
چیست این سقف بلند ساده بسیار نقش
زین معما هیچ دانا در جهان آگاه نیست

What is Cosmology?
What is our model of the Universe?

↓

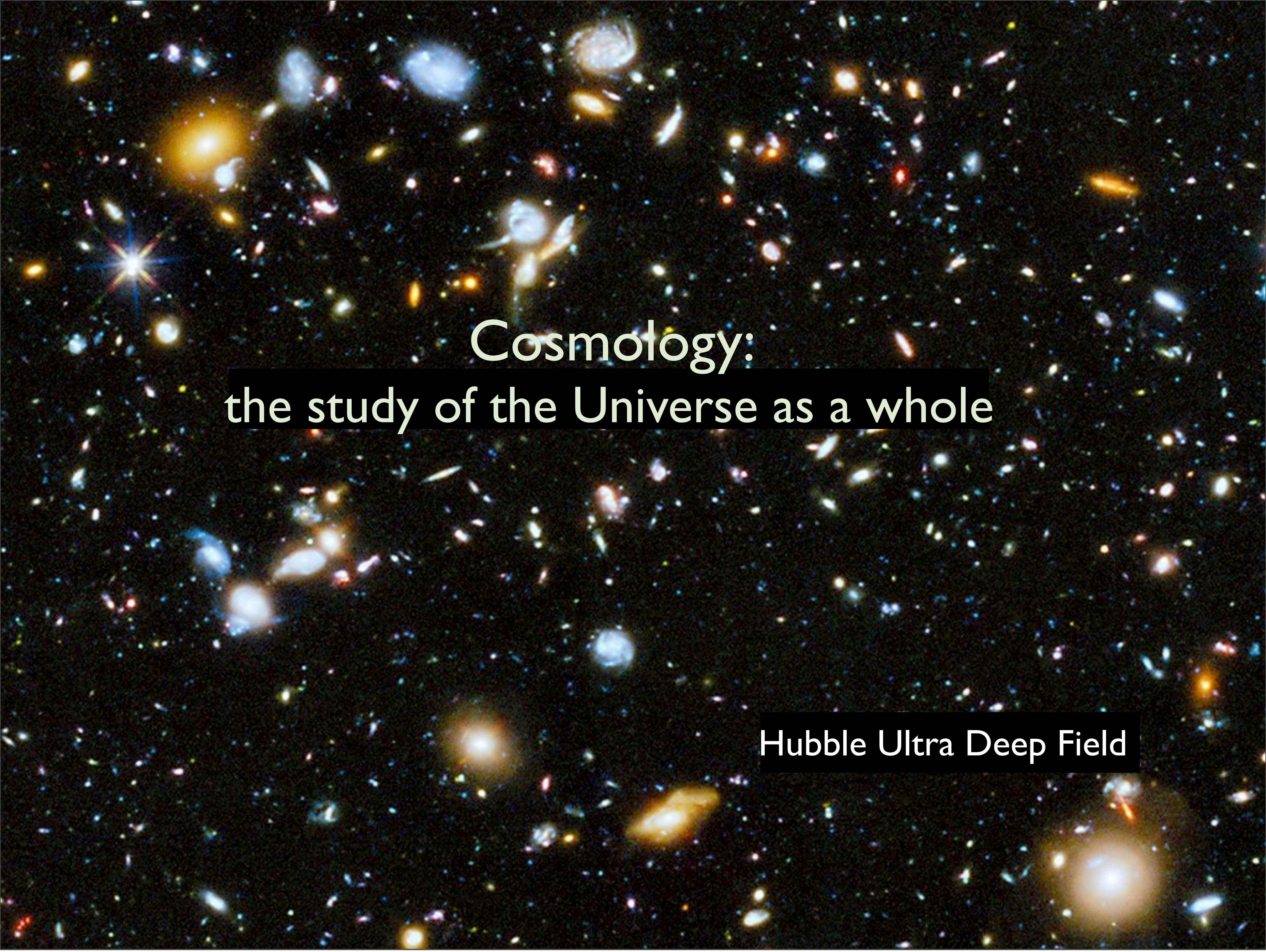
How did we learn about it?

↓

How well does it work?

↓

What sorts of problems exist?


Cosmology:
the study of the Universe as a whole
Hubble Ultra Deep Field

Our picture of universe

standard model of cosmology

or

Lambda-CDM

dark energy /
cosmological constant

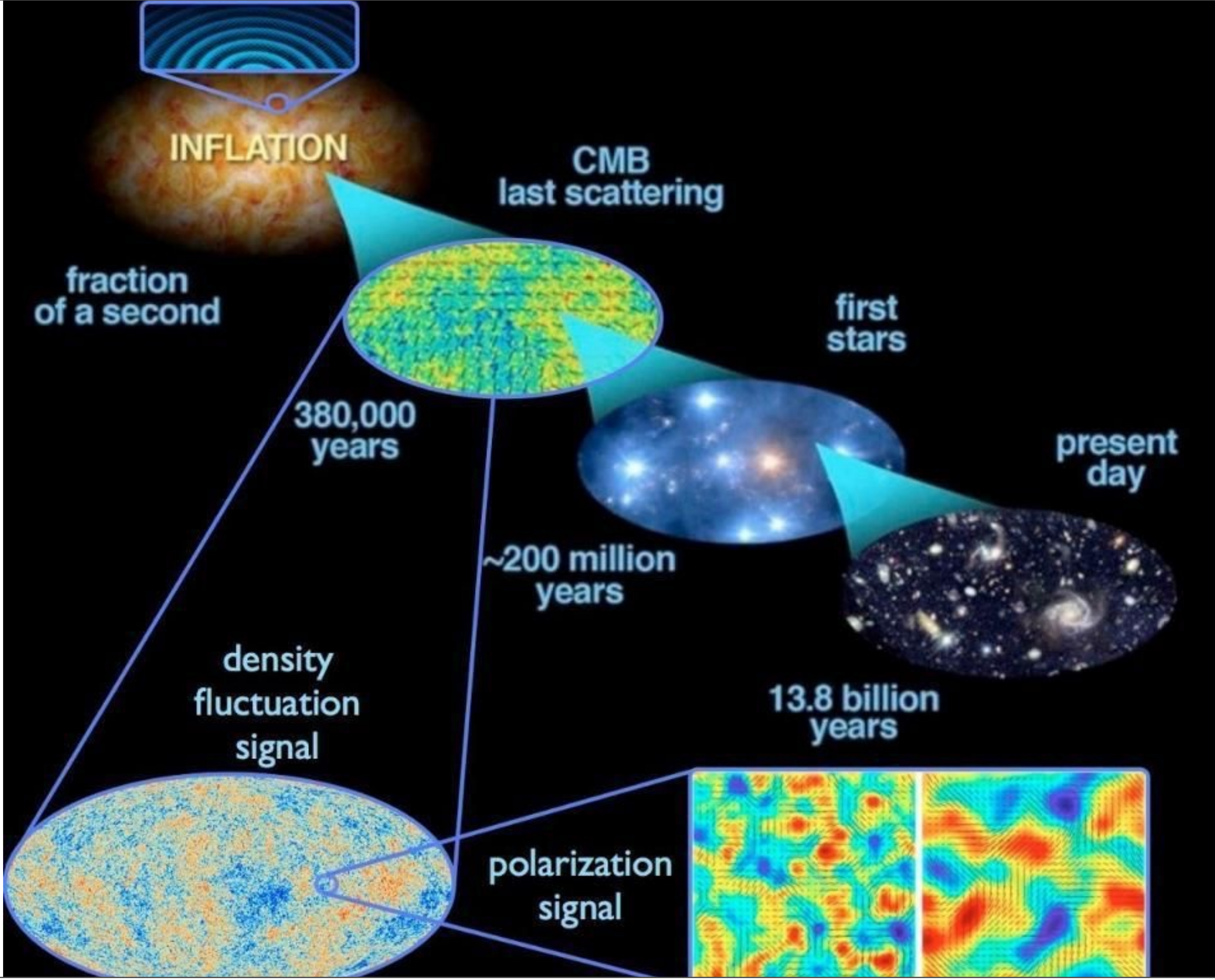
cold dark matter

theoretical basis:

