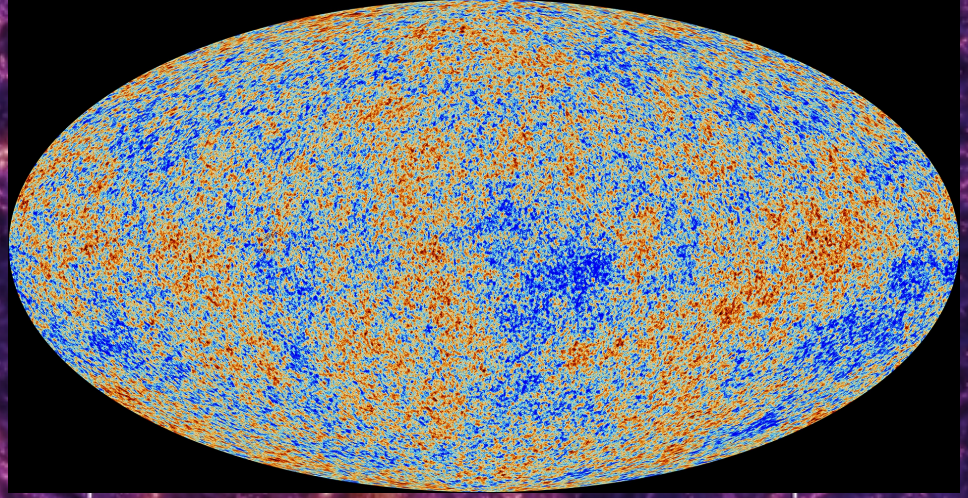
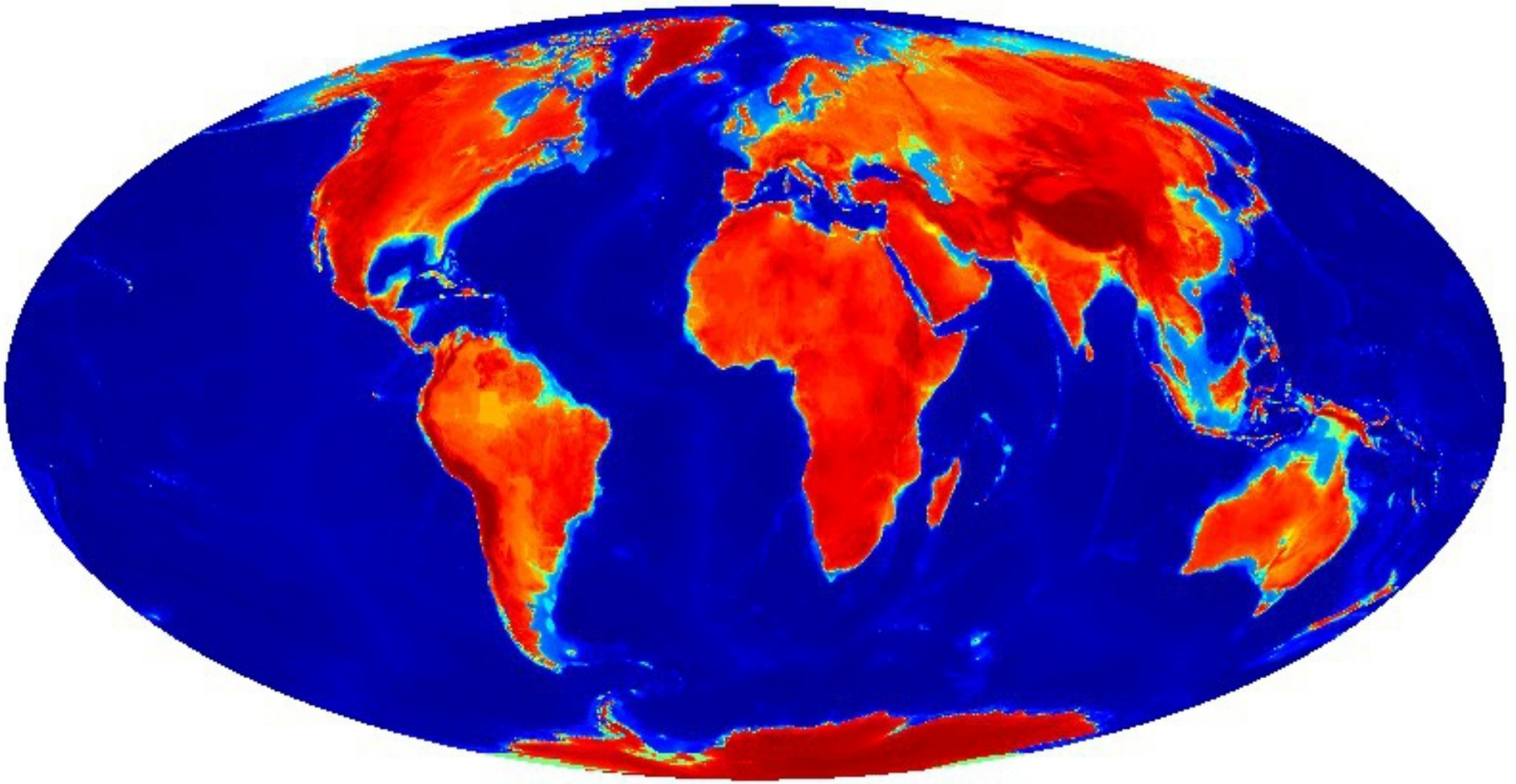
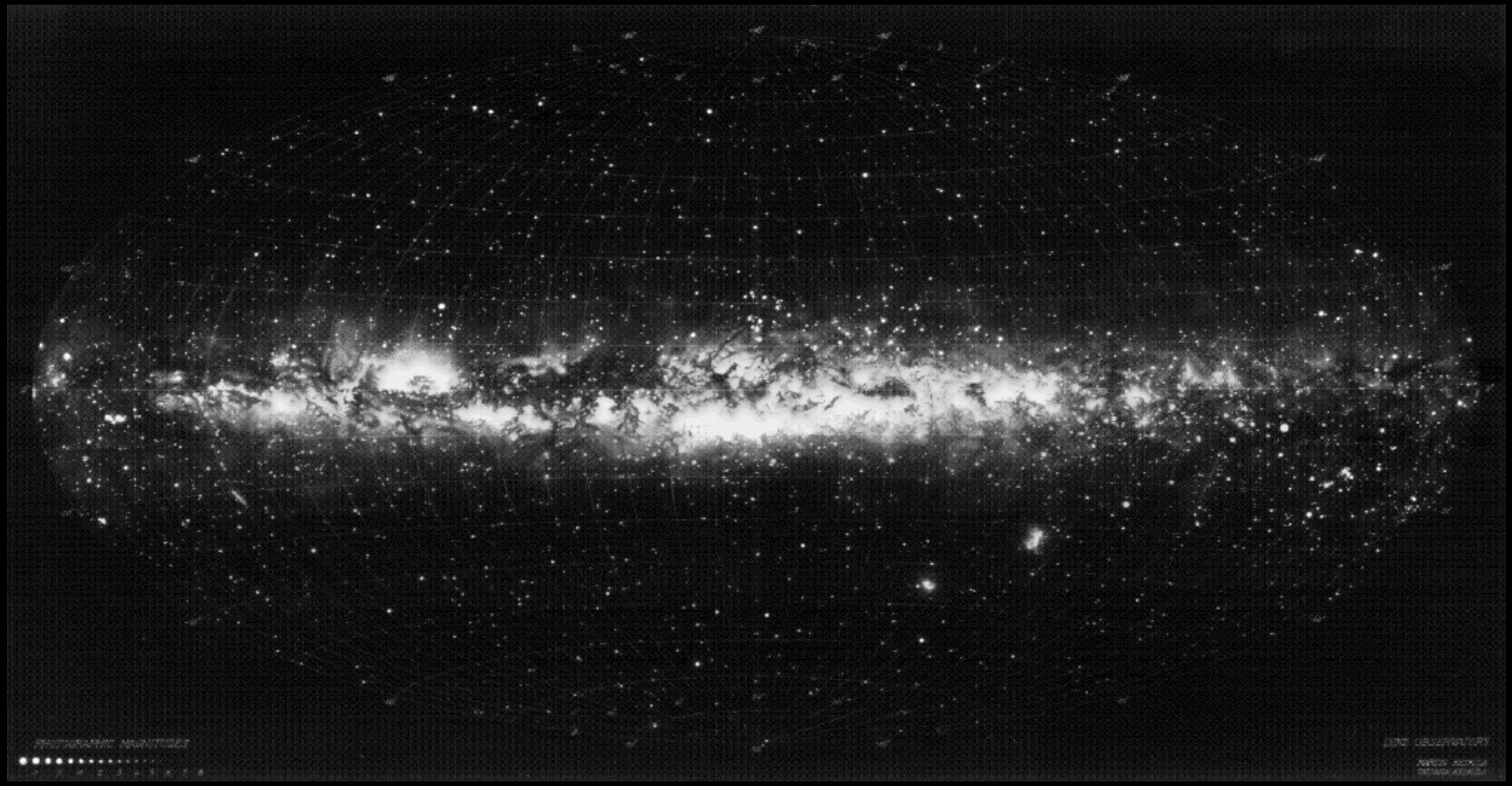


