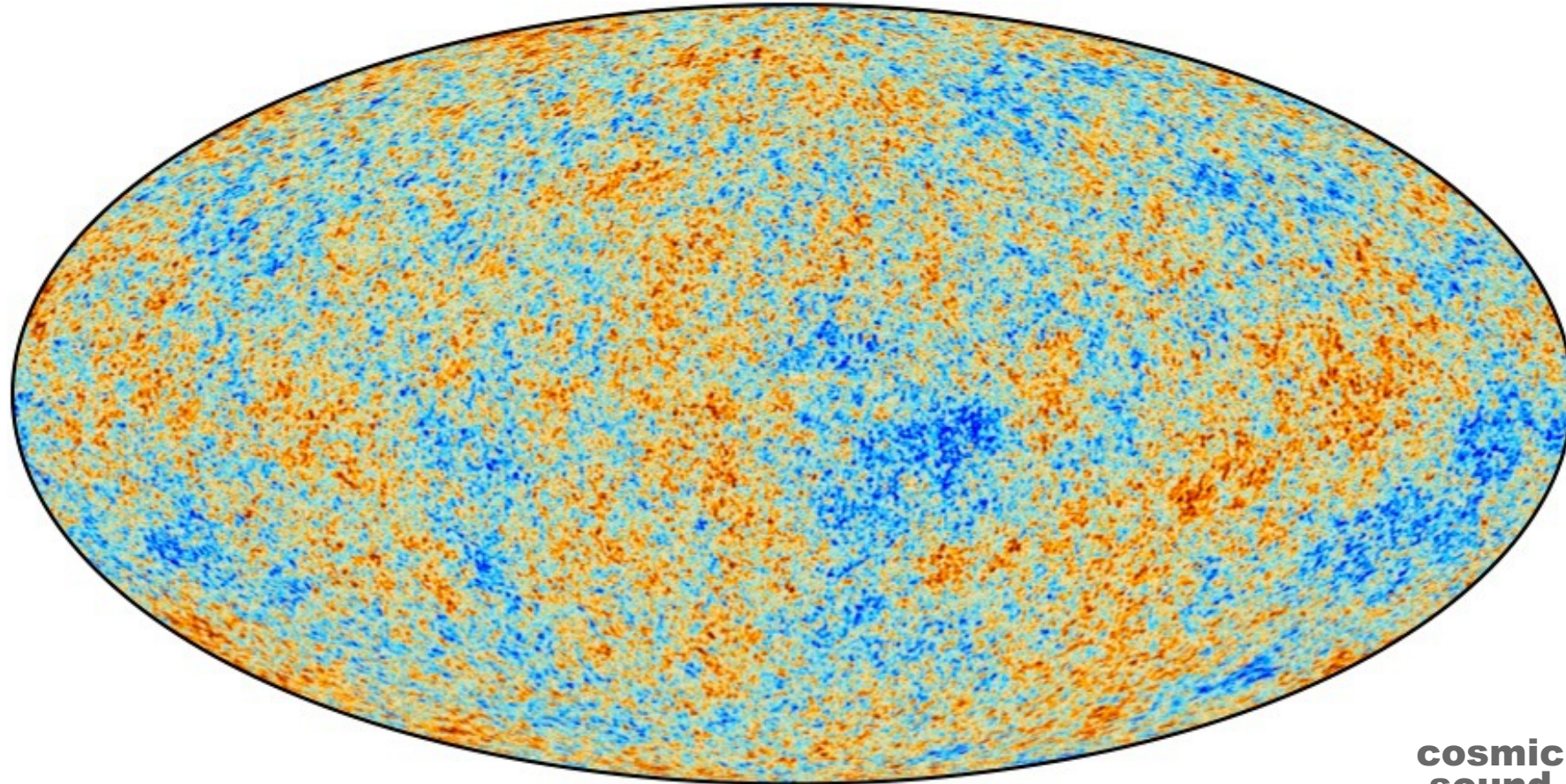


Planck

Temperature
changes in
micro-degrees

to even higher resolution with telescopes in Chile and the South Pole

Planck's primordial light unveiled
reveals **primordial sound waves**
=> the inharmonious '*music of the spheres*'
in 7+ numbers