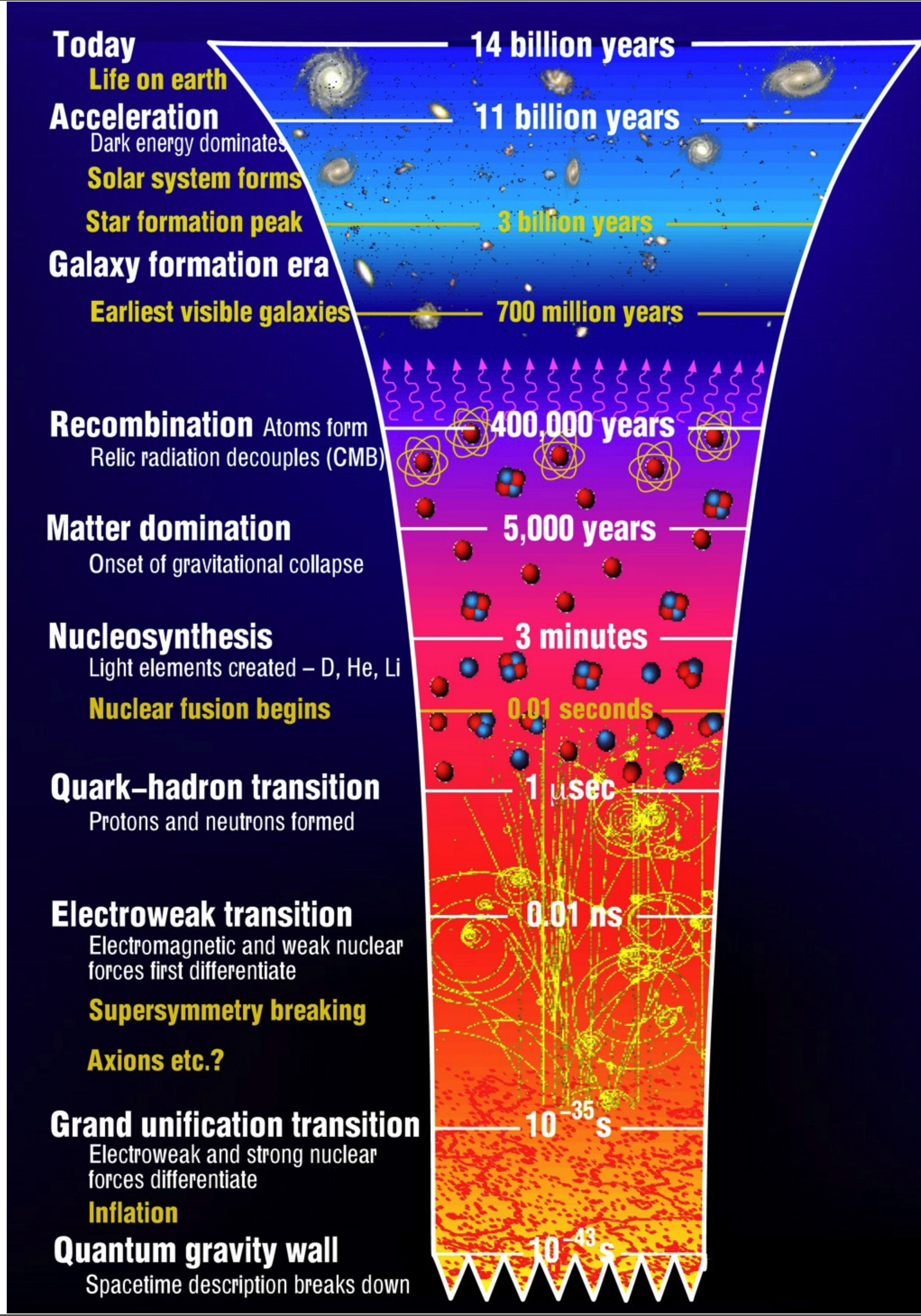
General Relativity

+ standard particle /atomic physics

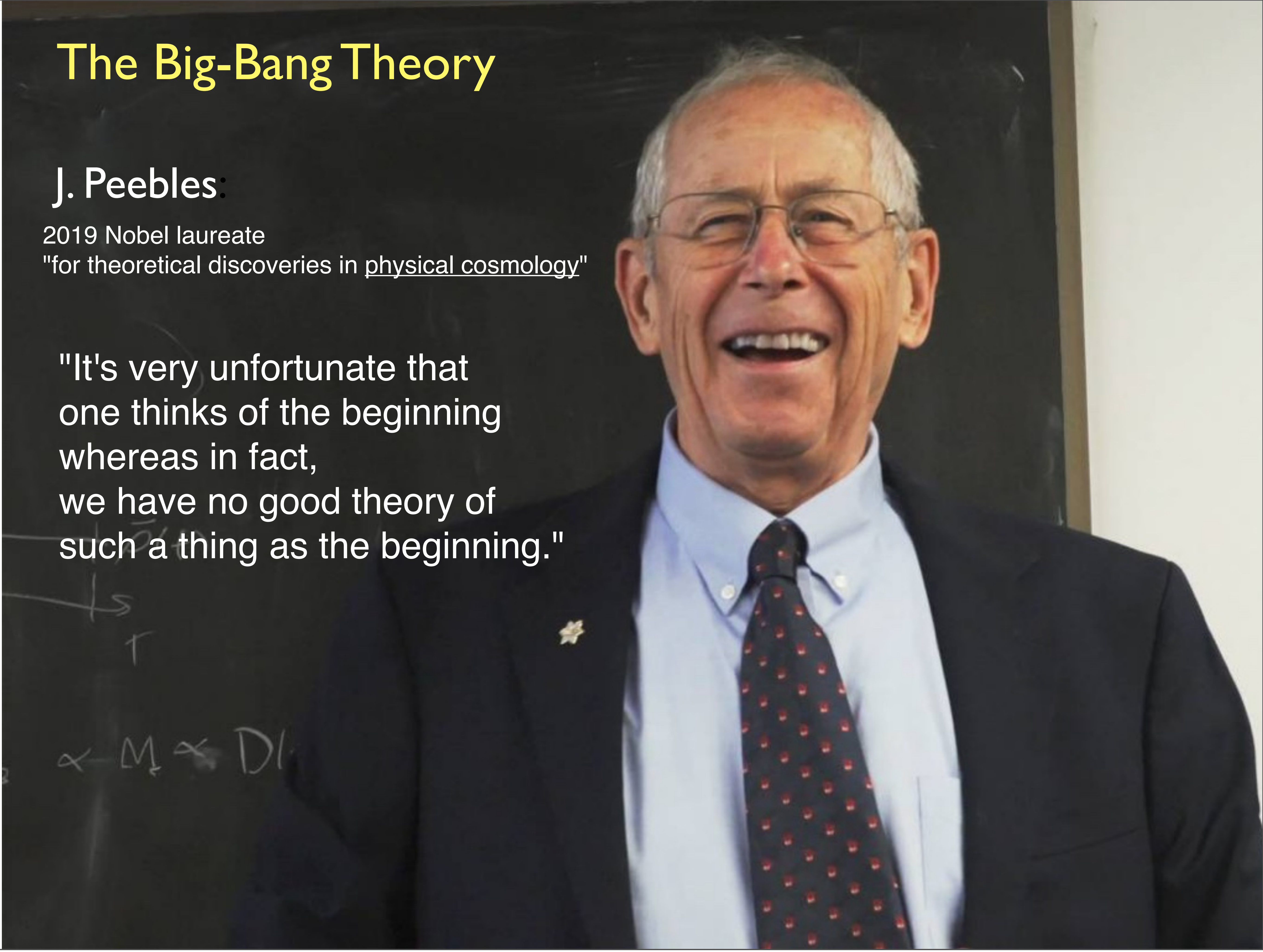
+ inflation


INFLATION
CMB
last scattering
fraction
of a second
first
stars
380,000
years
present
day
~200 million
years
density
fluctuation
signal
13.8 billion
years
polarization
signal

poor man's accelerator



The Big-Bang Theory



J. Peebles:

2019 Nobel laureate
"for theoretical discoveries in physical cosmology"

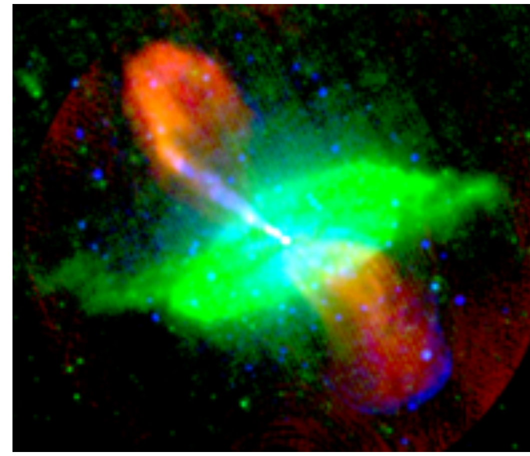
"It's very unfortunate that
one thinks of the beginning
whereas in fact,
we have no good theory of
such a thing as the beginning."