All from Nothing: the structuring of our Universe

Simon White
Max Planck Institute for Astrophysics

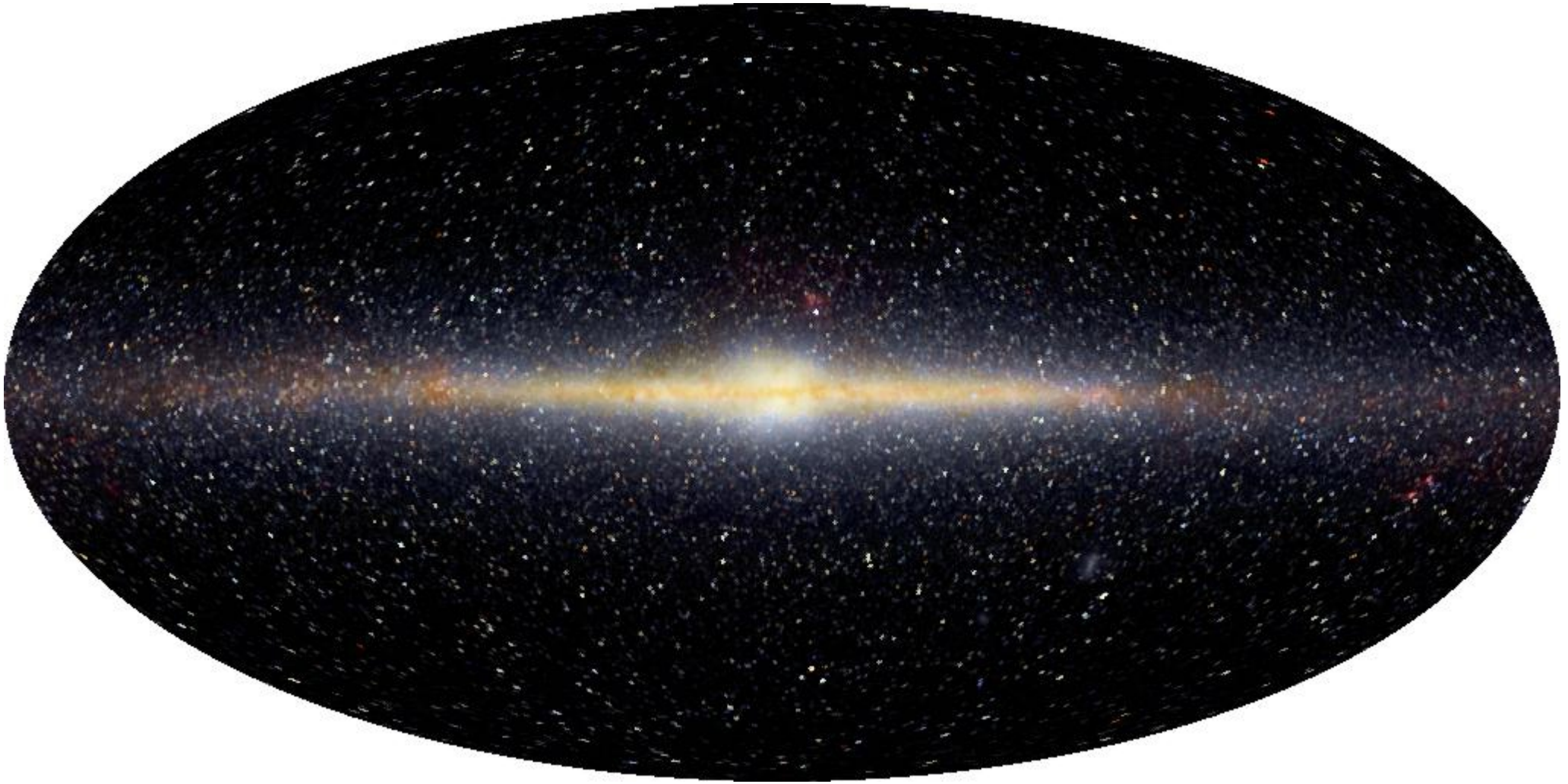


Star map of the whole sky



..out to 10,000 light-years

COBE's infrared map of the whole sky



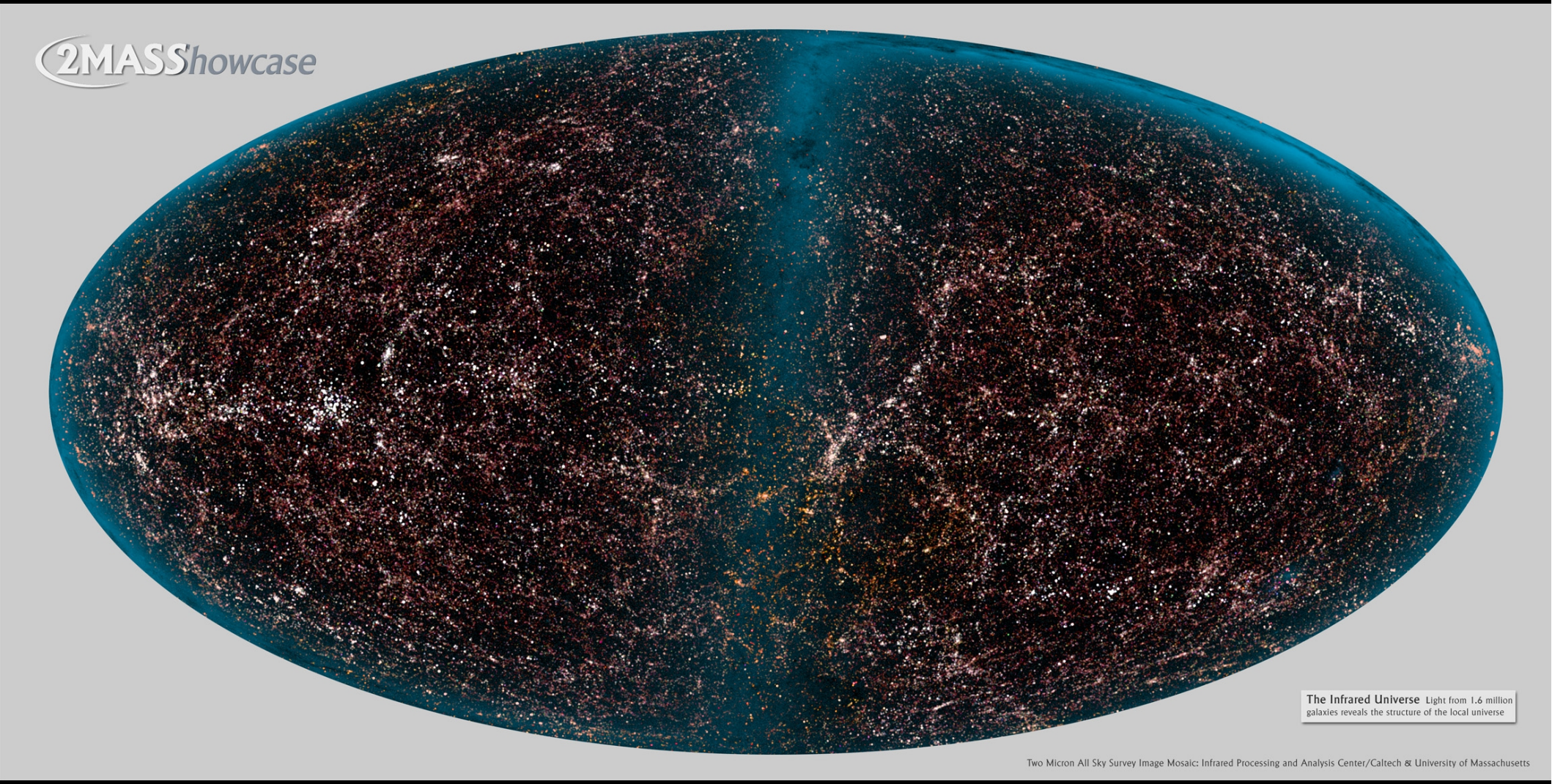
..out to 30,000 light-years

The Andromeda Nebula: our biggest neighbour

..out to 2,000,000 light-years


NGC 4414 -- another
Galaxy like our own

A galaxy map of the whole sky



..out 1,000,000,000 light-years

..out to more than 30,000,000,000 light-years

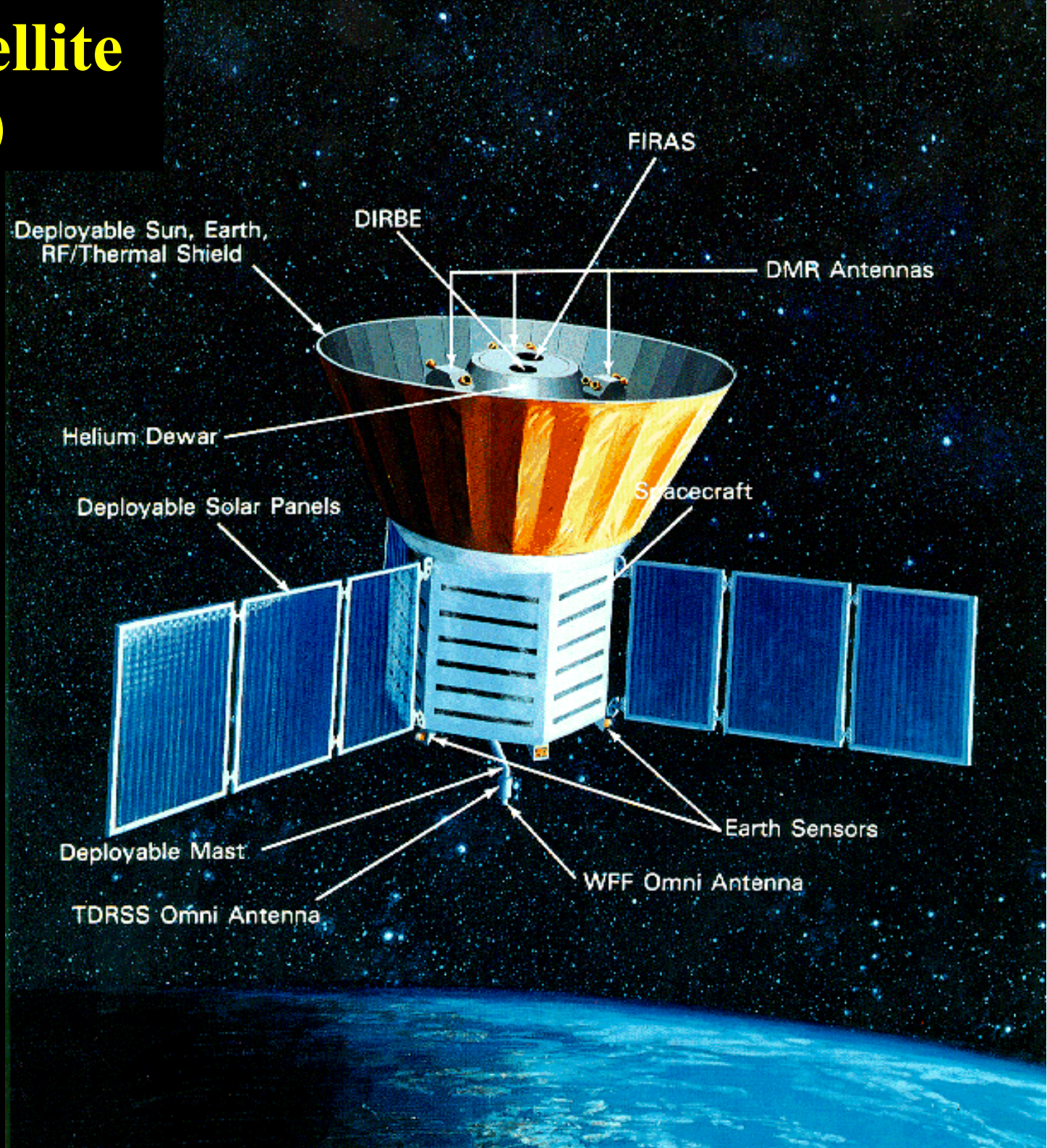
The deepest optical image ever made

A 300 hour exposure with the Hubble Space Telescope

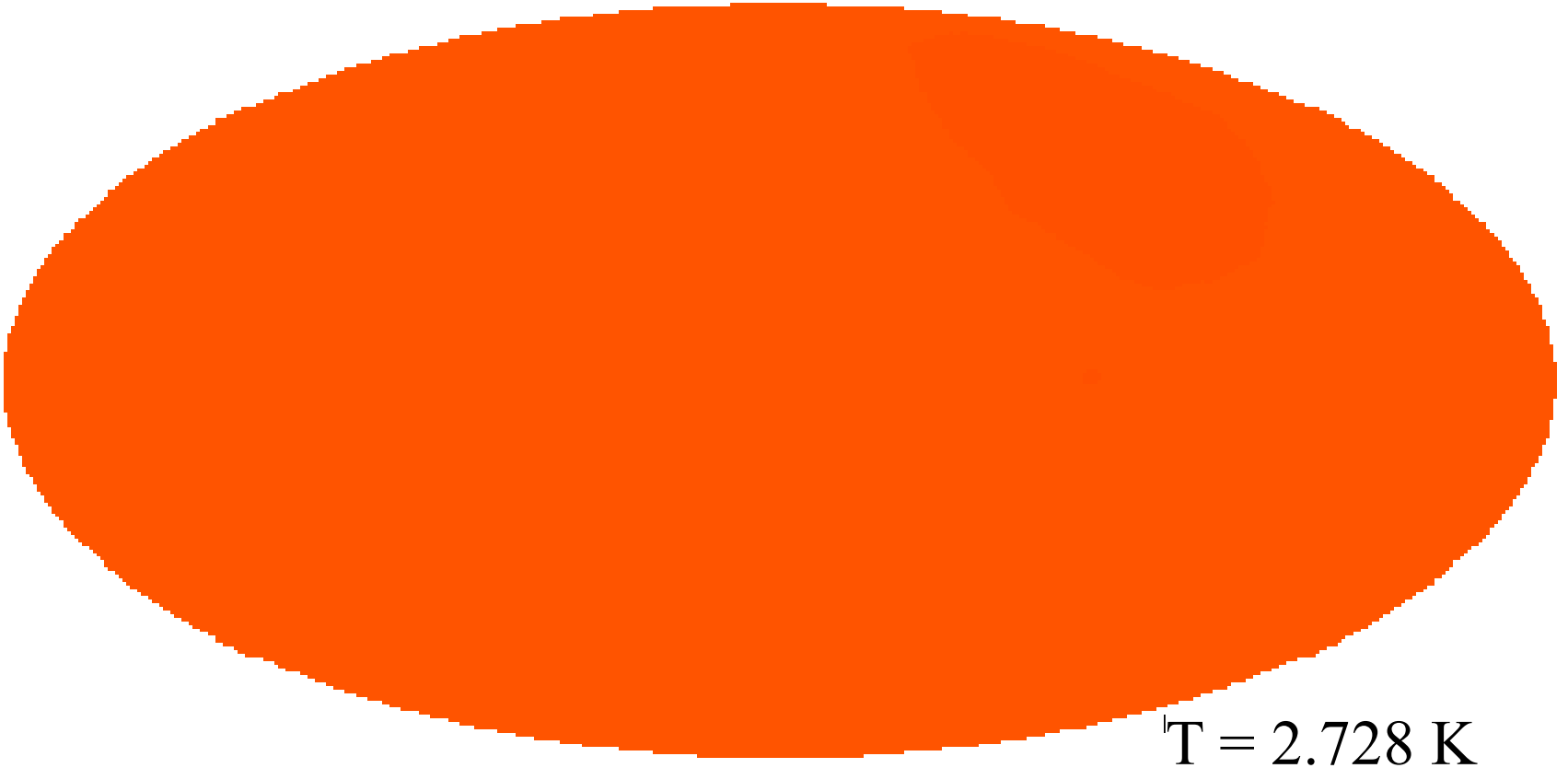
The COBE Satellite (1989 - 1993)

- Two Instruments mapped the whole sky at microwave and infra-red wavelengths
- One instrument took a precise spectrum of the sky at microwave wavelengths

Nobel Prize 2006



COBE's temperature map of the whole sky



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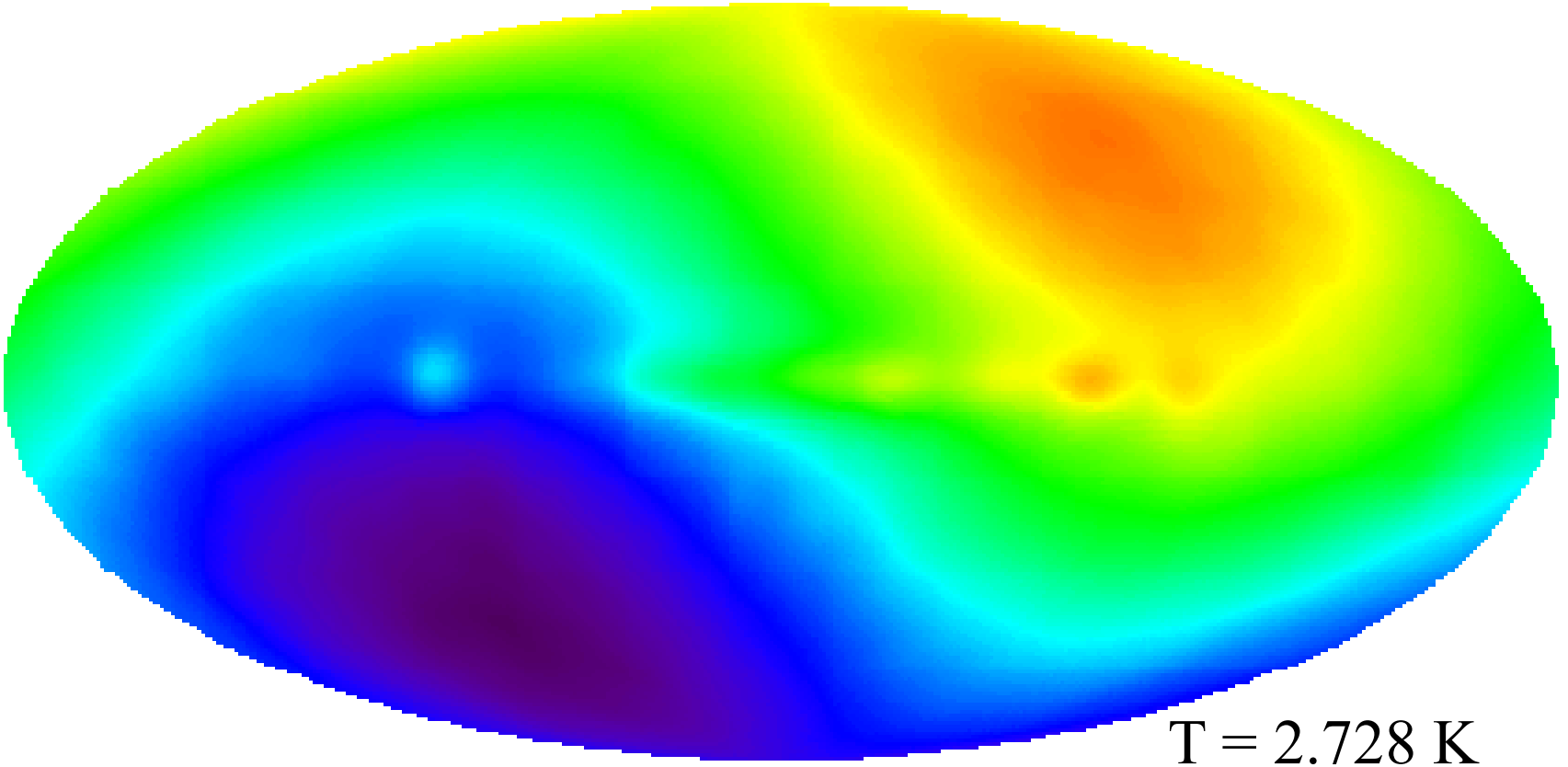
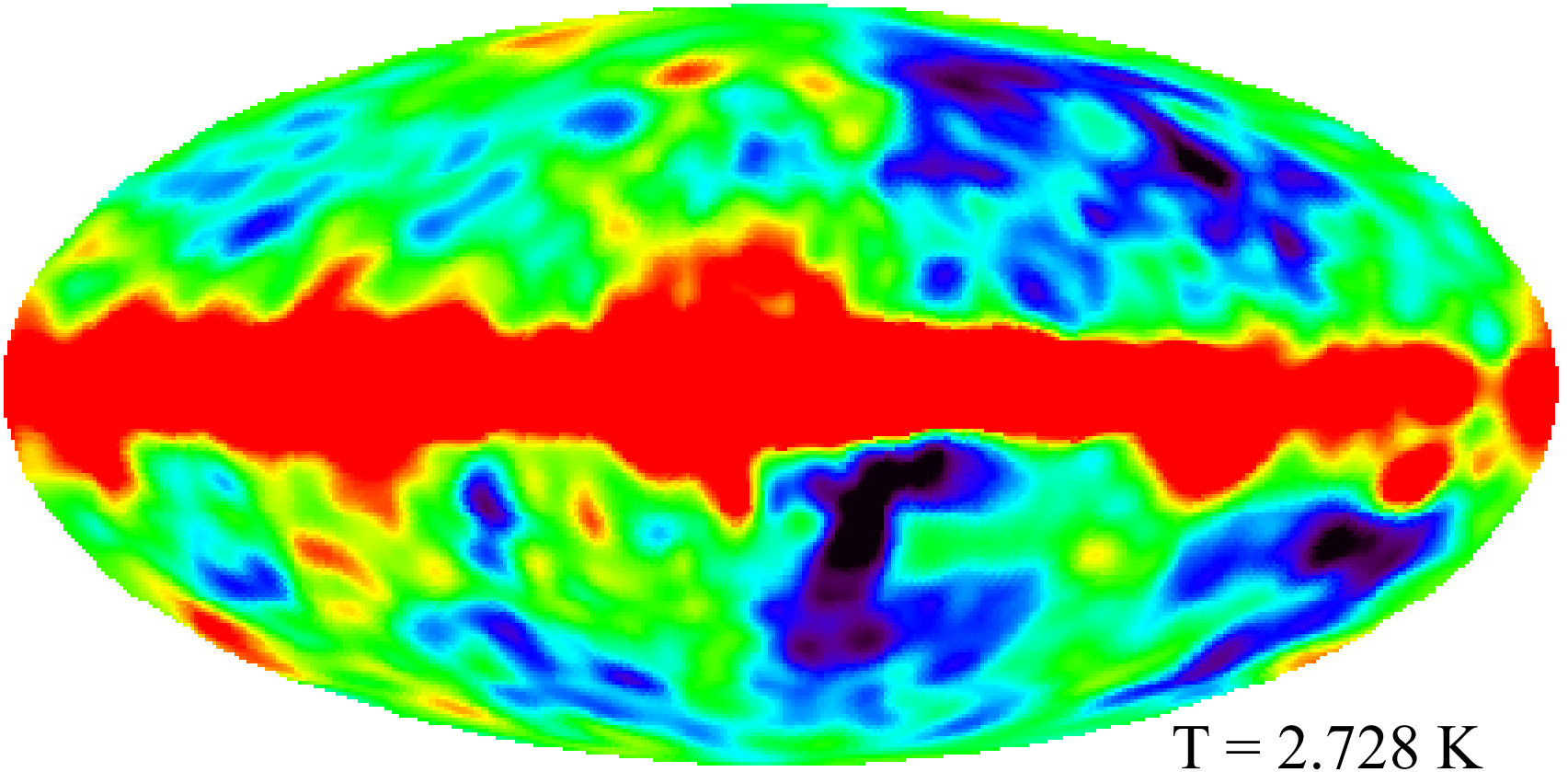