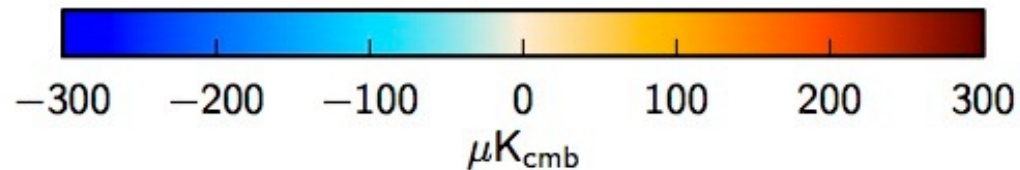
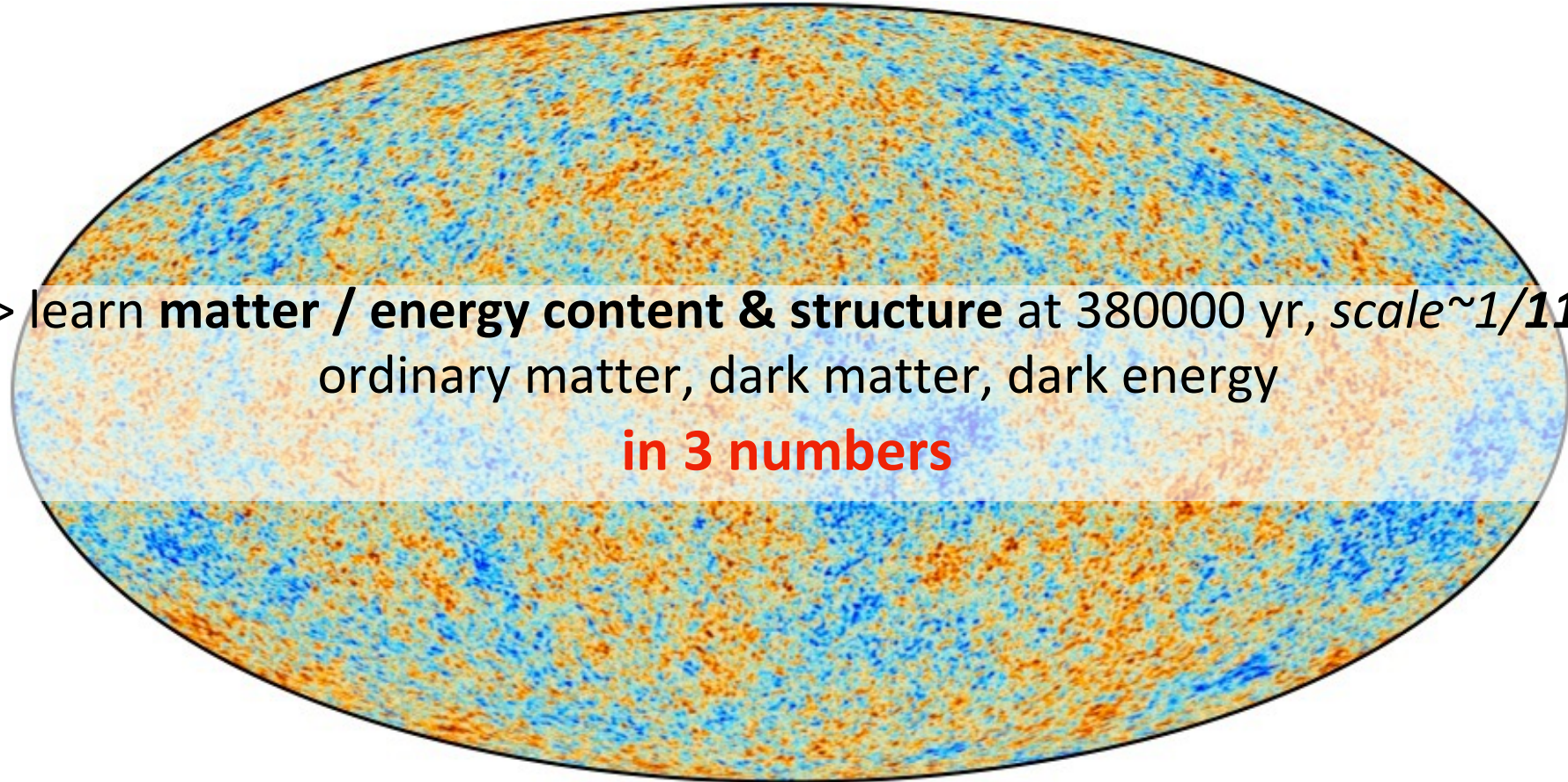
**cosmic
sound
realization**