We learn all this ...

through observations of

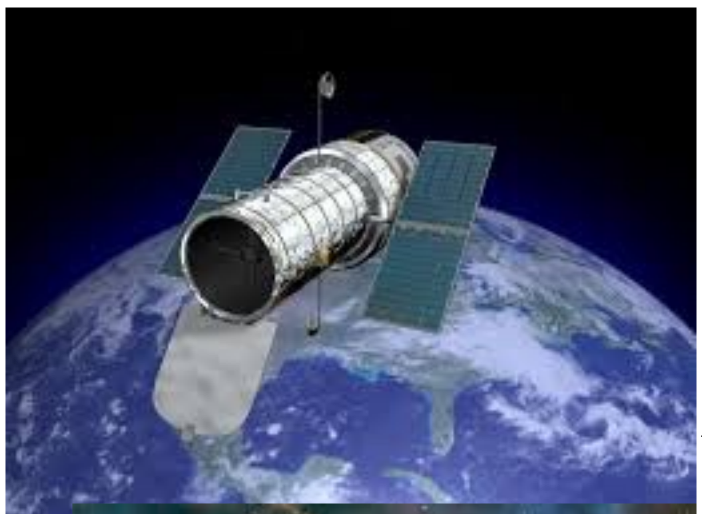
Electromagnetic waves
Cosmic neutrinos
Gravitational waves
cosmic rays
...

Electromagnetic waves



Radio

near IR/optical/UV



Hubble space telescope

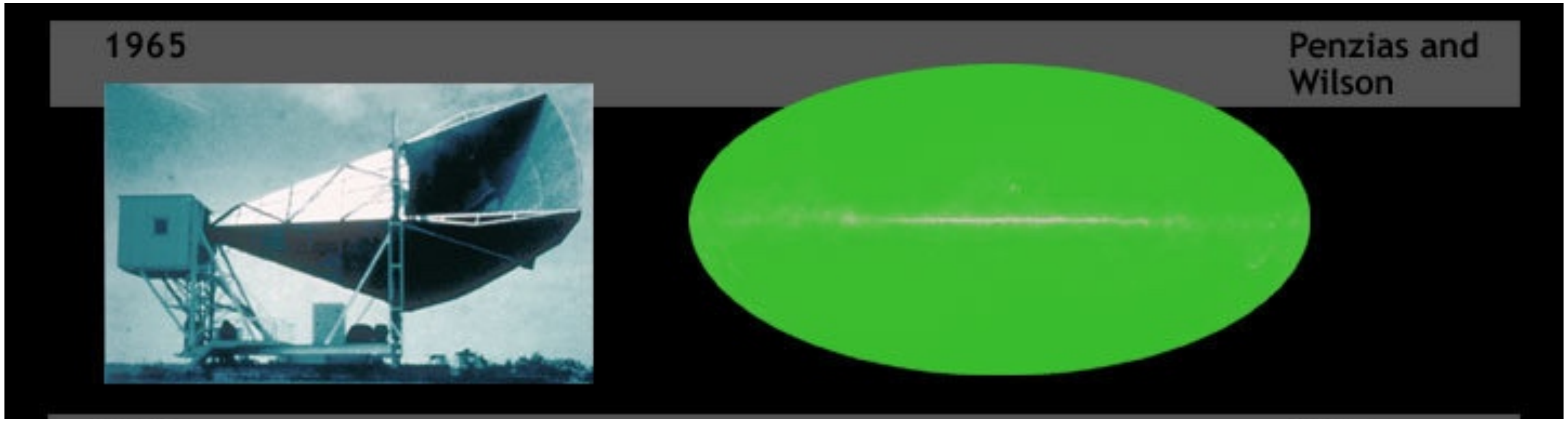
Spitzer Space Telescope (IR)

accelerated expansion

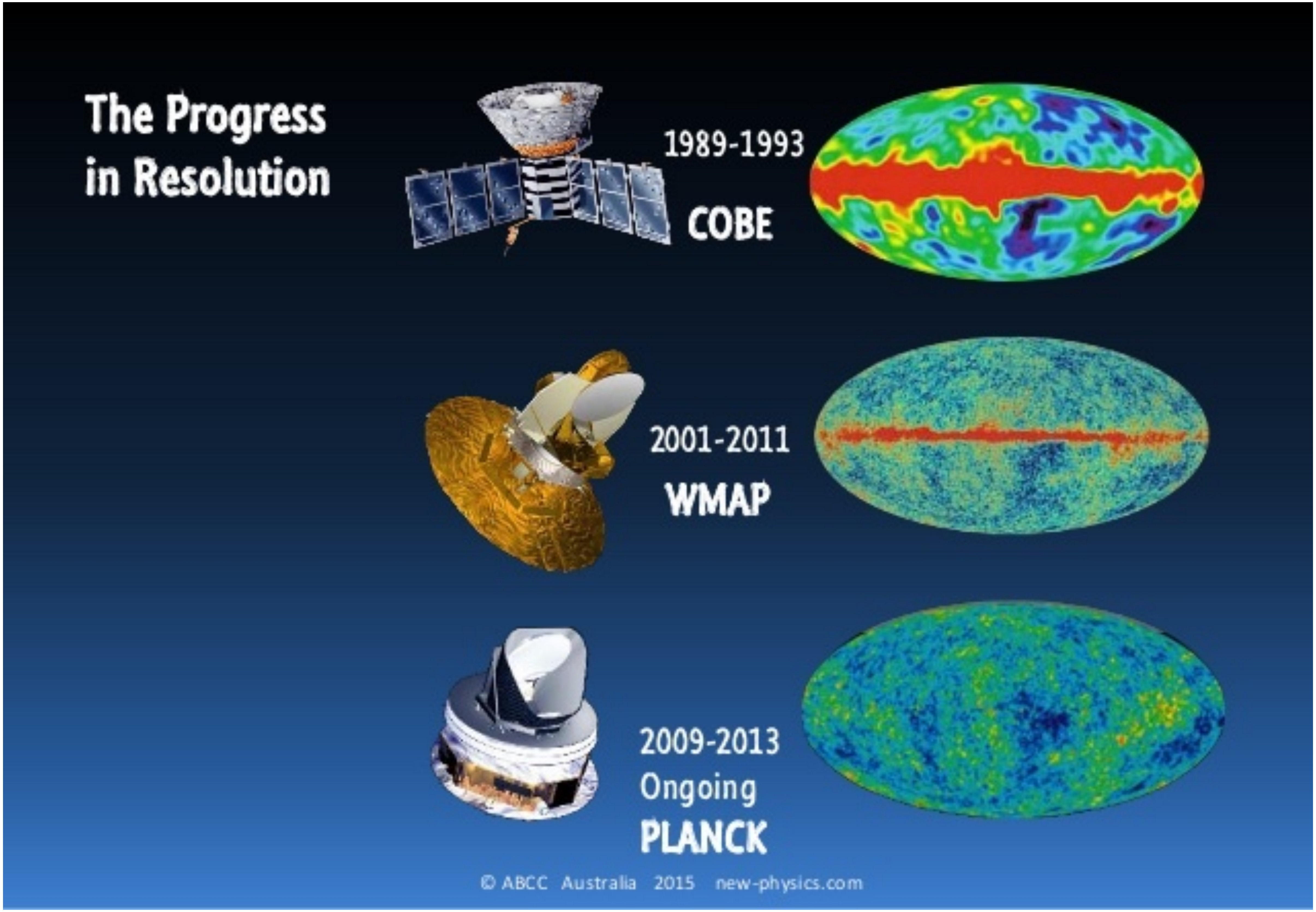
2011 Nobel prize to Perlmutter, Schmidt and Riess
"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"

image of the universe at its infancy
(~ 400,000 years old)