T = 2.728 K

$\Delta T = 0.0034$ K

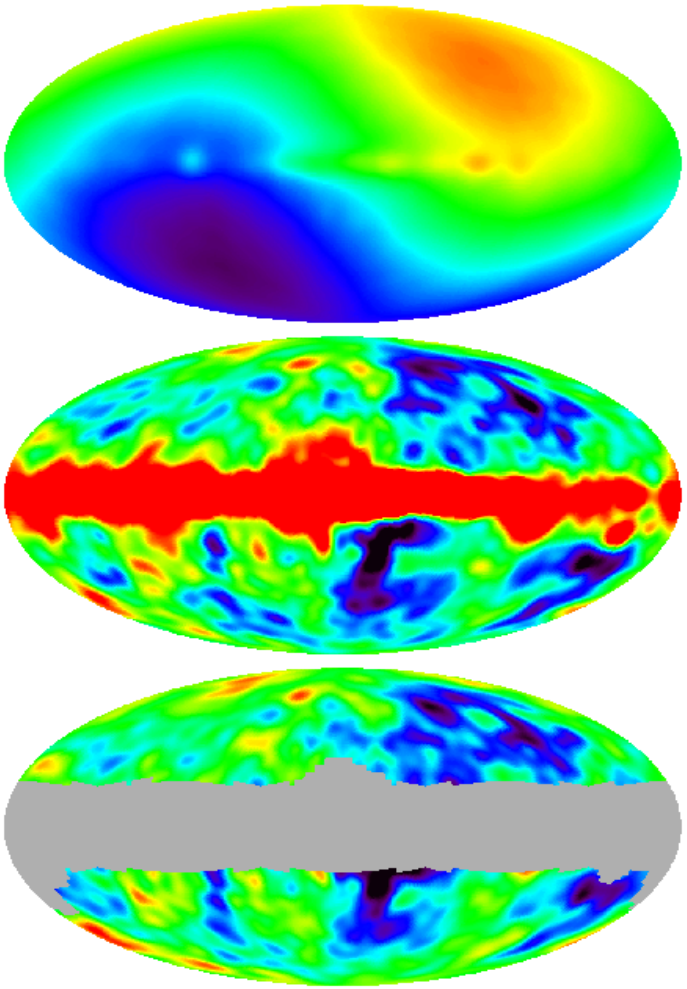
COBE's temperature map of the whole sky



T = 2.728 K

$\Delta T = 0.00002$ K

Structure in the COBE Map



- One side of the sky is cold, the other hot
  our Galaxy's motion through the cosmos
  → $V_{\text{Milchstrasse}} = 600$ km/s
- Radiation from dust and gas in our own Galaxy
- Structure in the microwave background itself

Structure in the microwave background

Where is the structure?

Structure in the microwave background

Where is the structure?

In cosmic clouds at the far edge of the visible Universe

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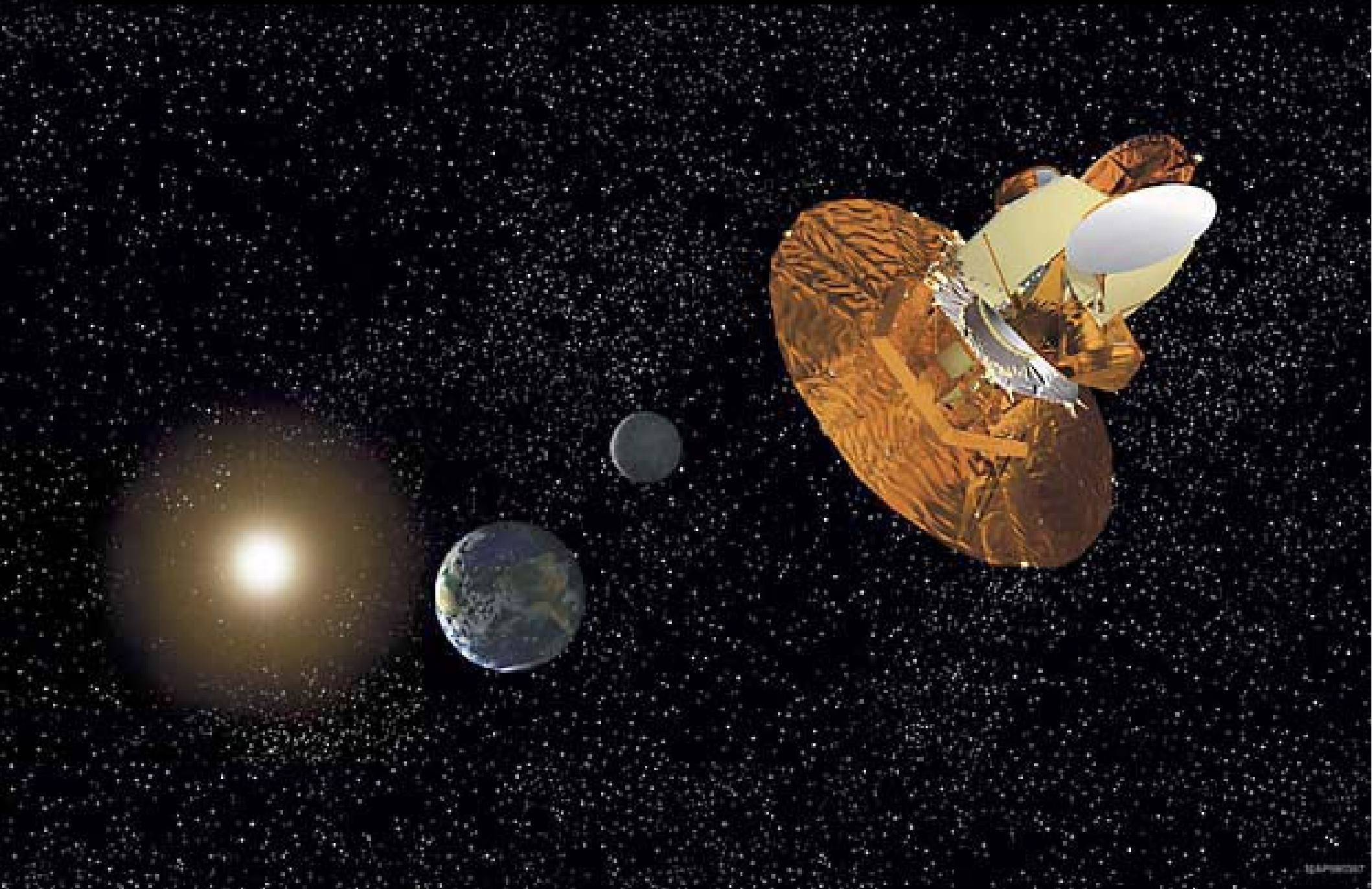
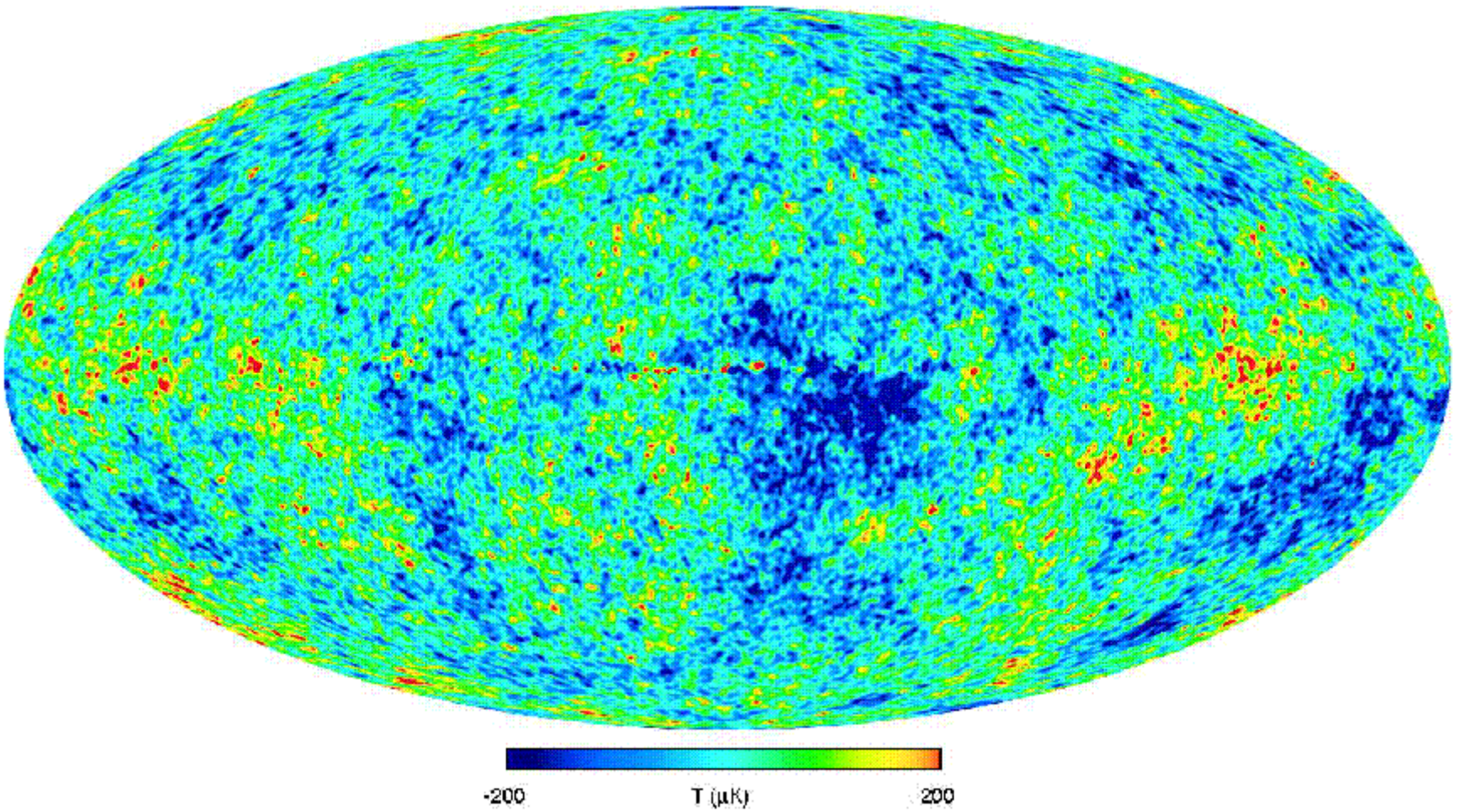
What has this structure become?

Everything we see around us (galaxies, stars, planets, people...)

The *WMAP* satellite at Lagrange point L2



WMAP's map of the whole sky



Bennett et al 2003

What do we learn from these structures?