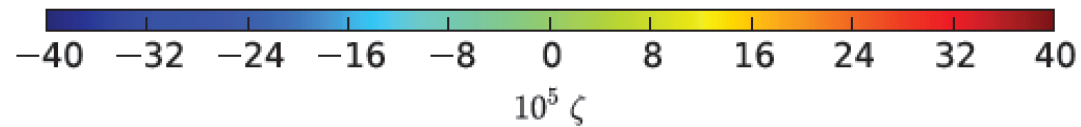
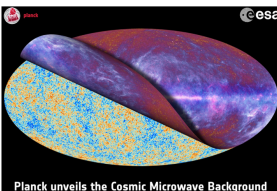
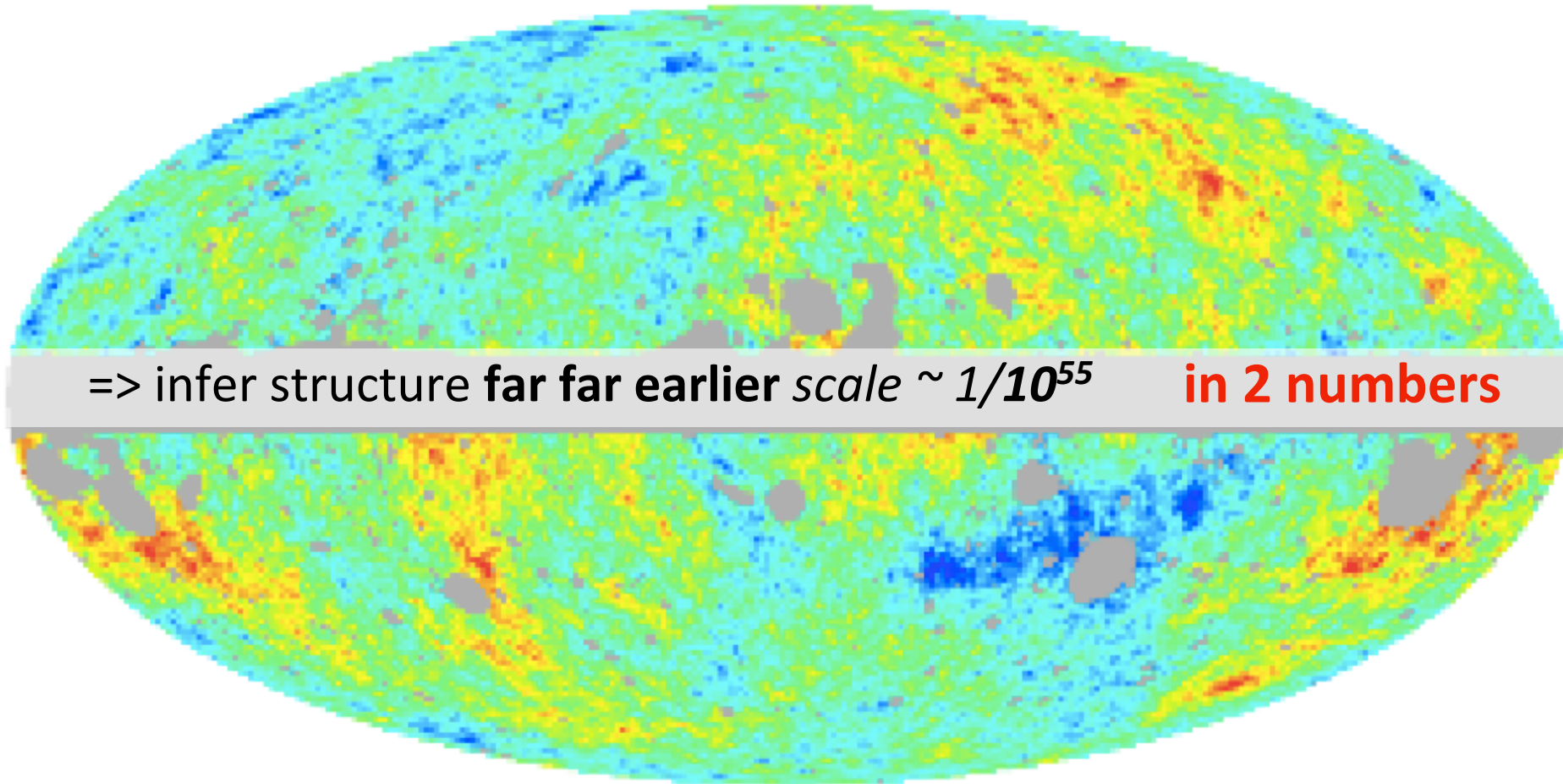
Planck's primordial light unveiled
reveals **primordial sound waves**
=> the inharmonious '*music of the spheres*'
in 7+ numbers