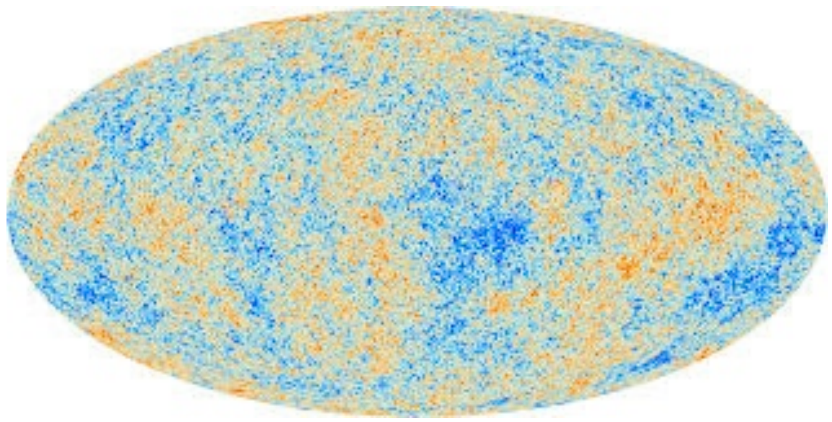
1978 Nobel prize shared by Penzias and Wilson
"for their discovery of cosmic microwave background radiation"

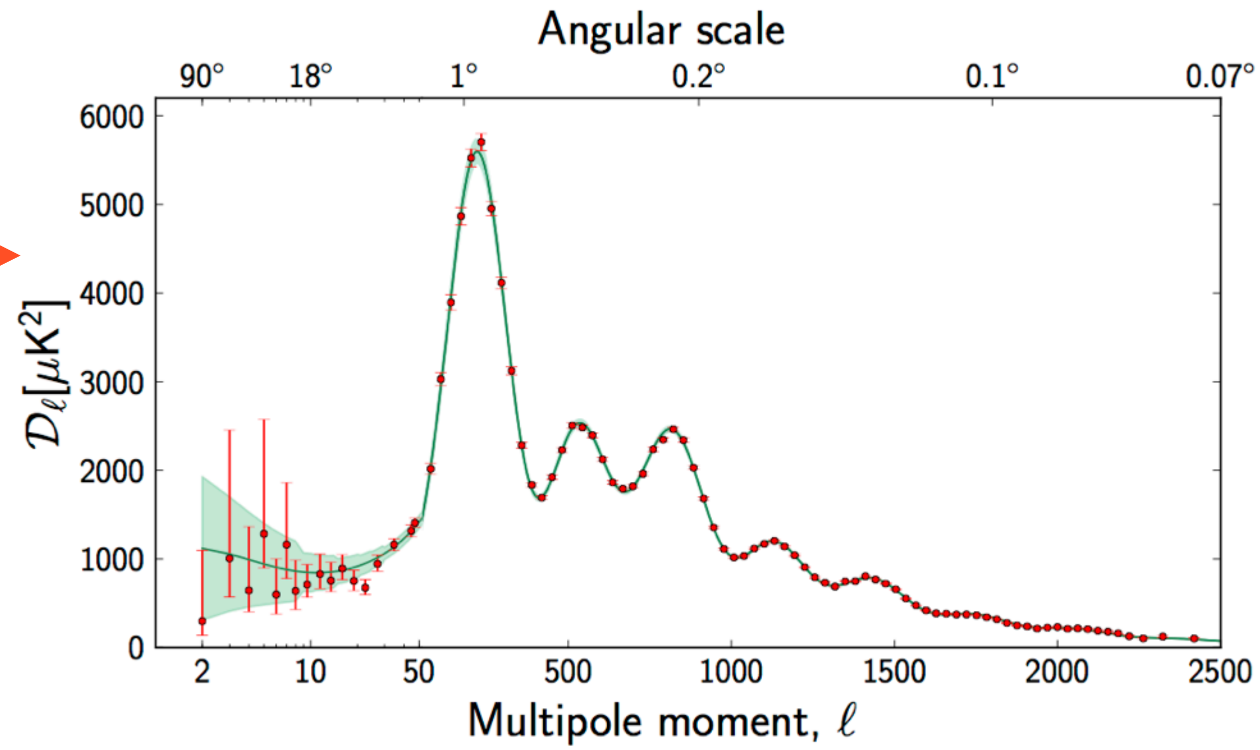

2006 Nobel prize to Mather and Smooth
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"



https://www.slideshare.net/StephenKwong1/ca-1002-making-cmb-maps

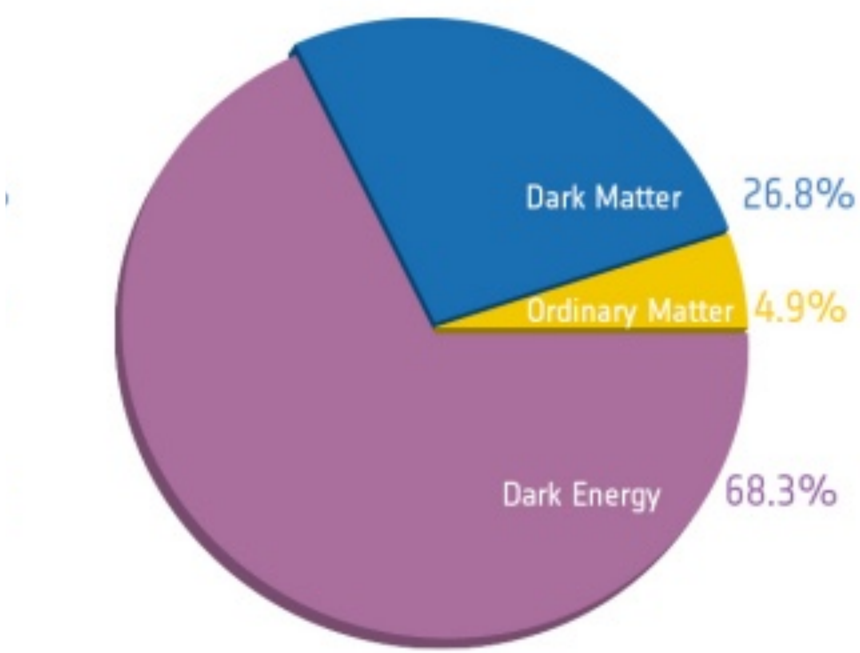
from CMB maps to cosmological parameters





Hubble constant

Parameter	TT+lowP+lensing 68% limits	TT,TE,EE+lowP+lensing+ext 68% limits
n_s	0.9677 ± 0.0060	0.9667 ± 0.0040
H_0	67.81 ± 0.92	67.74 ± 0.46
Ω_Λ	0.692 ± 0.012	0.6911 ± 0.0062
Ω_m	0.308 ± 0.012	0.3089 ± 0.0062
$\Omega_b h^2$	0.02226 ± 0.00023	0.02230 ± 0.00014
$\Omega_c h^2$	0.1186 ± 0.0020	0.1188 ± 0.0010
σ_8	0.8149 ± 0.0093	0.8159 ± 0.0086
z_{re}	$8.8^{+1.7}_{-1.4}$	$8.8^{+1.2}_{-1.1}$
Age/Gyr	13.799 ± 0.038	13.799 ± 0.021