The pattern of structure is influenced by three things:

--the geometry of the Universe

--the content of the Universe

--the process which created the structure

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- ordinary atomic (baryonic) matter
- Dark (non-baryonic) Matter
- Dark Energy

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--the process which created the structure
- The earliest instants of creation

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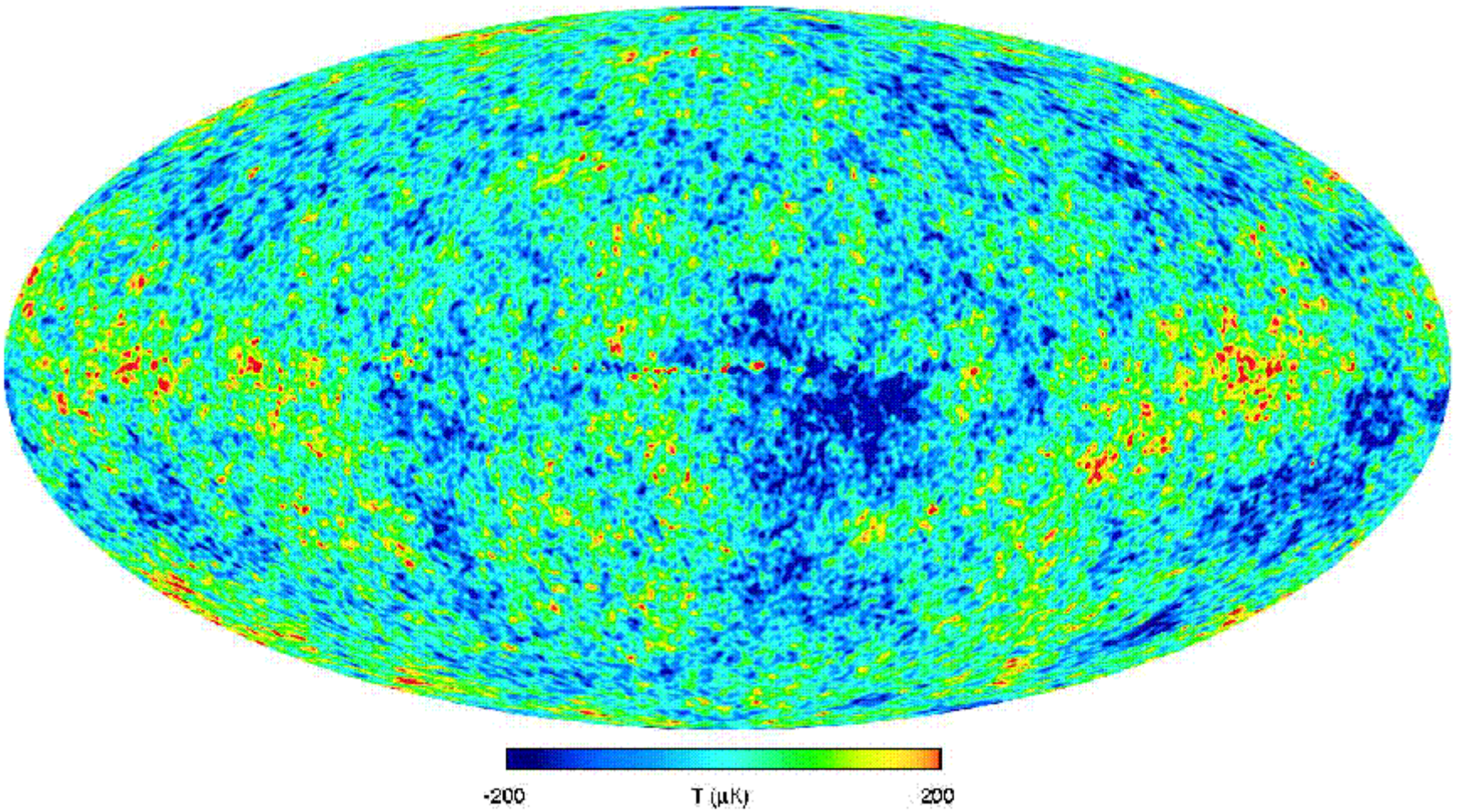

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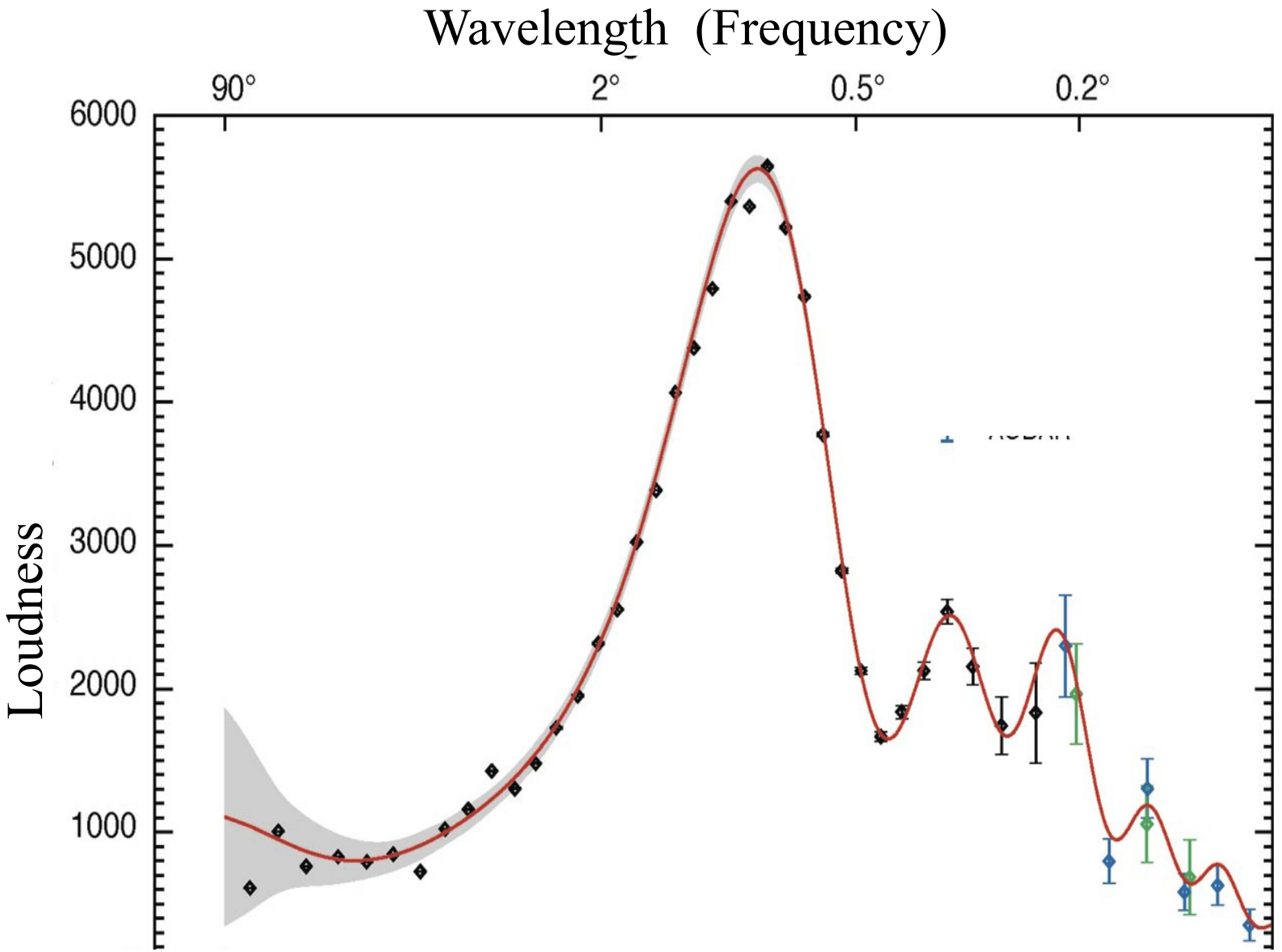

The harmonic content of sound waves in the cosmic clouds:
WMAP measurements compared to a theoretical prediction

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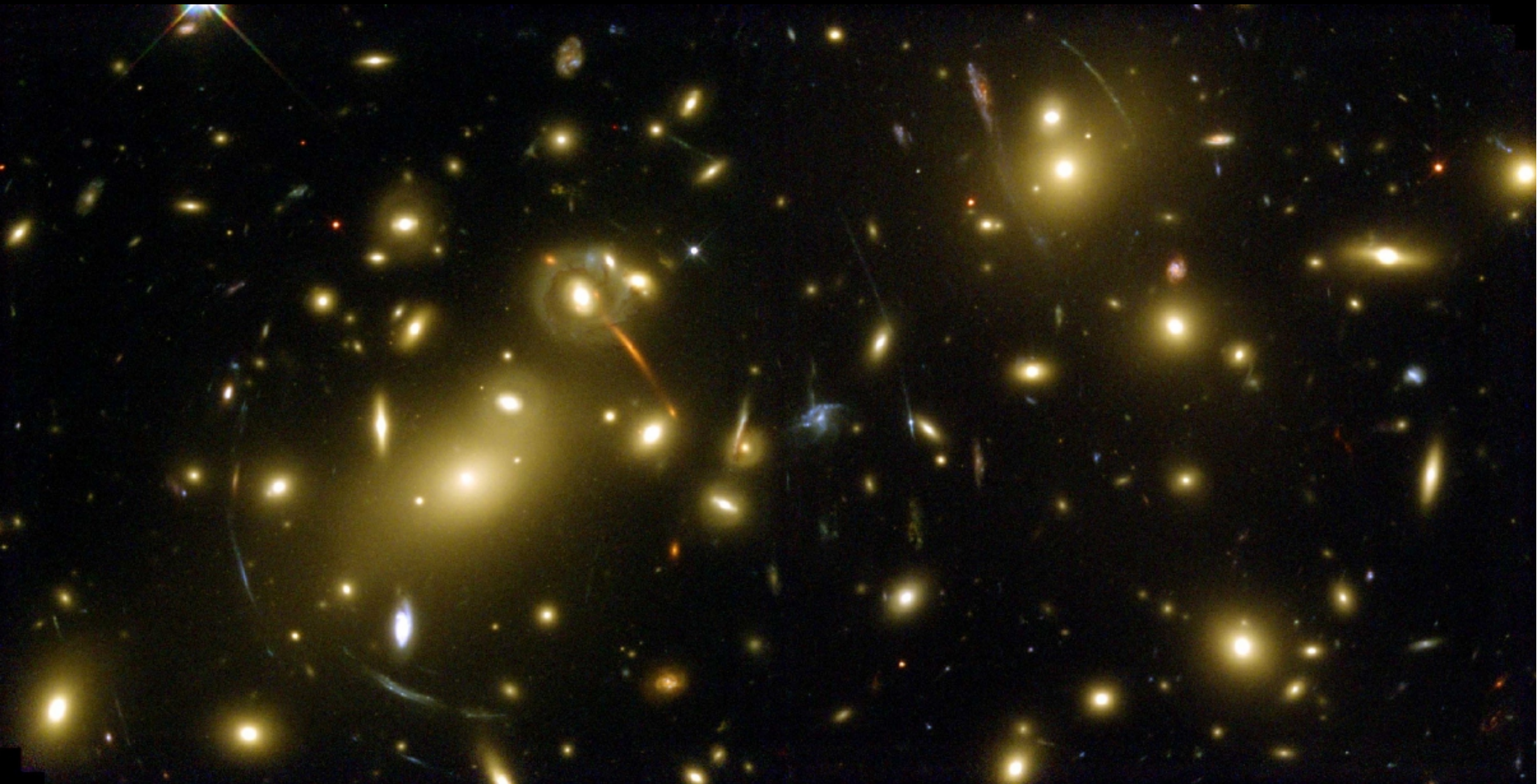
  (already "seen" through gravitational lensing effects)

A galaxy cluster acting as a gravitational lens

Abell 2218



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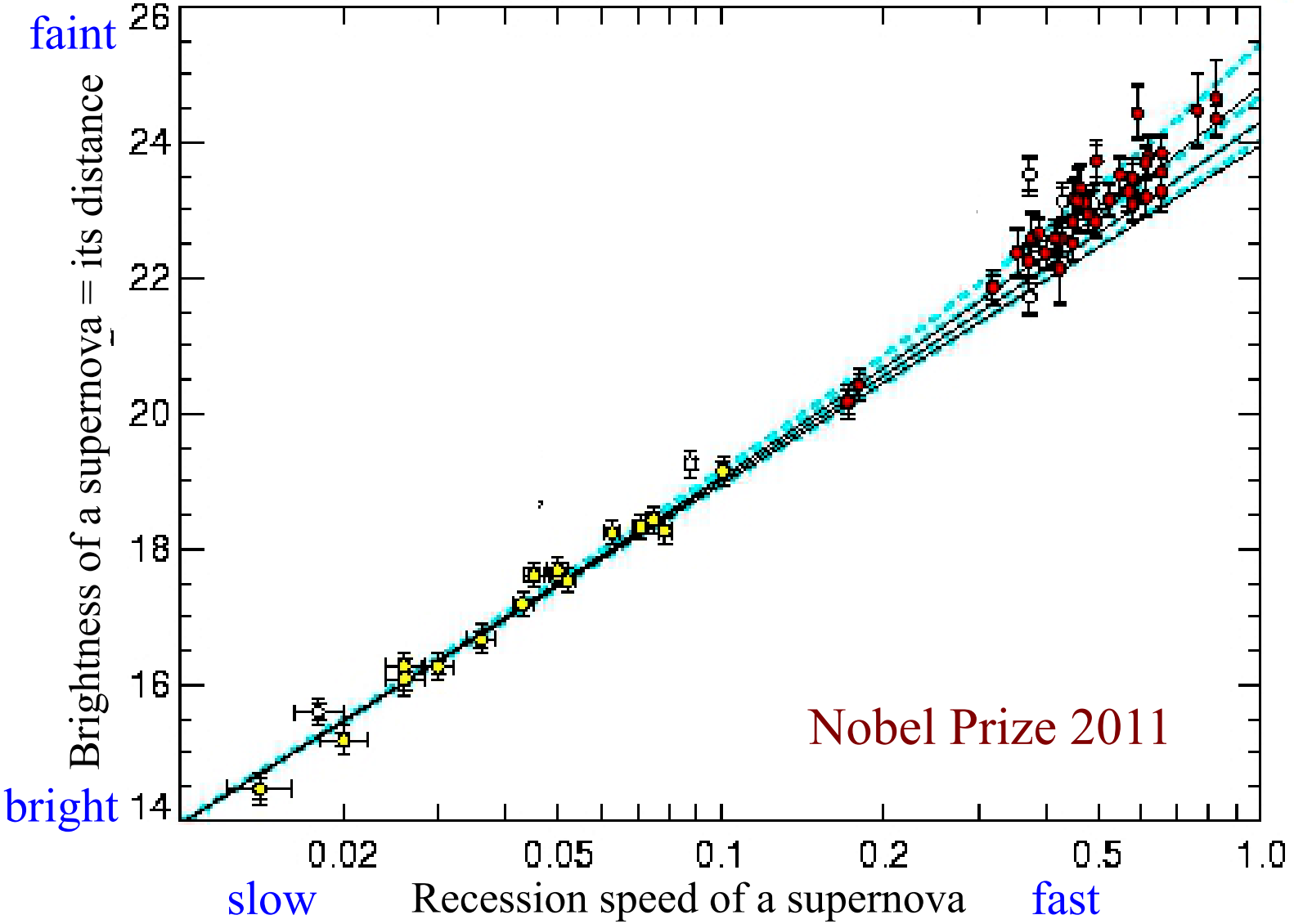
Dark Energy drives cosmic acceleration



Distant supernovae, seen when the Universe was younger, are fainter than expected → the Universe expands **faster** today than in the past