=> learn **matter / energy content & structure** at 380000 yr, *scale*~1/**1100**
ordinary matter, dark matter, dark energy

in 3 numbers

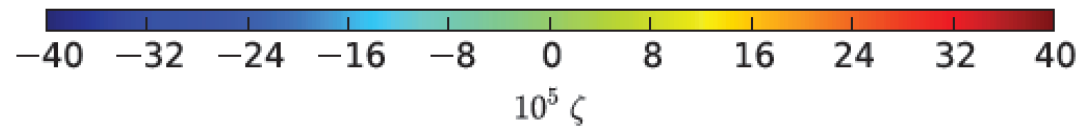
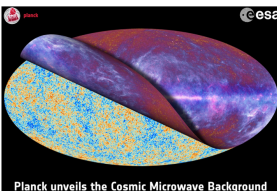


reveals **primordial sound** from far earlier times
=> the inharmonious early Universe *'music of the spheres'*



reveals **primordial sound** from far earlier times
=> the inharmonious early Universe *'music of the spheres'*
in 2⁺ numbers

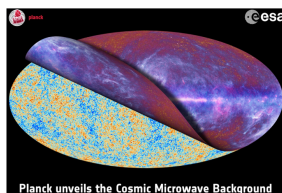
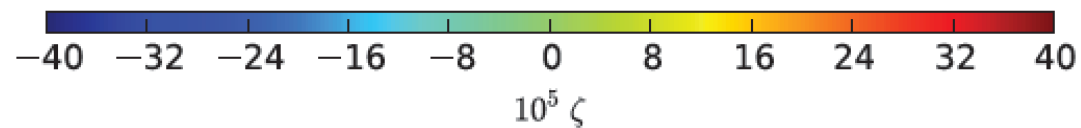
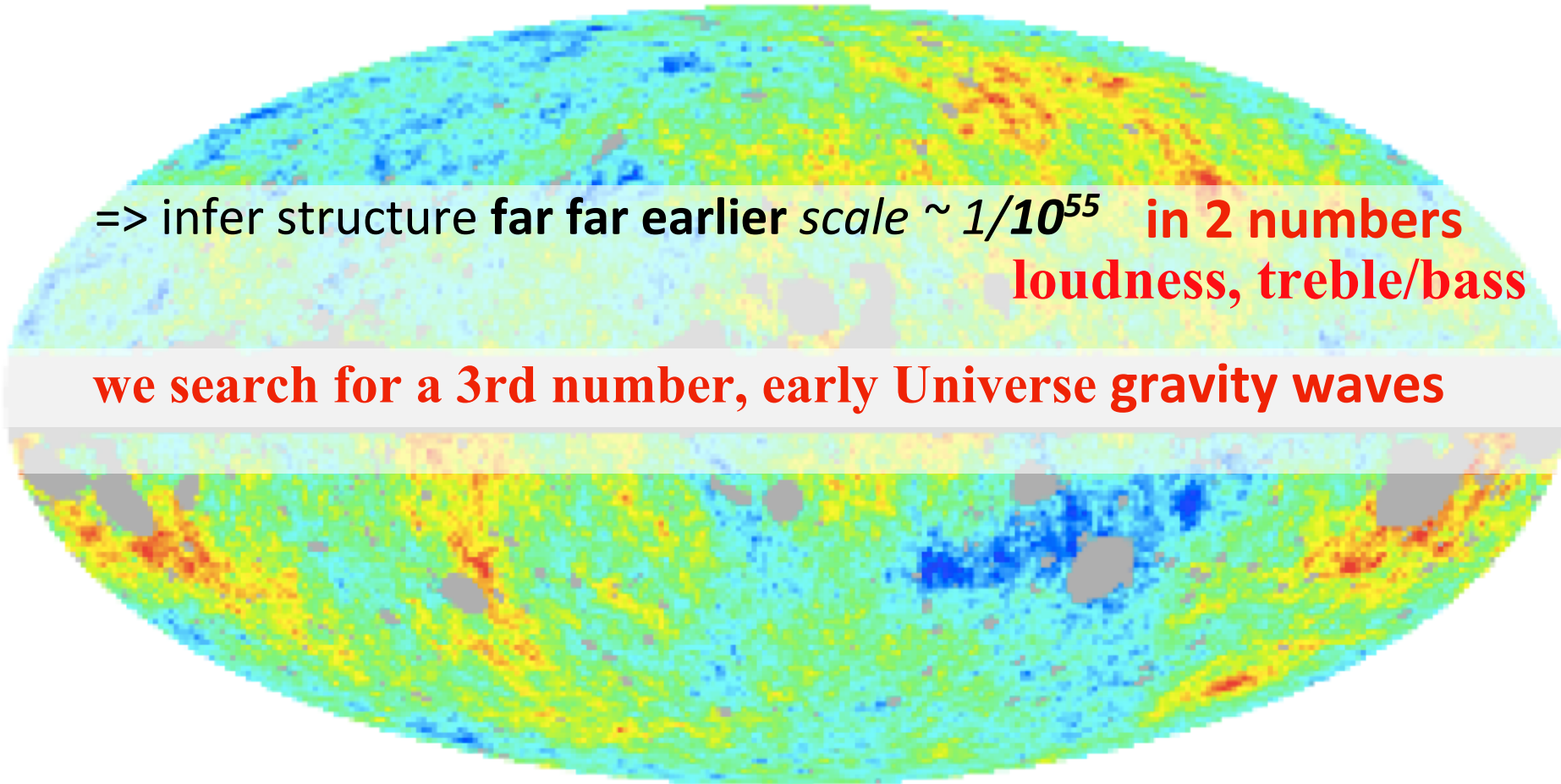
the ultra early Universe sounds like **classical music**
(all parts of the audible spectrum are used),
with slightly more bass than treble
sound is **noise-like**, as random as can be
Planck's most celebrated findings



reveals **primordial sound** from far earlier times
=> the inharmonious early Universe *'music of the spheres'*

=> infer structure far far earlier *scale* $\sim 1/10^{55}$ **in 2 numbers**
loudness, treble/bass