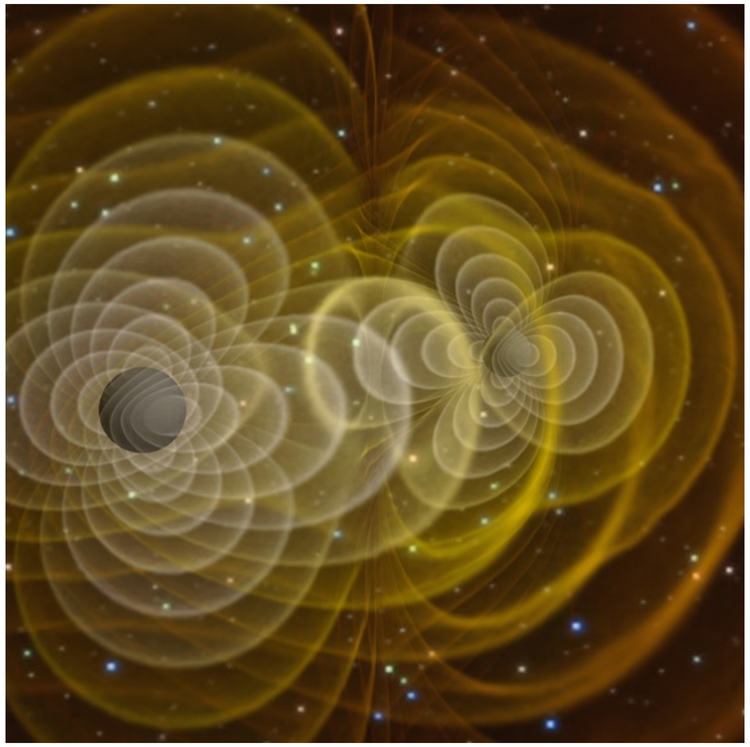


Cosmic neutrino background

-- relic from the beginning ...
   only a few seconds old
-- very hard to detect

Gravitational waves

disturbances in the curvature of spacetime propagating as waves at the speed of light

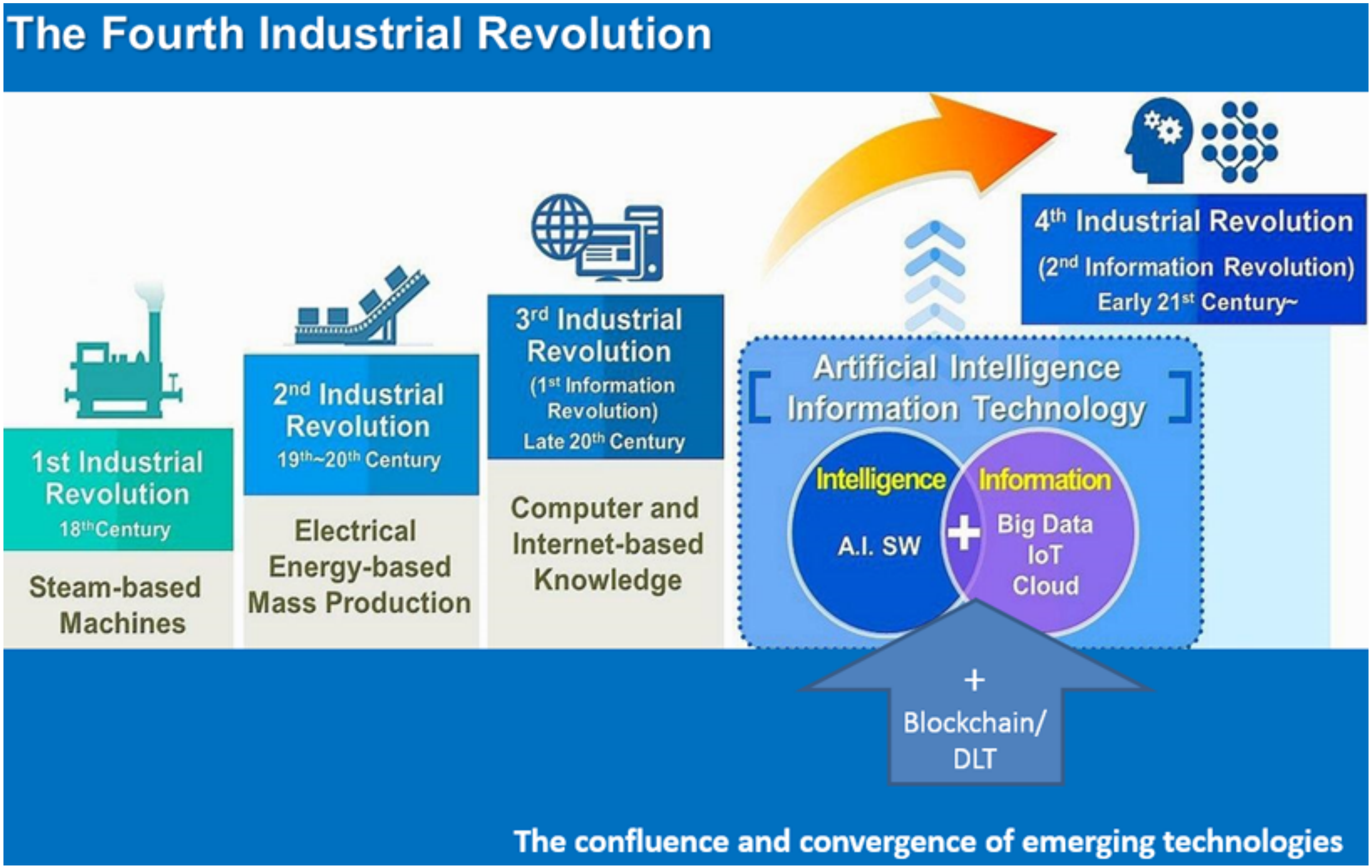


2017 Nobel prize to Rainer Weiss, Kip Thorne and Barry C. Barish "for decisive contributions to the LIGO detector and the observation of gravitational waves."[13]

GWs can tell us about dark energy and early universe!

a blessing and a curse

BIG DATA


The Fourth Industrial Revolution
1st Industrial Revolution
18thCentury
Steam-based Machines
2nd Industrial Revolution
19th~20th Century
Electrical Energy-based Mass Production
3rd Industrial Revolution
(1st Information Revolution)
Late 20th Century
Computer and Internet-based Knowledge
4th Industrial Revolution
(2nd Information Revolution)
Early 21st Century~
Artificial Intelligence
Information Technology
Intelligence
A.I. SW
Information
Big Data
IoT
Cloud
+
Blockchain/
DLT
The confluence and convergence of emerging technologies