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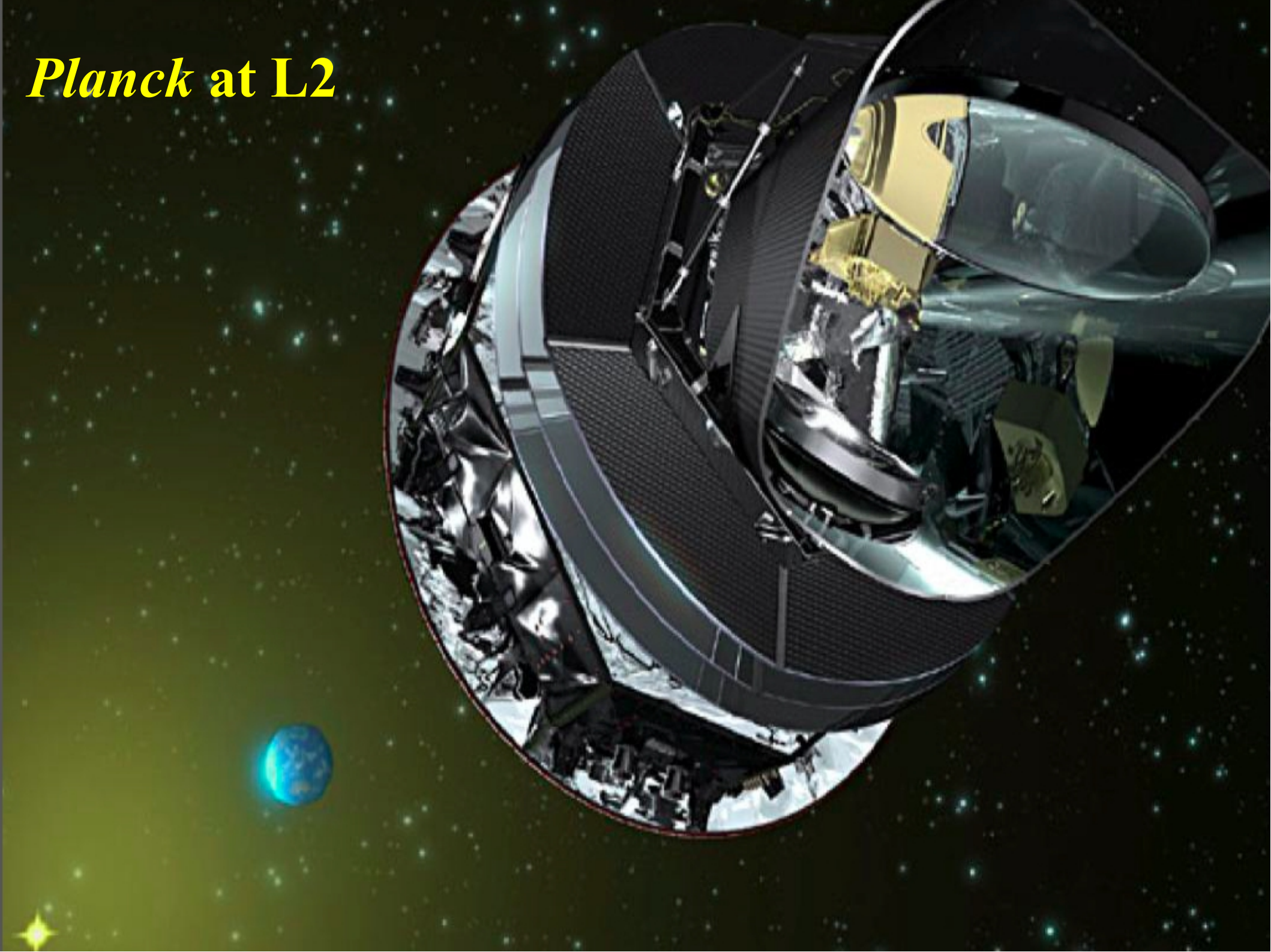
Everything formed from the Vacuum!