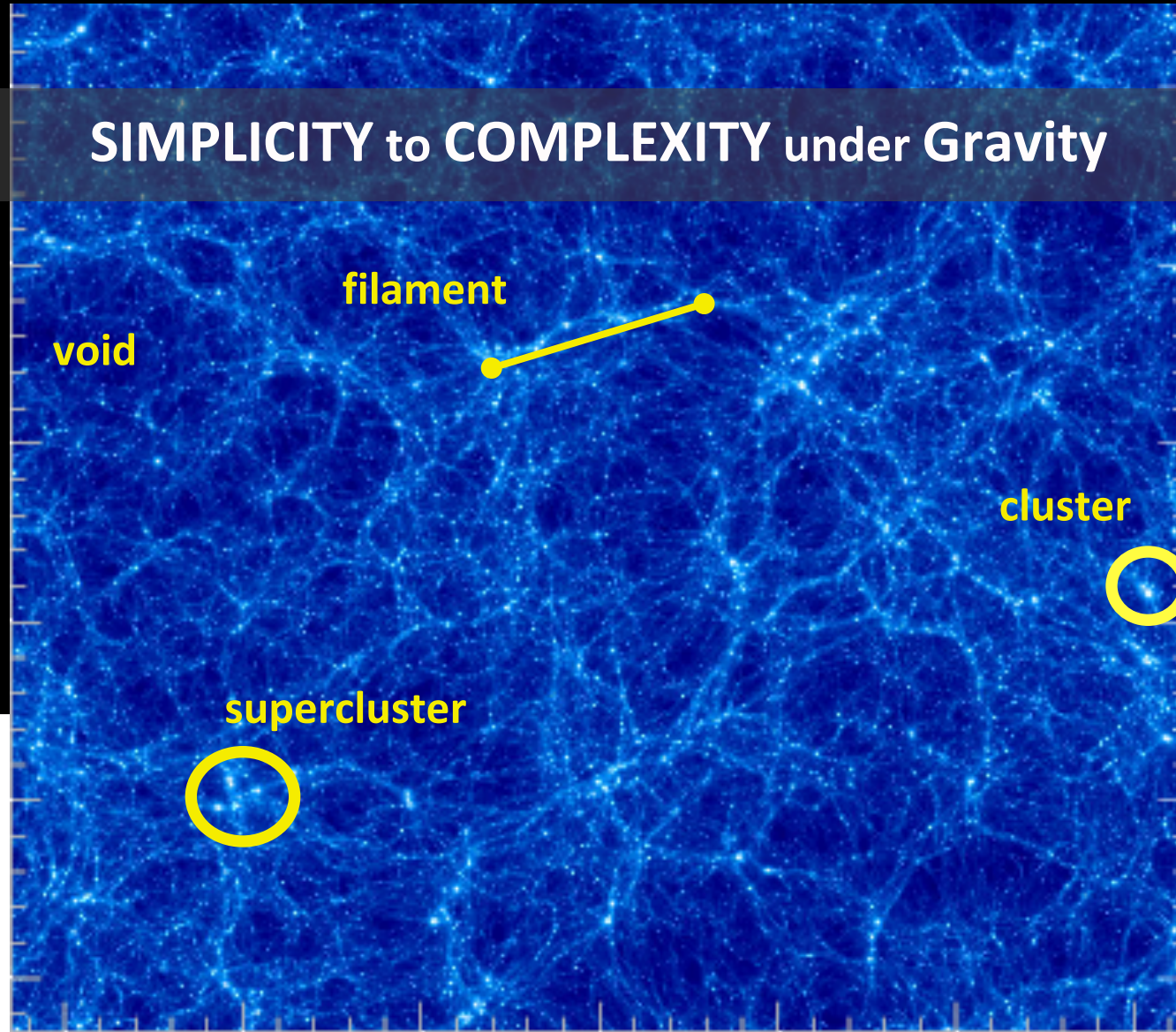
we search for a 3rd number, early Universe gravity waves



Simulation of the 7⁺ numbers

begets the **Cosmic Web** of clusters now & galaxies forming

SIMPLICITY to COMPLEXITY under Gravity

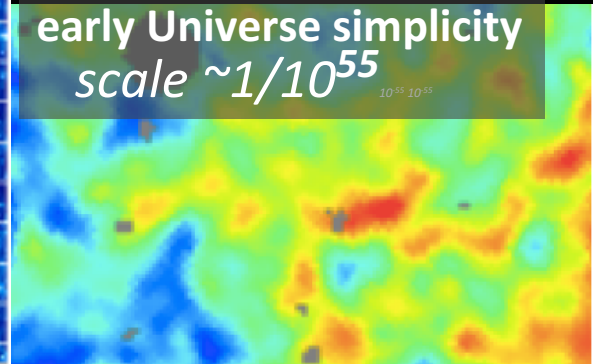


~ **billion light years**

state of the art simulation

- + ordinary matter
- + dark matter
- + dark energy

early Universe simplicity
scale $\sim 1/10^{55}$



Let there be....