cosmology as a science of big data

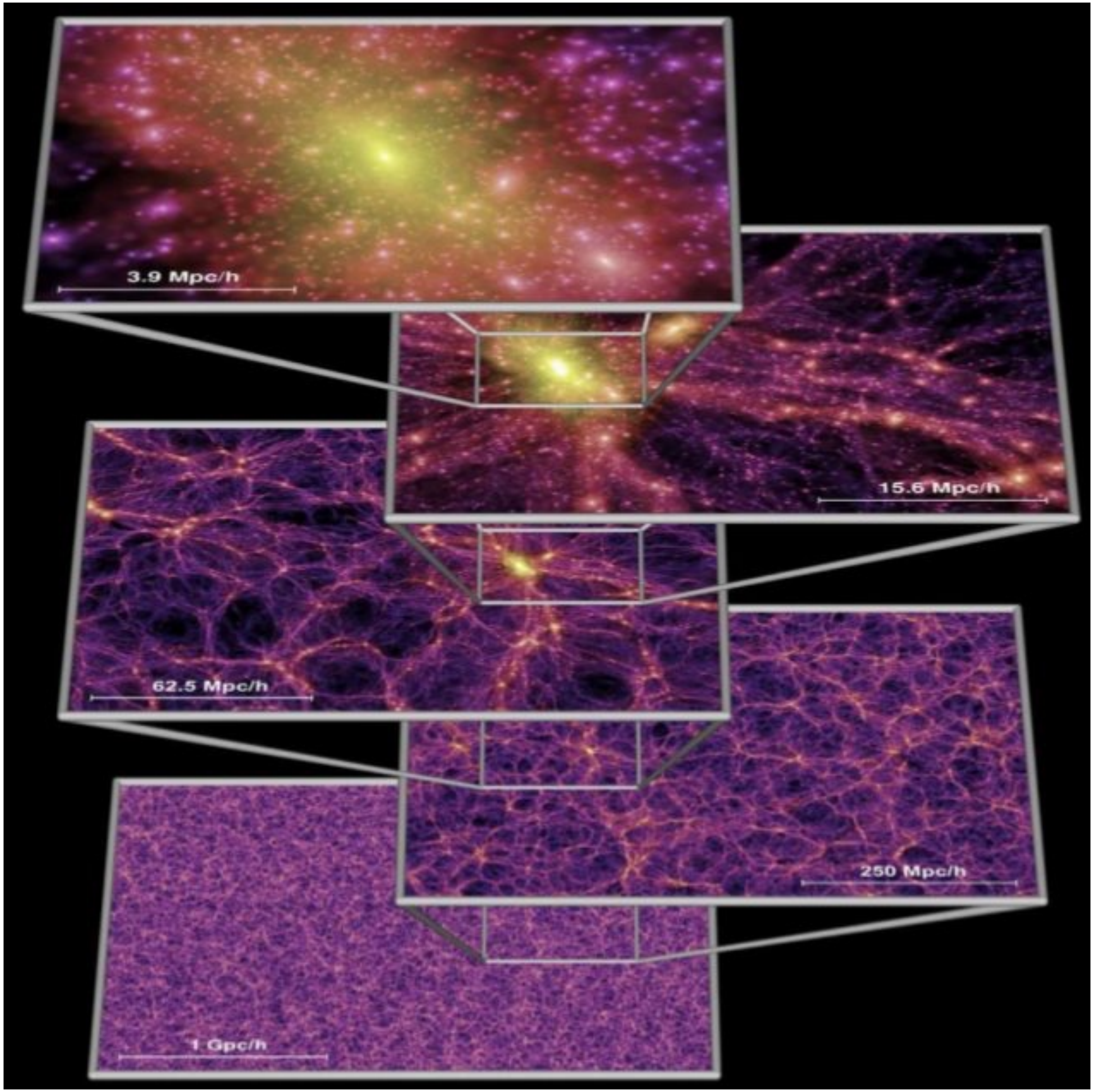
- technology improvement

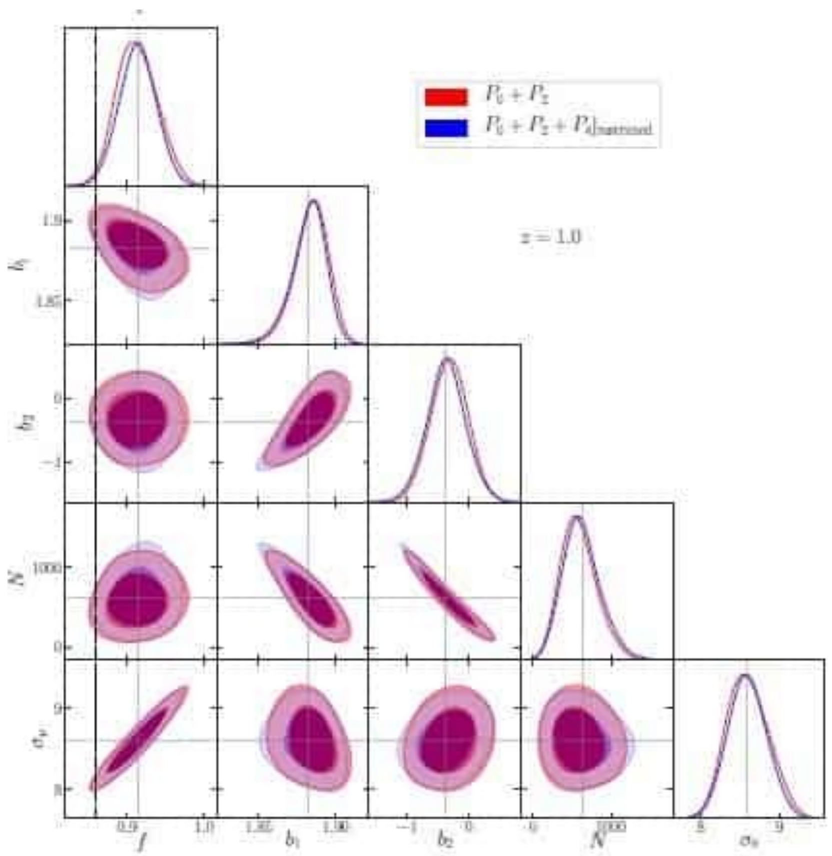
- huge huge amount of data coming, mapping the cosmos at different epochs, with high resolution

- information extraction from data is a daunting, exciting task:
  - -- data are random fields
  - -- model building and comparison with data
  - -- hard to make a self-consistent, theoretically sound model that explains all data.

- cosmology is among the leading sciences in data science

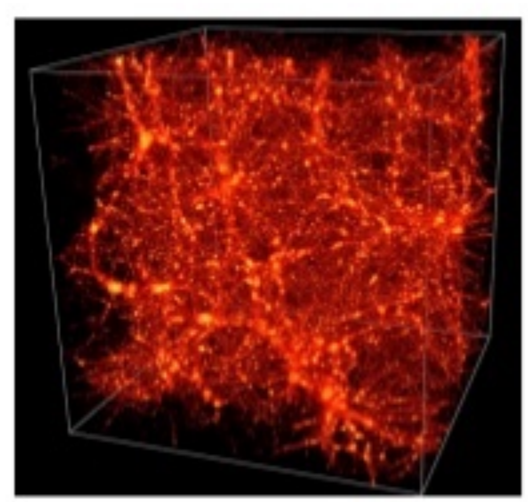
Cosmology has become data driven and phenomenological.