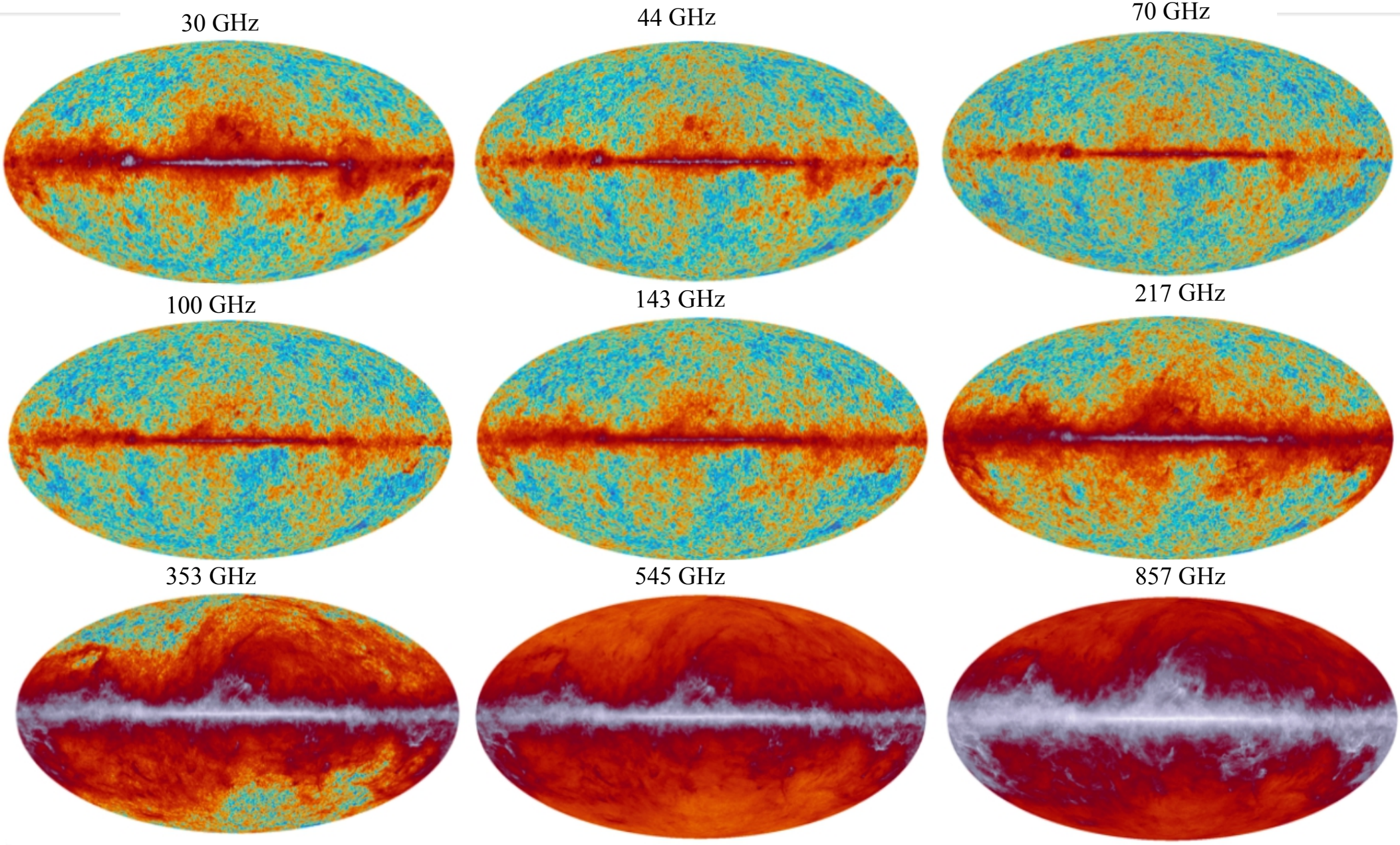
Launch of the *Planck* satellite

Kourou, French Guyana: May 14, 2009

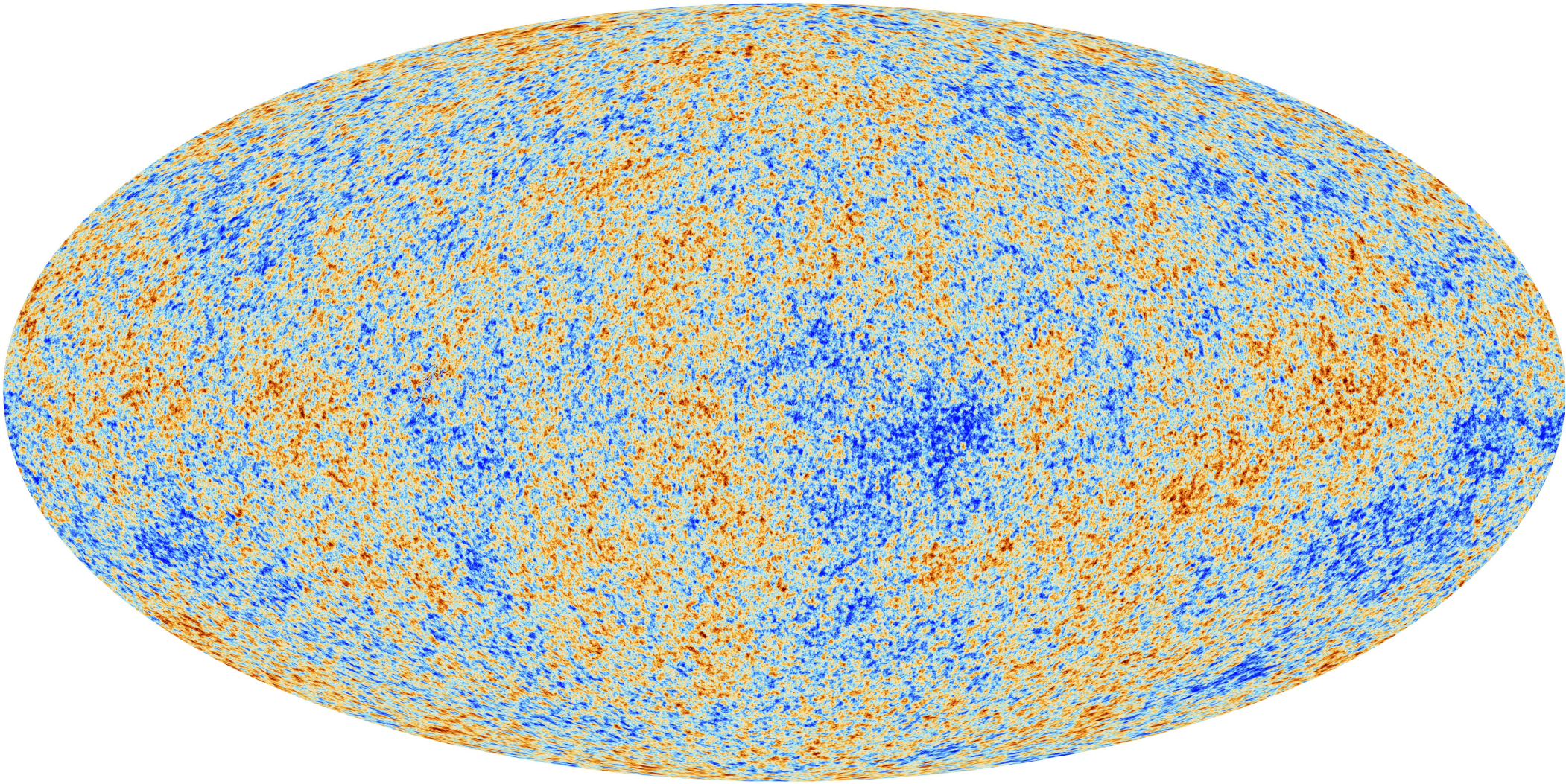
Planck at L2



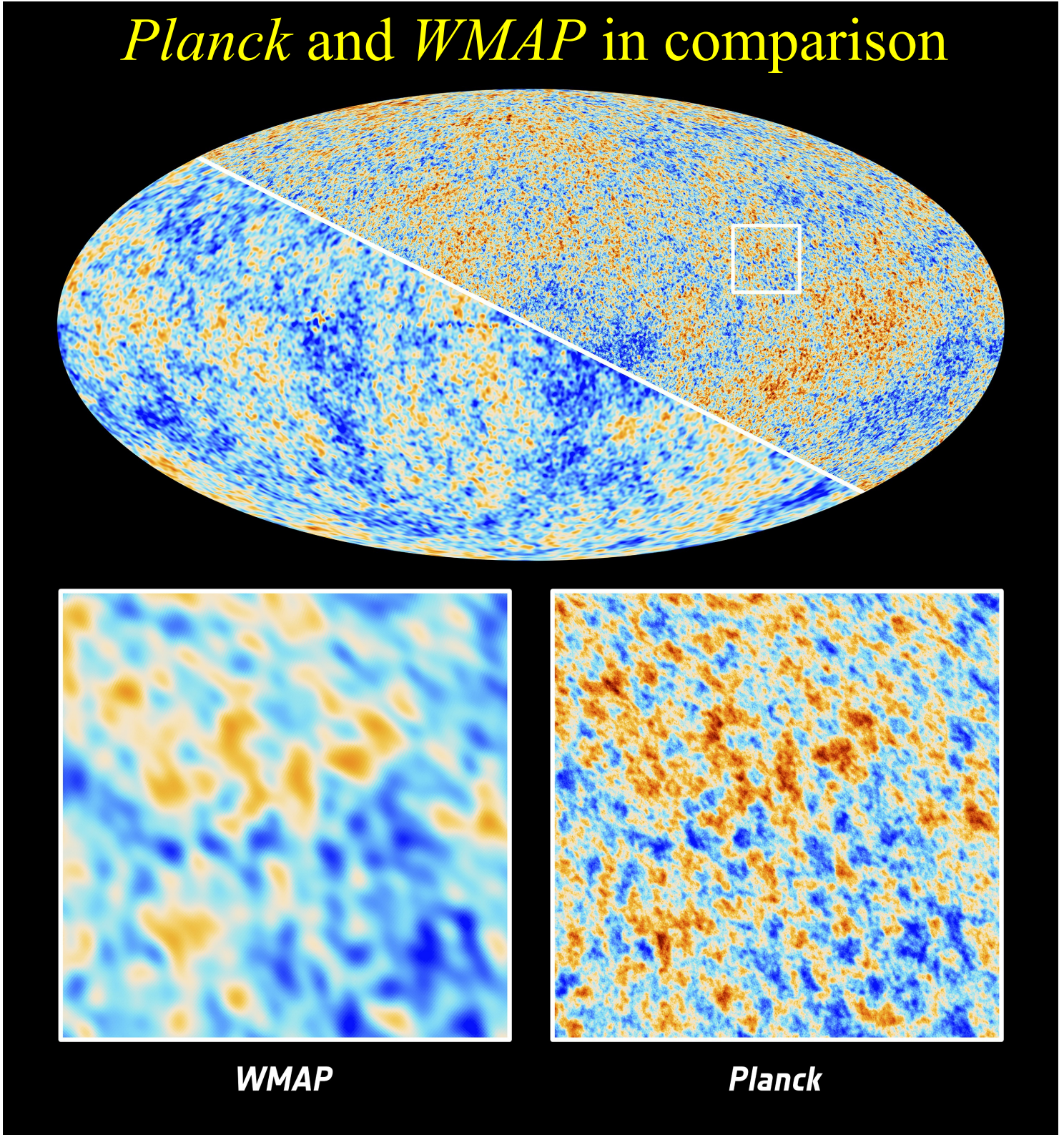
The nine *Planck* maps



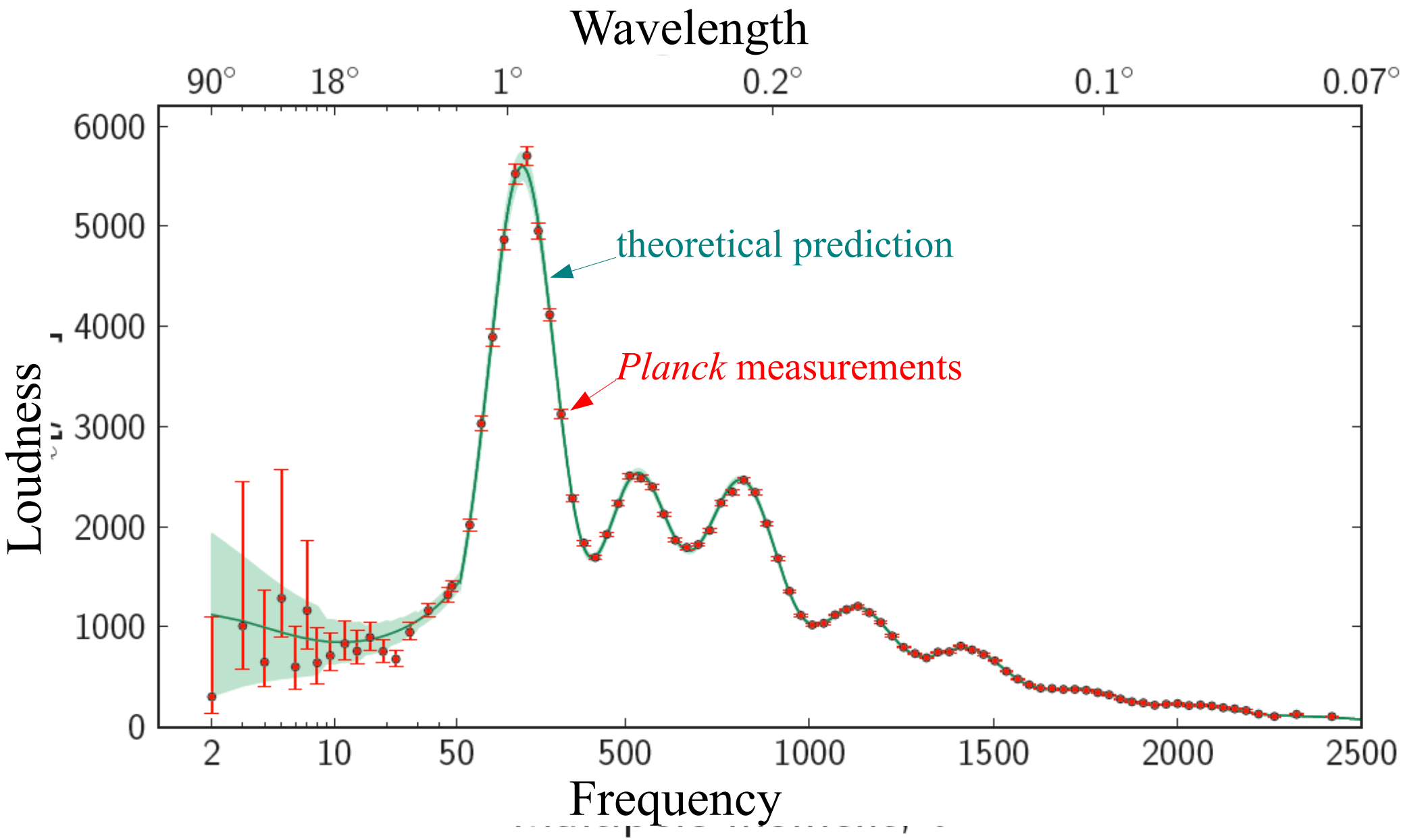
The *Planck* map of the microwave background

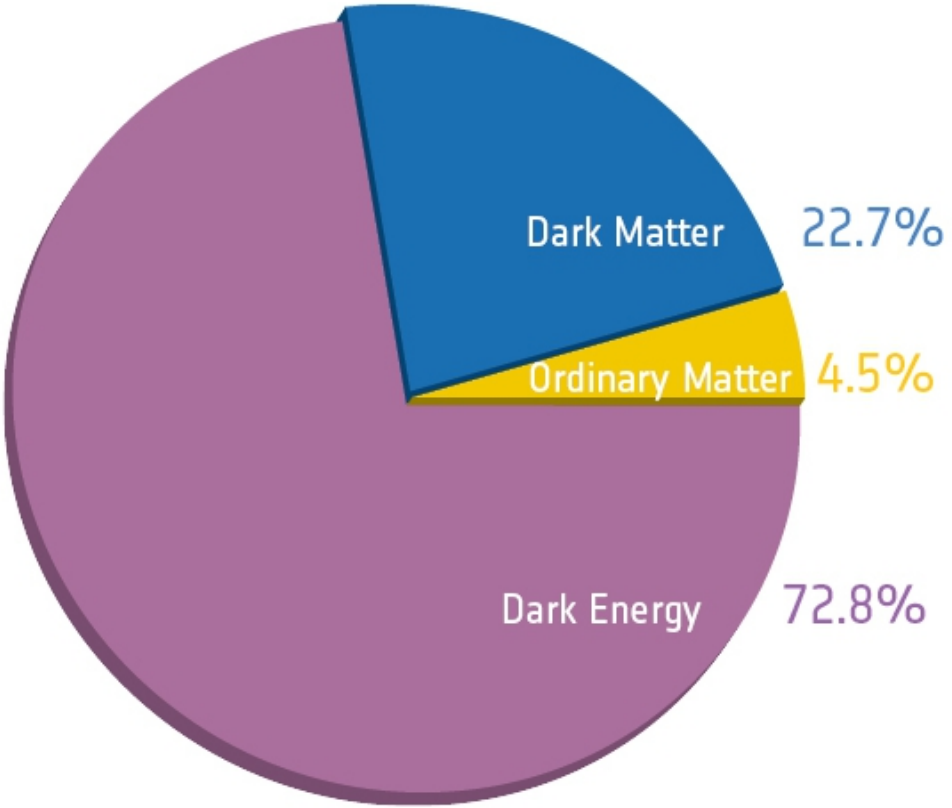


An image of the boundary of the observable Universe

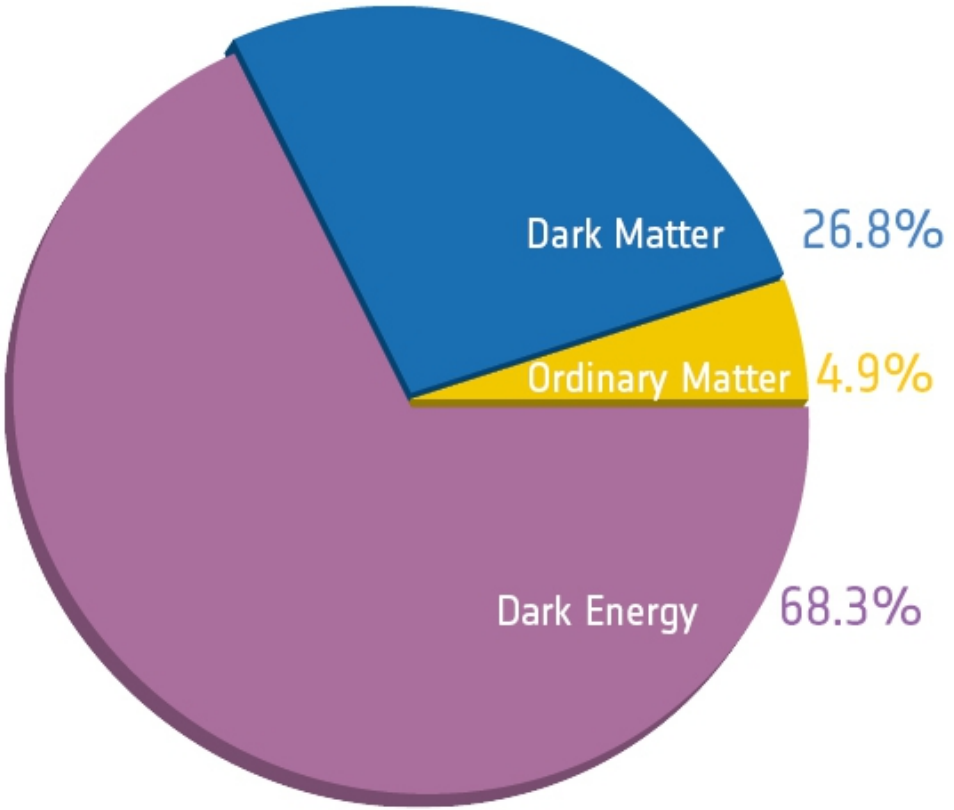

Planck and *WMAP* in comparison
WMAP
Planck

Sound content of the cosmic clouds according to *Planck*





before *Planck*



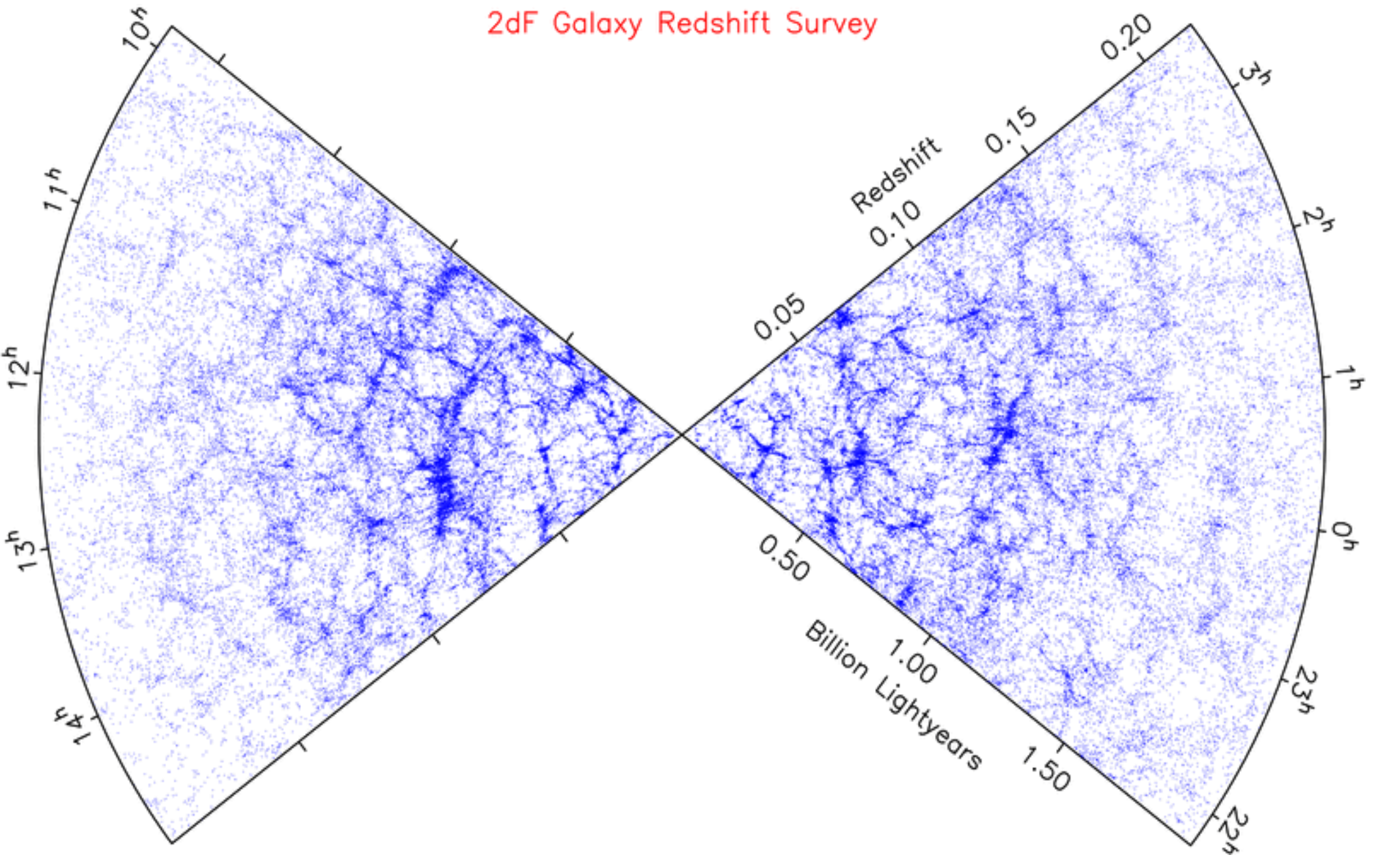
after *Planck*

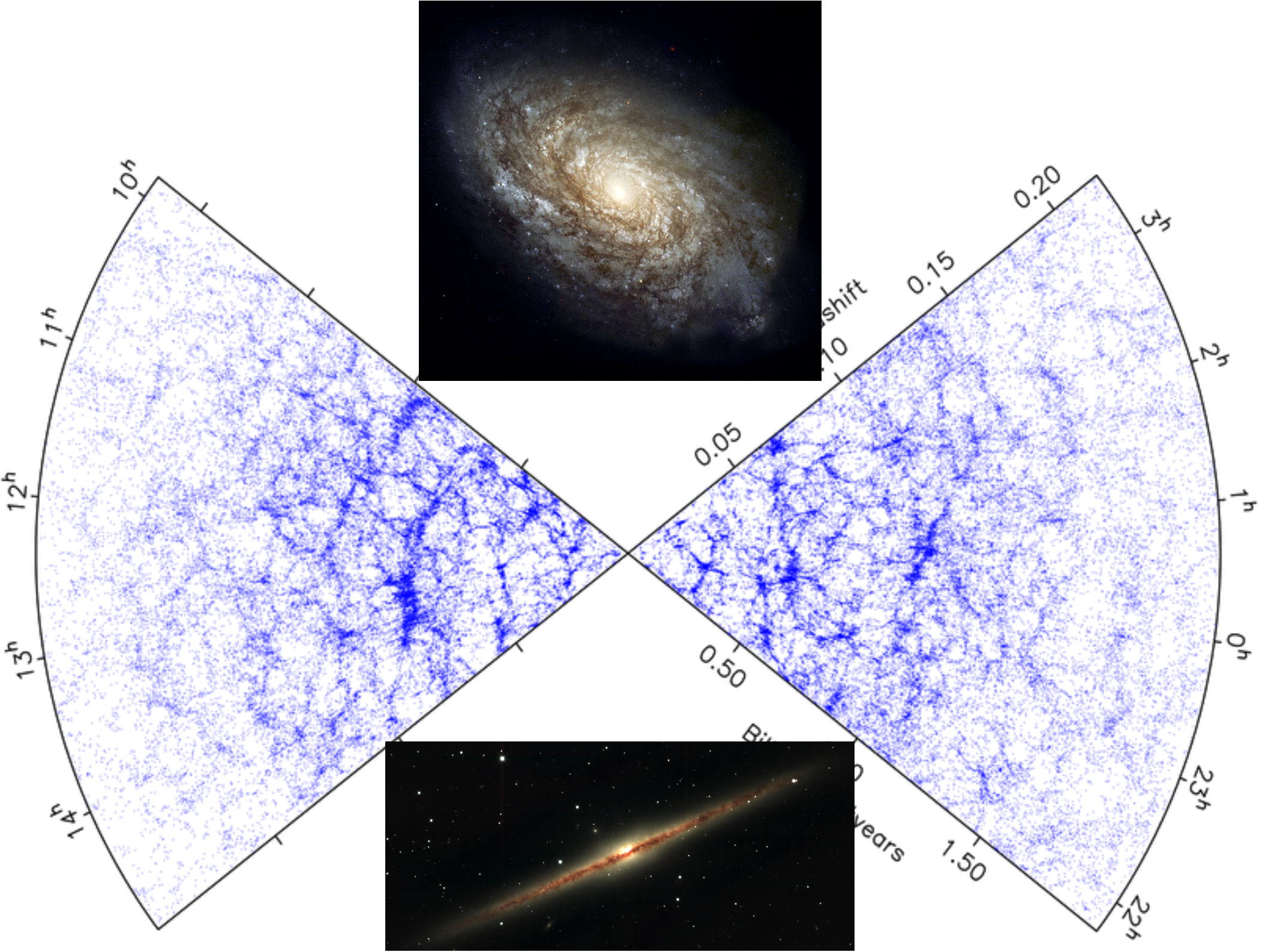
The Universe is still flat – now to better than 0.5% precision

Its expansion rate is 7% slower than previously thought, so its age has increased by 80,000,000 years!