SIMPLE

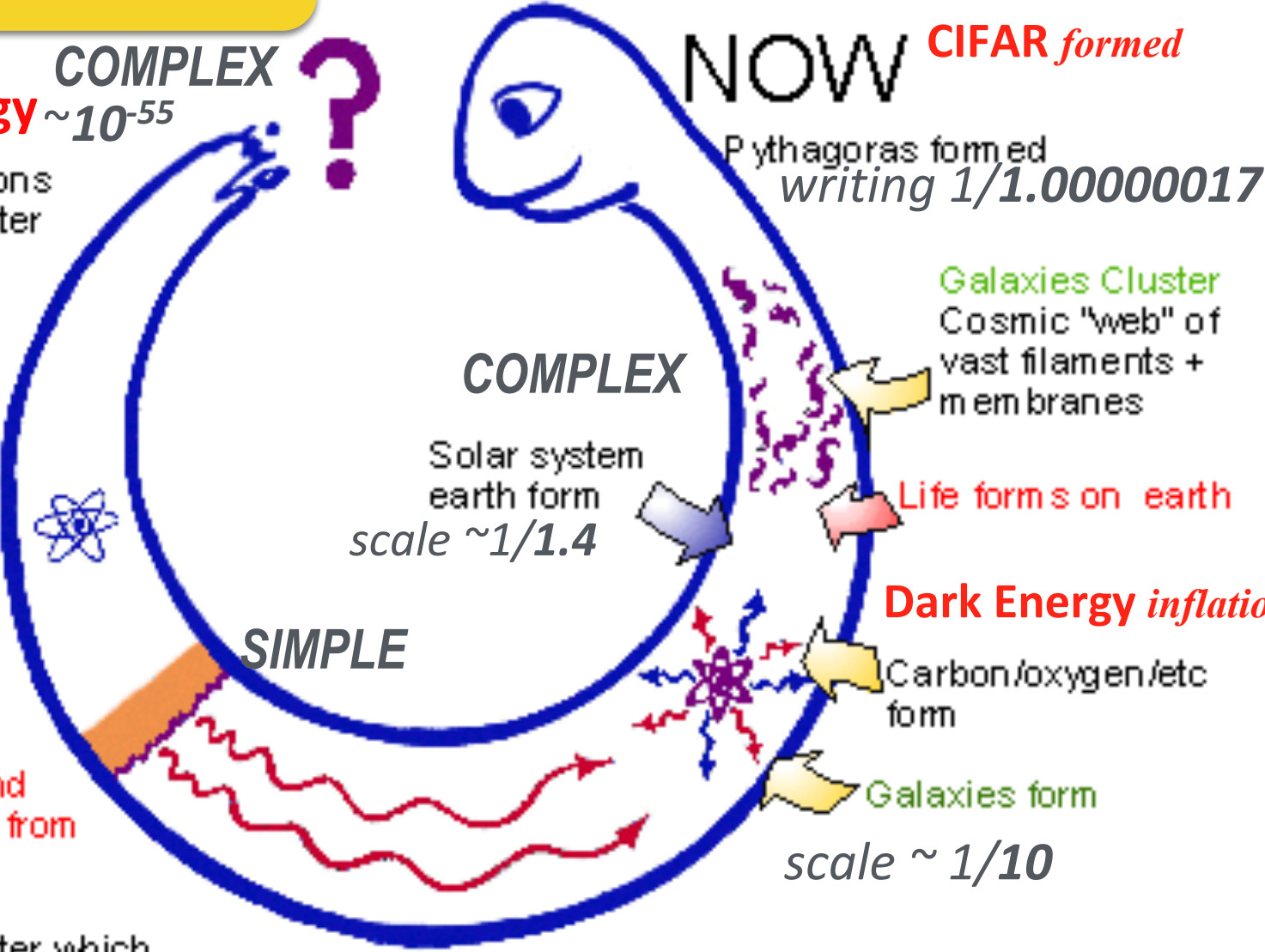
2 numbers +1
early **Dark Energy** $\sim 10^{-55}$ **COMPLEX** ?

Inflation fluctuations form: quantum jitter
let there be Heat
scale $\sim 10^{-29}$

Dark Matter
Protons/Neutrons form
light nuclei
Helium forms

let there be Light
Cosmic background radiation released from matter
carries imprint of fluctuations in matter which grow to generate galaxies etc.

scale $\sim 1/1100$ 7+ numbers



NOW **CIFAR formed**
Pythagoras formed
writing $1/1.00000017$

COMPLEX

Solar system
earth form
scale $\sim 1/1.4$

SIMPLE

Galaxies Cluster
Cosmic "web" of
vast filaments +
membranes

Life forms on earth

Dark Energy inflation

Carbon/oxygen/etc
form

Galaxies form

scale $\sim 1/10$