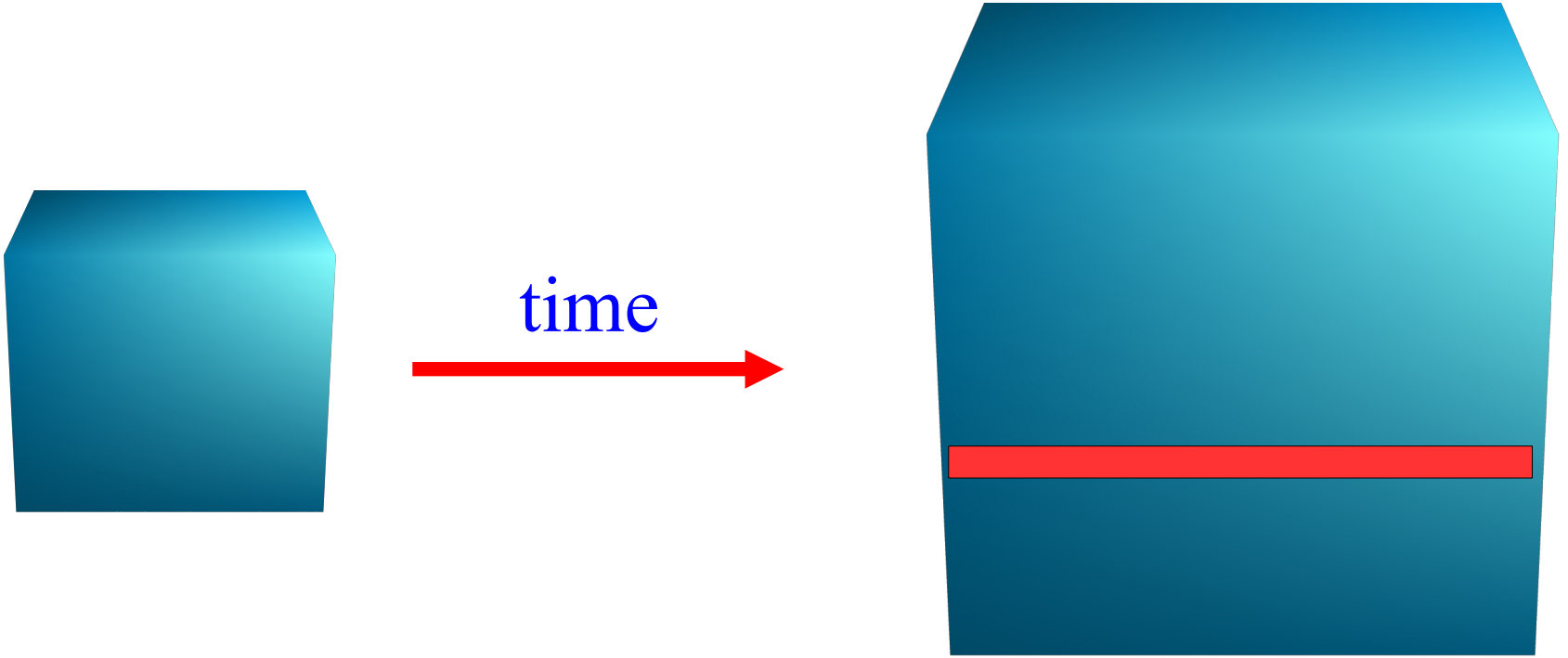
Planck results strongly support the idea that all structure originated from quantum zero-point fluctuations of the very early vacuum

Large-scale structure in the present-day Universe




10h
11h
12h
13h
14h
0.05
0.10
0.15
0.20
0.50
1.50
1h
2h
3h
0h
22h
23h

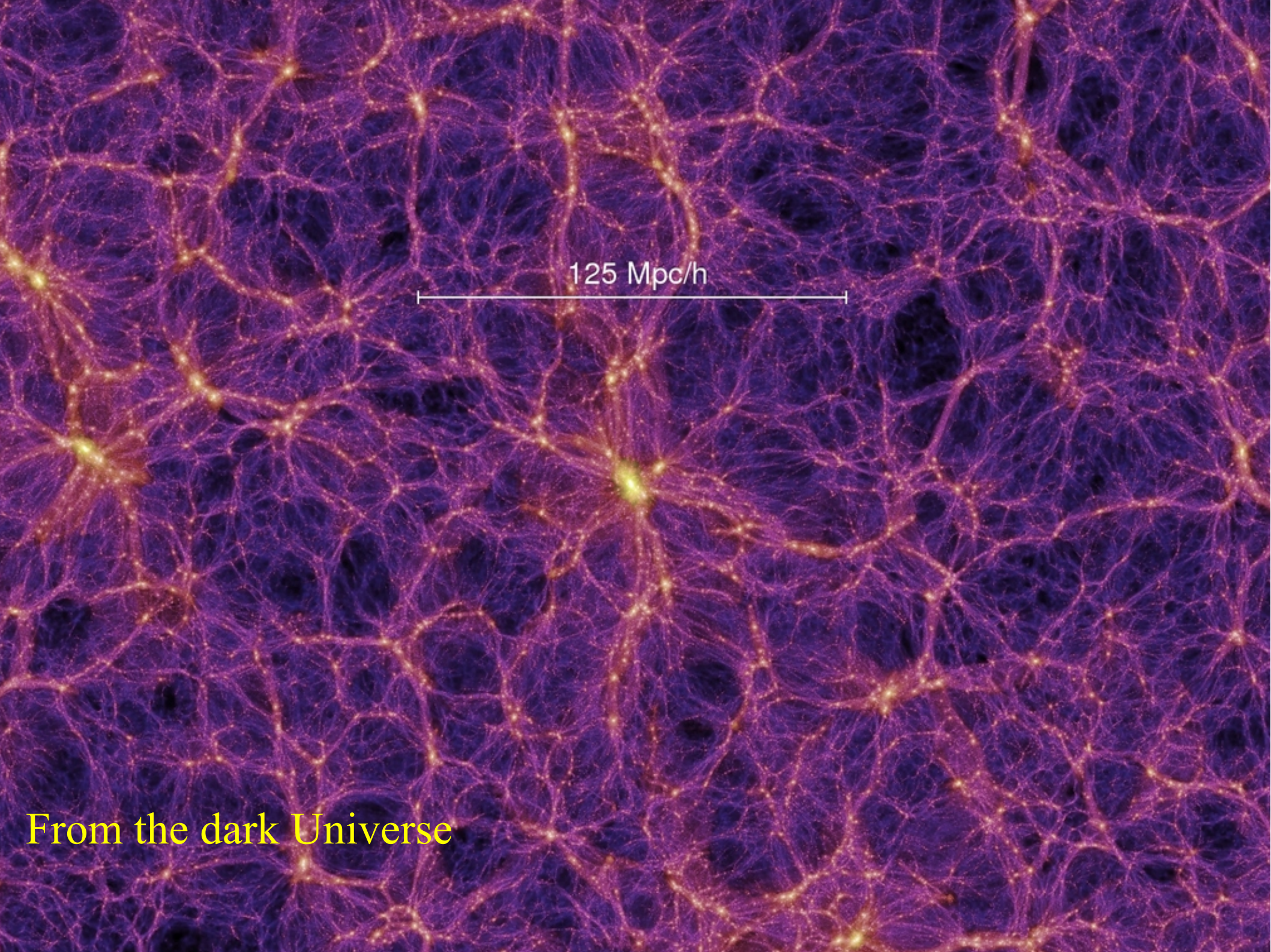
How to follow cosmic evolution in a supercomputer



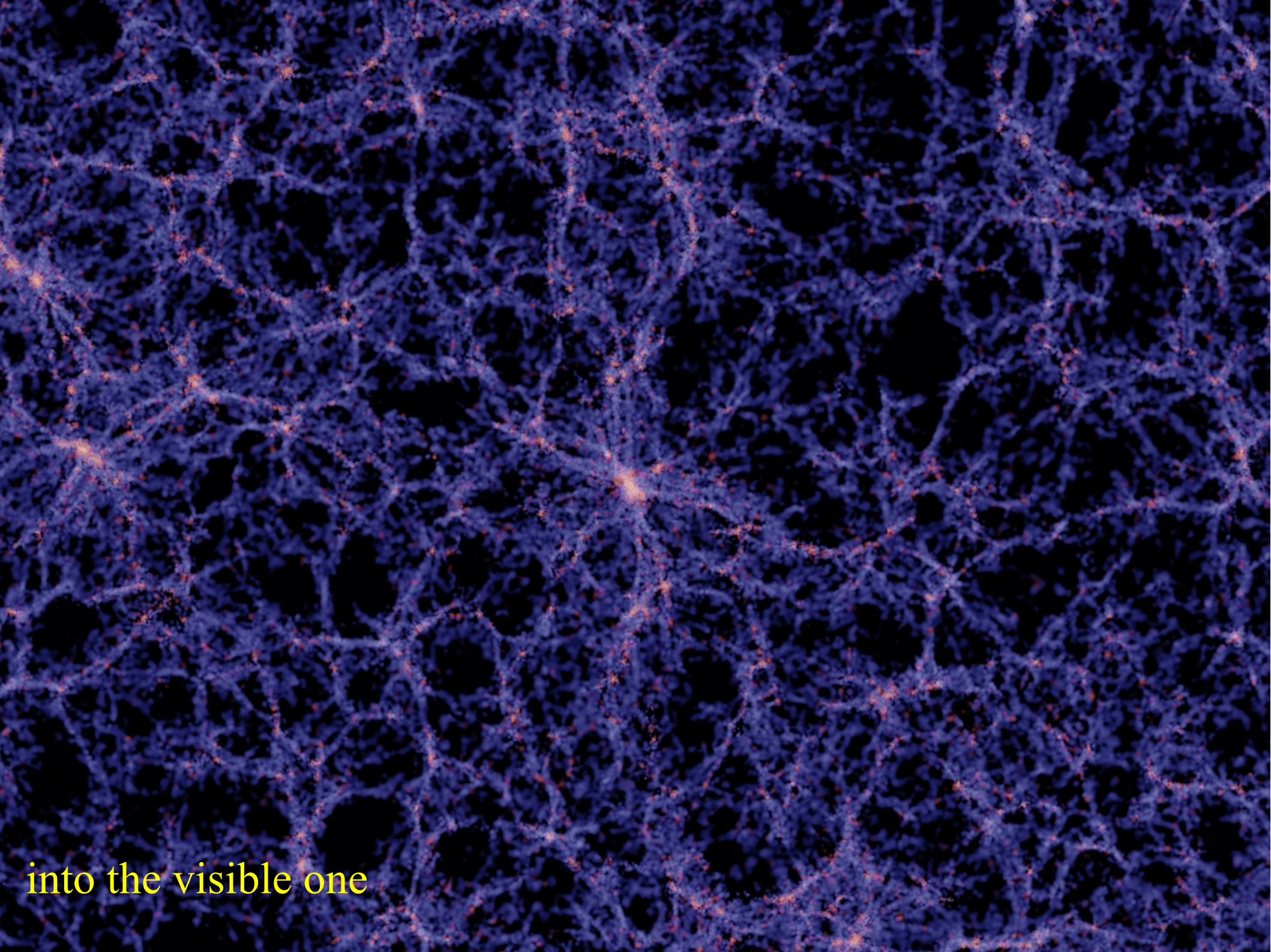
- Follow the material in a cube which expands with the Universe
- Start 400,000 years after the Big Bang
- Set initial conditions to match microwave background structure
- Calculate the evolution forwards to the present day

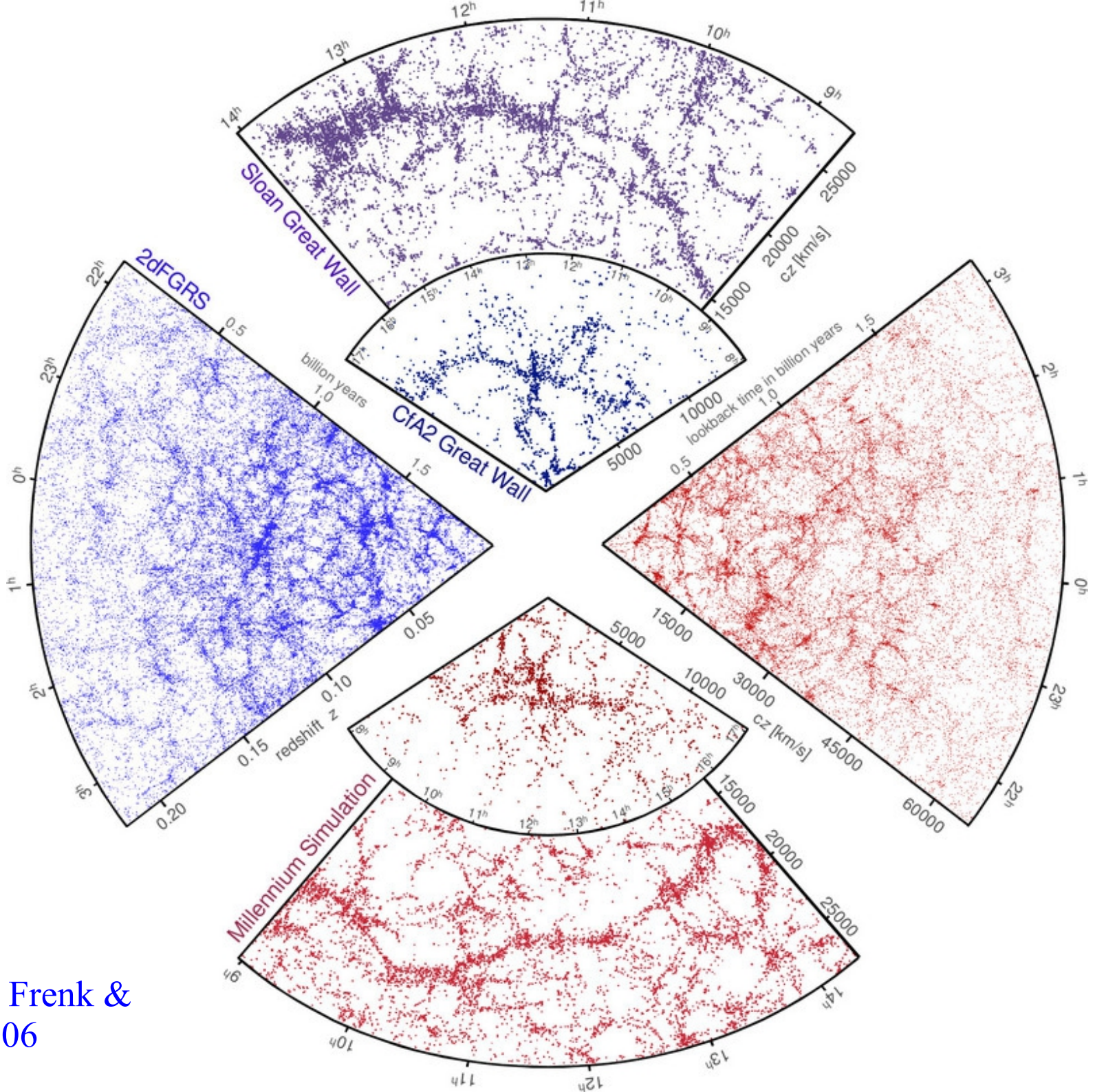
Images of the Dark Matter distribution in a virtual Universe

- Evolution of structure in a thin, expanding slice
- A zoom from the entire visible Universe into a galaxy cluster
- A flight through the dark Universe



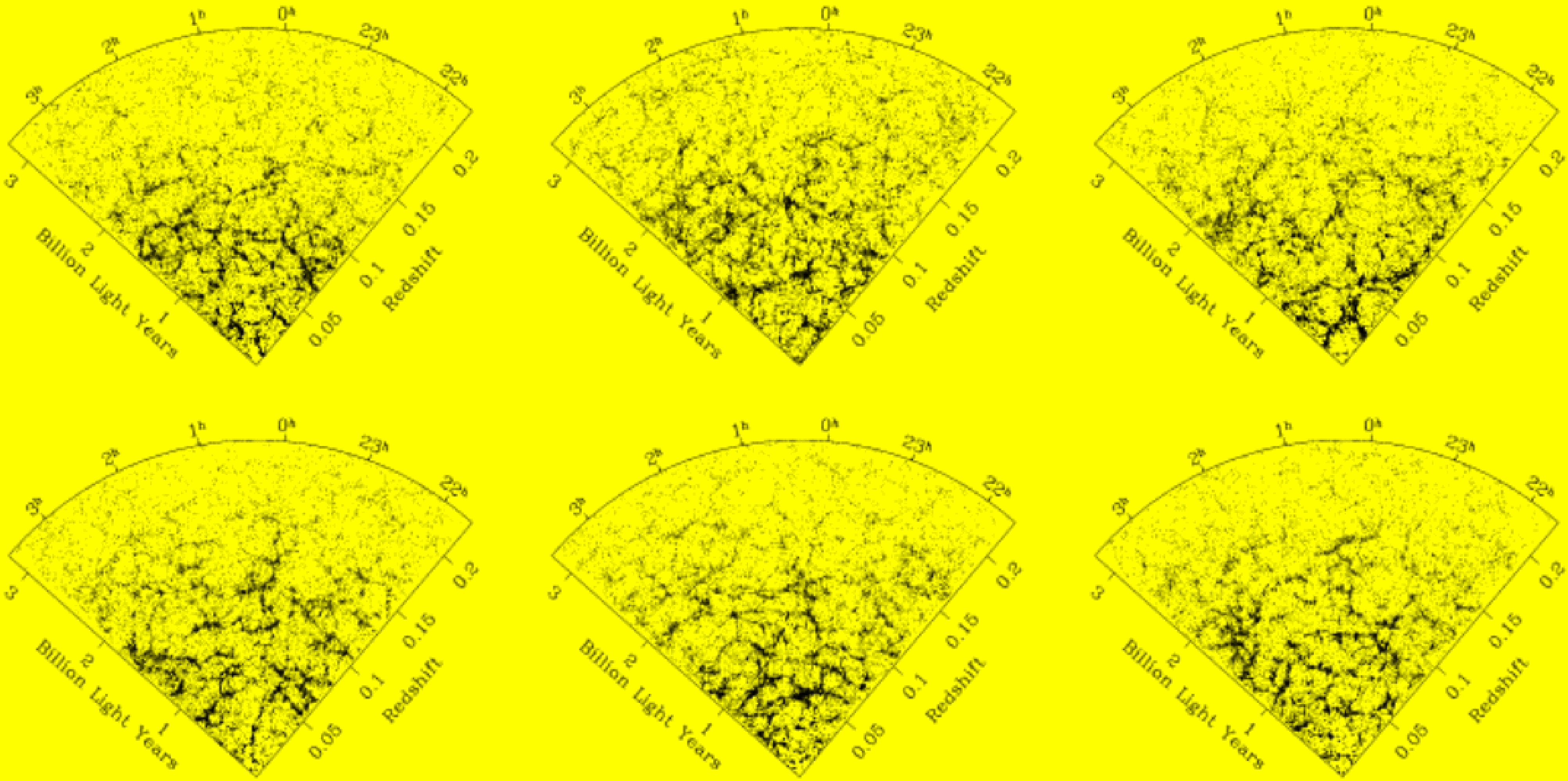
From the dark Universe


into the visible one



Springel, Frenk &
White 2006

Virtual versus real Universes

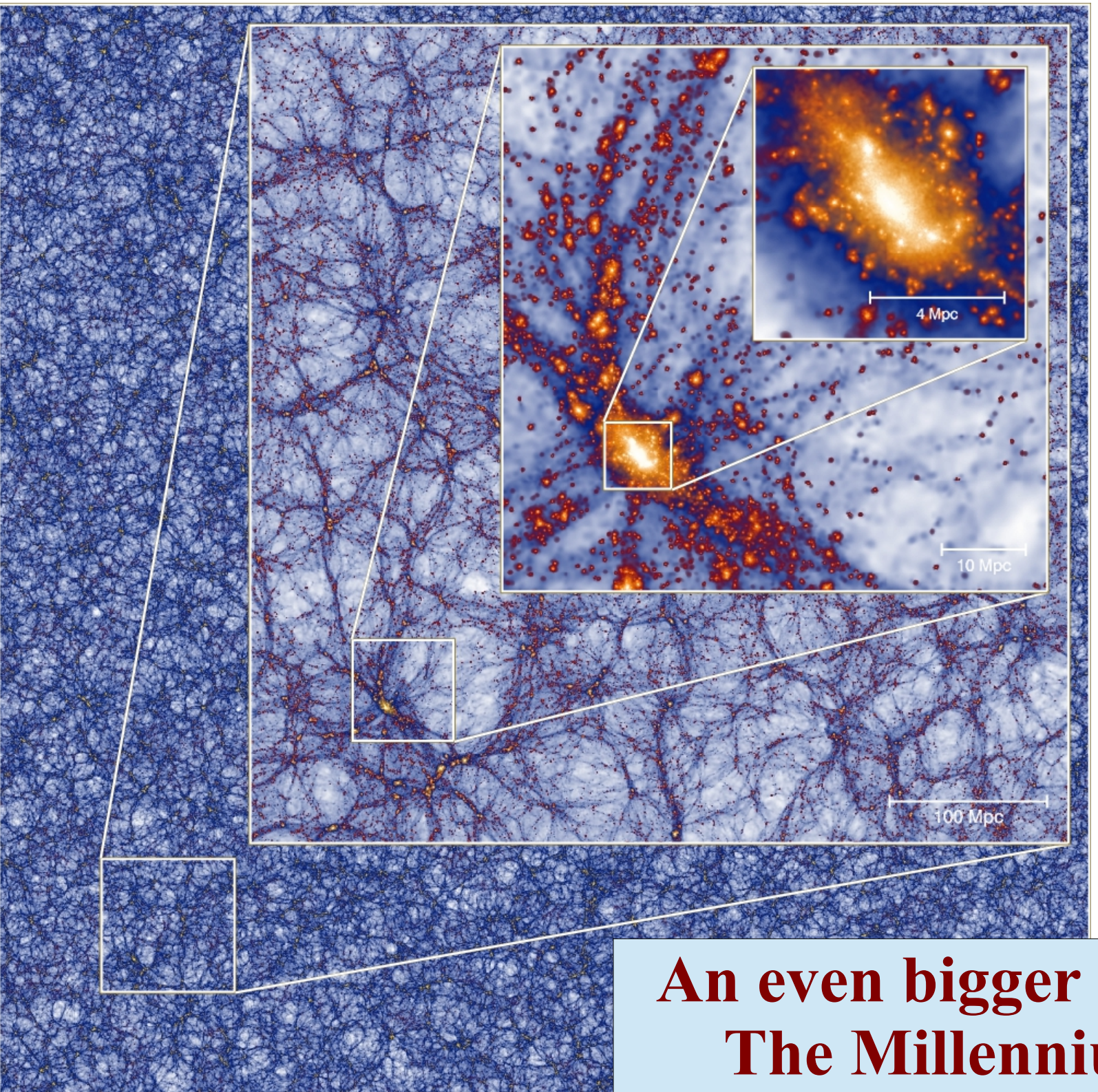


To conclude.....

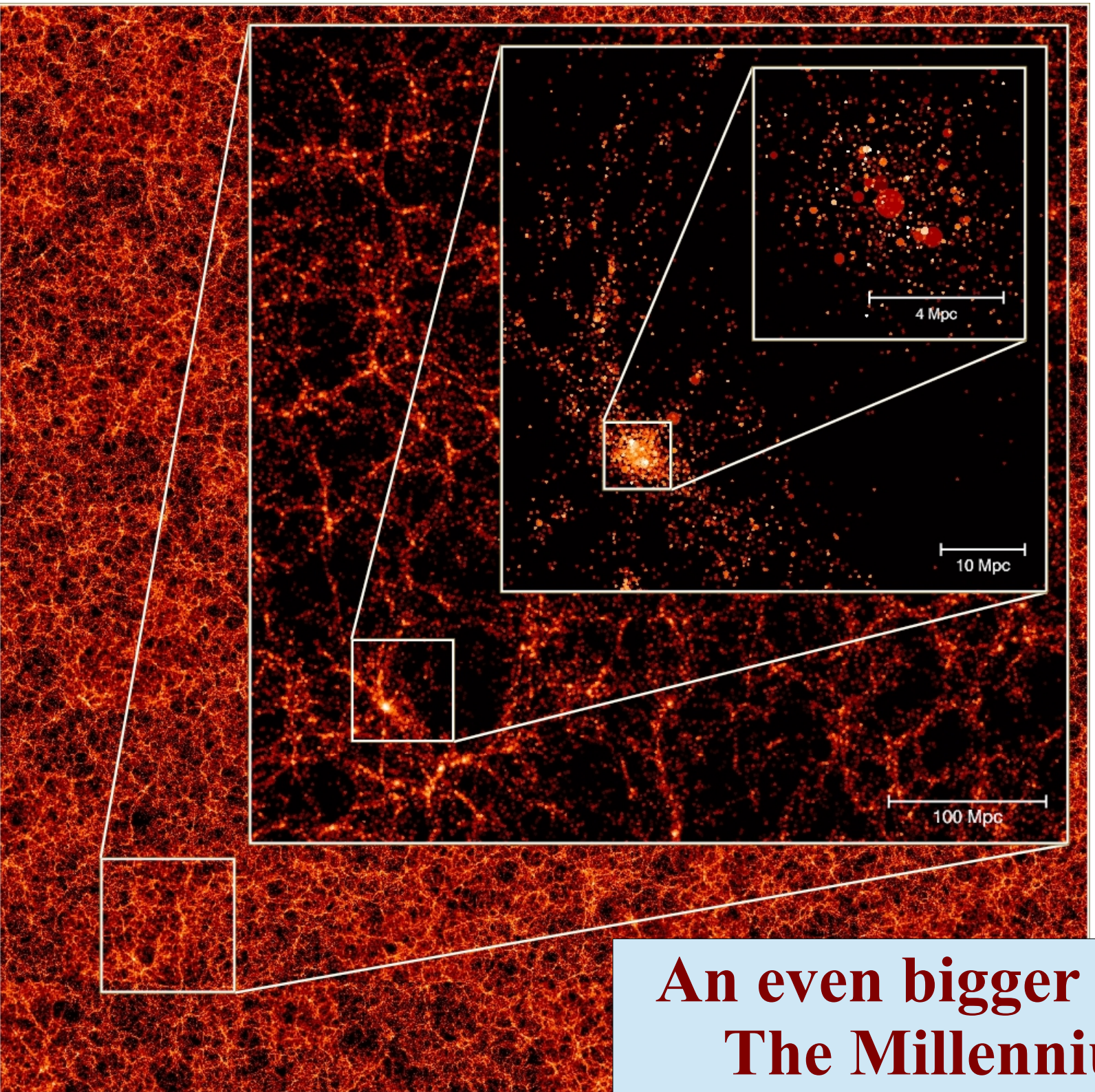
- Our Universe was born 13.7 billion years ago in a hot and almost uniform explosion -- the Big Bang
- All structure grew from quantum fluctuations of the early vacuum -- Everything has formed from "nothing"!
- Only 5% of today's Universe is made of ordinary matter
- About 27% is made of as yet unidentified elementary particles -- the Dark Matter
- About 68% consists of a new form of energy which accelerates the expansion of today's Universe -- the Dark Energy
- Galaxies and galaxy clusters, stars and planets formed out of sound waves in the primordial gas through the effects of Gravity

Can we calculate into the future?

- What will happen to our Milky Way when it runs into the Andromeda nebula in about 3.5 billion years from now?
- What will become of the Earth?
- What will happen to humankind?



An even bigger simulation: The Millennium XXL



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