3.9 Mpc/h
15.6 Mpc/h
62.5 Mpc/h
250 Mpc/h
1 Gpc/h

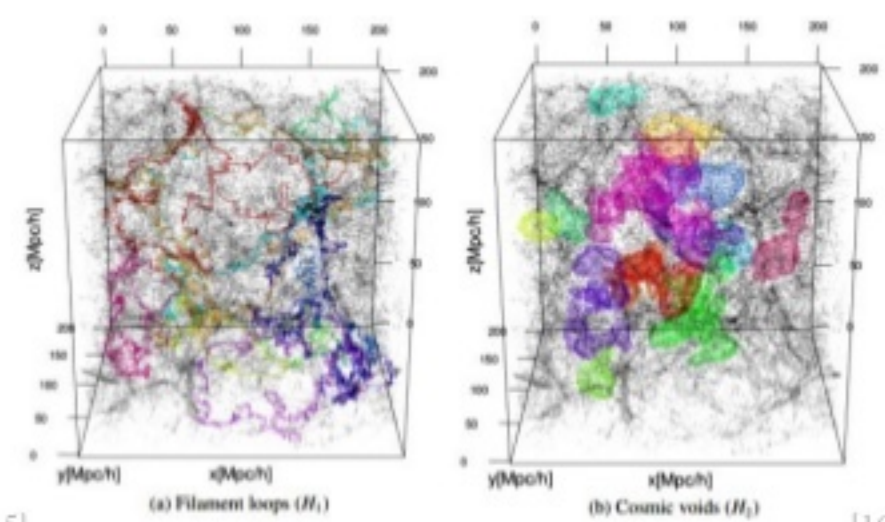


statistical
methods

topological
methods



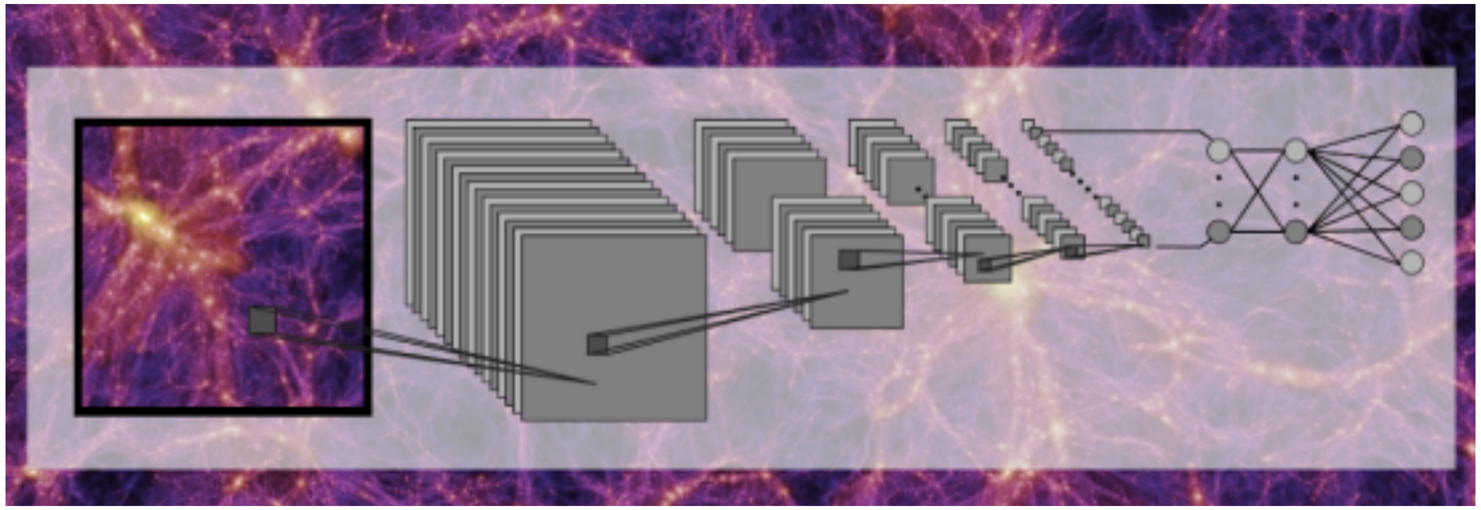
[15]



[16]

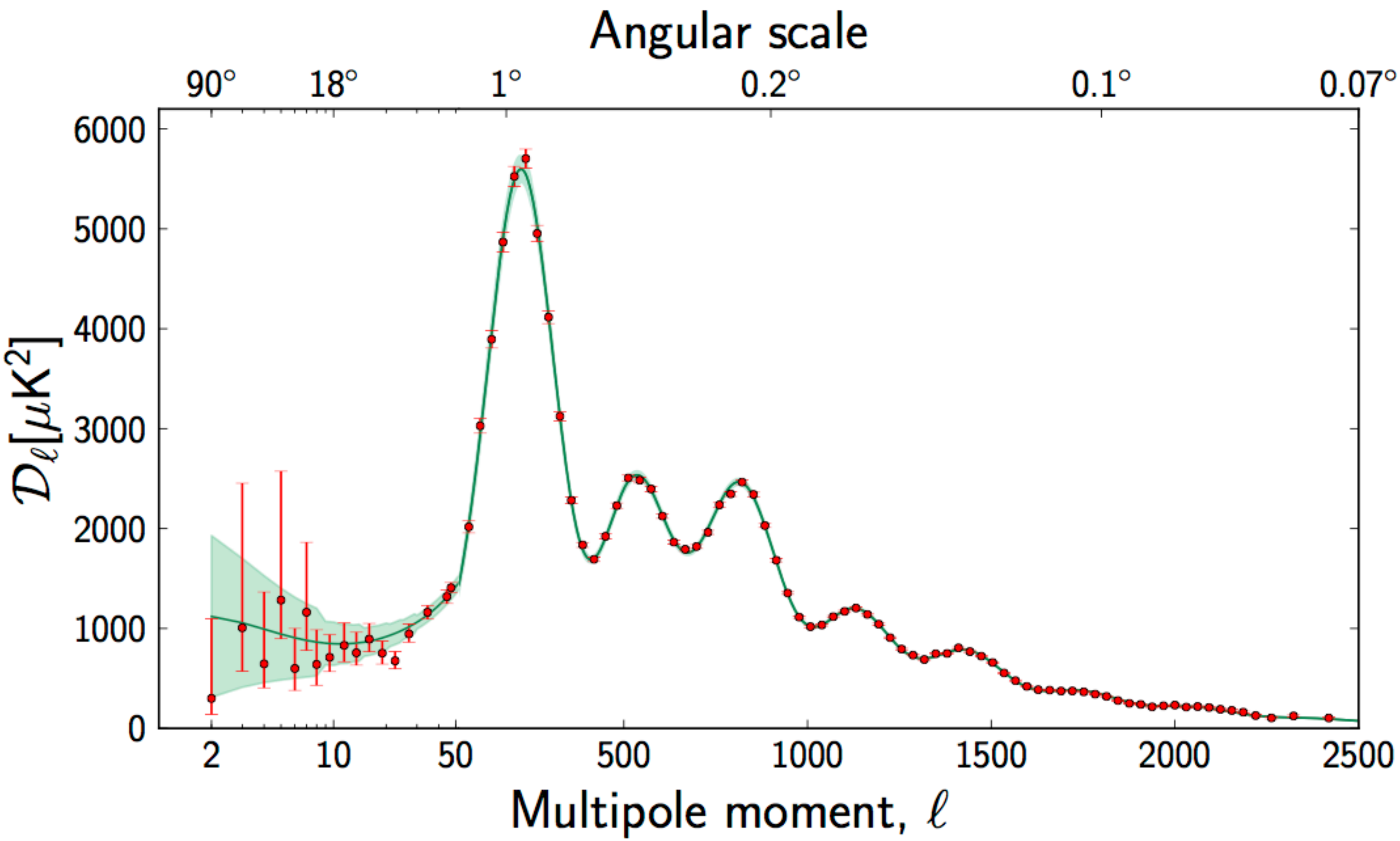
https://www.slideshare.net/CarlaFedericaMelia/topological-data-analysis-and-persistent-homology-126895845 learning algorithms and neural networks

less biased by man-based impressions



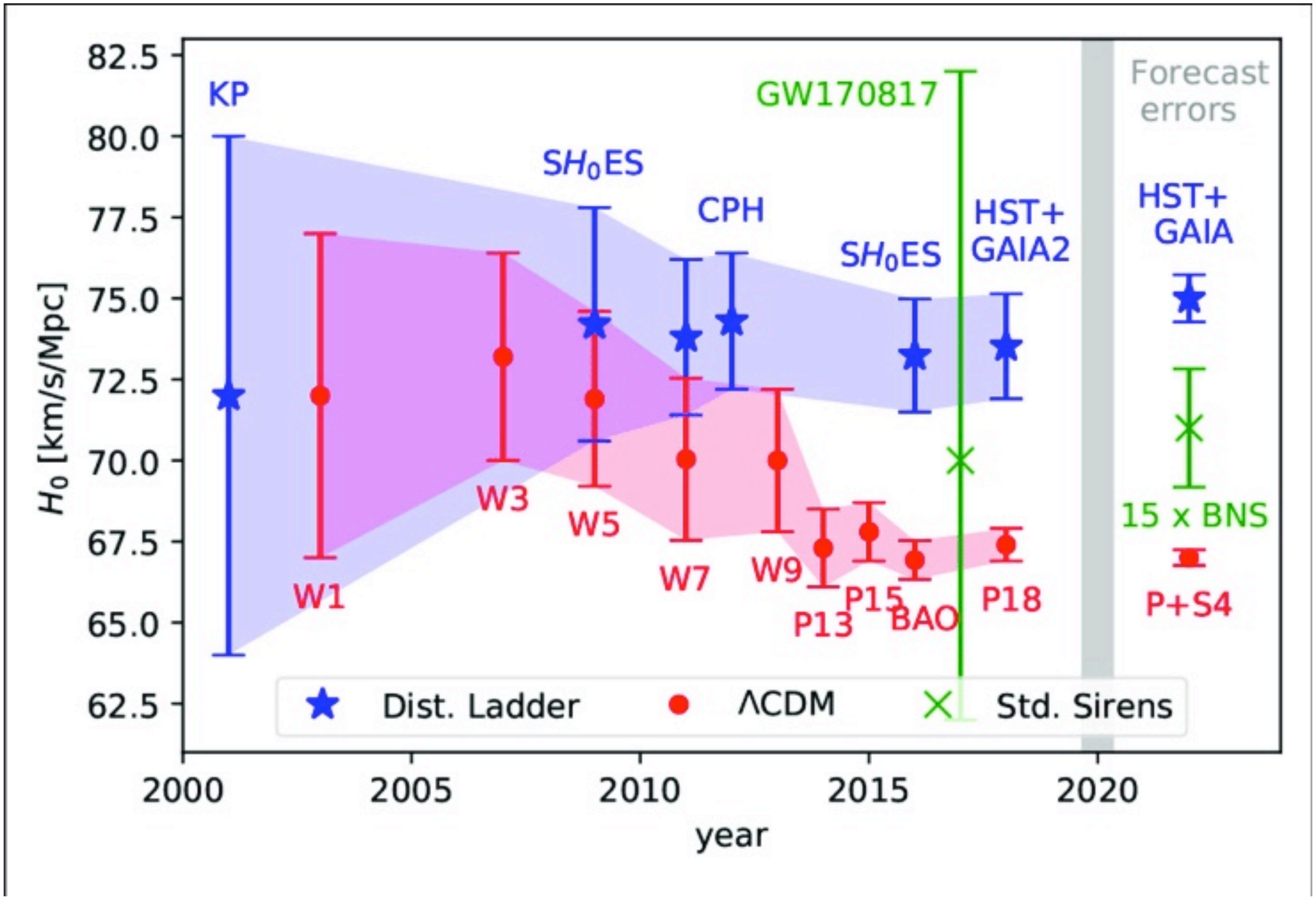
https://cosmology.ethz.ch/news-and-events/refregier-group/2019/07/artificial-intelligence-methods-in-cosmology.html here is the problem:

Our picture is extraordinarily good!



maybe just a few *tensions and anomalies* ...

Hubble tension (or crisis?)



but let’s remember
at the end of nineteenth century

So profound were these and other developments that it was generally accepted that all the important laws of physics had been discovered and that, henceforth, research would be concerned with clearing up minor problems and particularly with improvements of method and measurement.

https://en.wikipedia.org/wiki/History_of_physics

Philipp von Jolly to Planck at 1878:
“In this field, almost everything is already discovered, and all that remains is to fill a few holes.”

Lambda-CDM
simple and observationally successful

but

early universe?
dark energy? cosmological constant?
nature of dark matter?
fine-tuning?
topology (and connectivity) of space?
dimension of the world?
negative mass?
quantum gravity?
multiverse?
...

Fundamental problems

1- the uniqueness of the Universe

- scientific = reproducible
- cosmology : produce a science of one specific objects
- only one universe to study
- nothing similar to compare the laws and proposals to with
- cosmology has one leg in science and one leg out
- distinction between laws of nature and boundary conditions obscure.
- not clear what is a law of nature and what is not.
- eg physical constants: constant or environment-dependent?
- string-theory landscape: all dimensionless constants are dynamical,
  not supported observationally
- arrow of time (second law of thermodynamic):
  a result of initial condition in the early Universe

Fundamental Issues and Problems of Cosmology, G. Ellis (2011)

2- did the universe have a start?

- a start where the matter, space, time and the laws of physics came into being.

- do some laws governing this process? or was it a once-off affair?

- if laws exist, they should probably happen more
  ... resulting in multiverse? but no experiment can ever support this.

- what was the previous kind of existence of the universe?
  - -- nothing?
  - -- from vacuum fluctuations in some previous spacetime
    - --- the problem is transferred back to another kind of existence.
  - -- eternal (eg cyclic):
    - --- vast number of possibilities. why these laws and not others?

- if there is a law for creation, the laws pre-existed the universe.
  then it could not be nothing! what kind of existence did they have?

3- the limits of testing

- the laws of physics at early universe under the conditions they had, as we cannot reach those energies.

- we proceed by extrapolation : extend what we know into the unknown

- test the extrapolation by cosmological consequences.

- we have then an *explanation* that only applies to *one* phenomenon (eg inflation: *ad hoc* cause for one particular feature).

- sometimes there are specific predictions for the theory to be tested, but usually not enough to confirm the chain of reasoning lead to it. degeneracies exist!

4- the problem of infinities

- cosmology (and in particular, multiverse) contains infinite number of entities (stars, galaxies, ...)

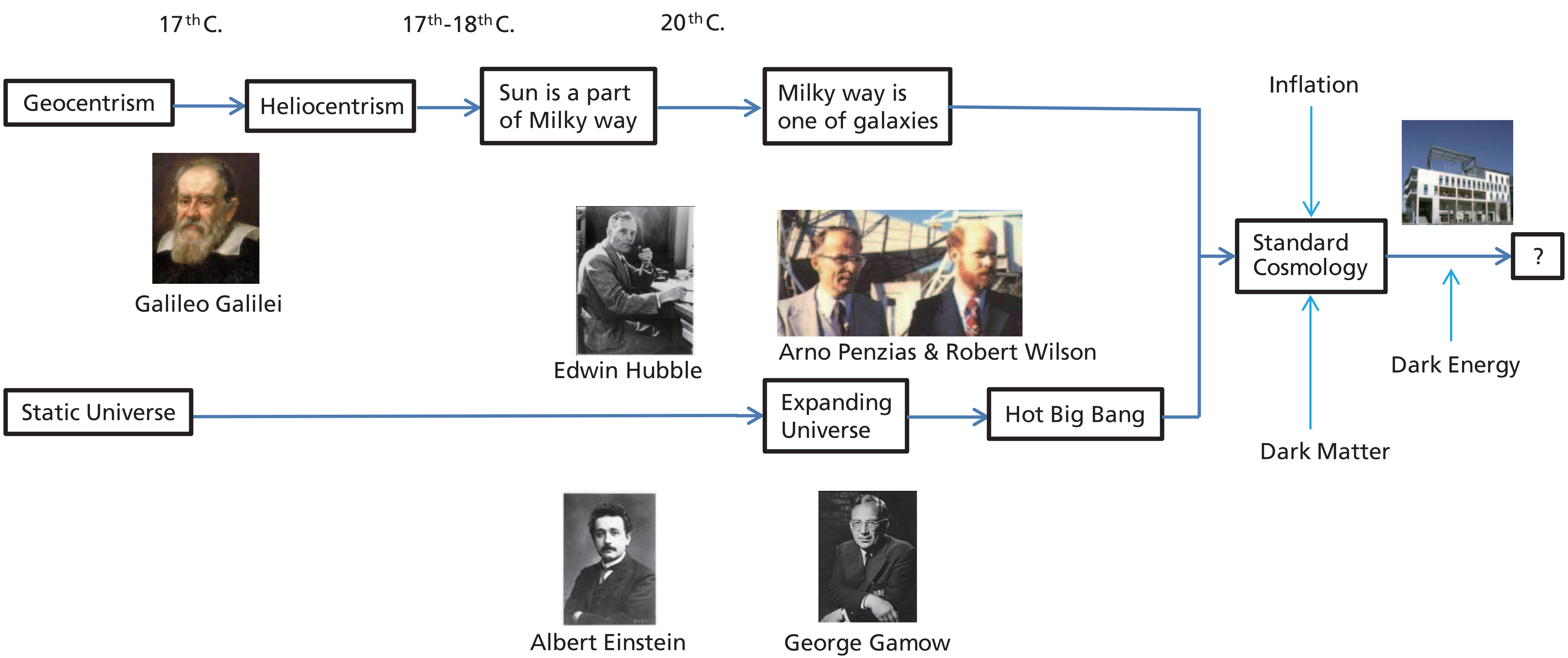
- conceptually problematic:

Our principal result is that the infinite is nowhere to be found in reality.
It neither exists in nature nor provides a legitimate basis for rational thought…
The role that remains for the infinite to play is solely that of an idea…
which transcends all experience and which completes the concrete as a totality. . .

(D. Hilbert)

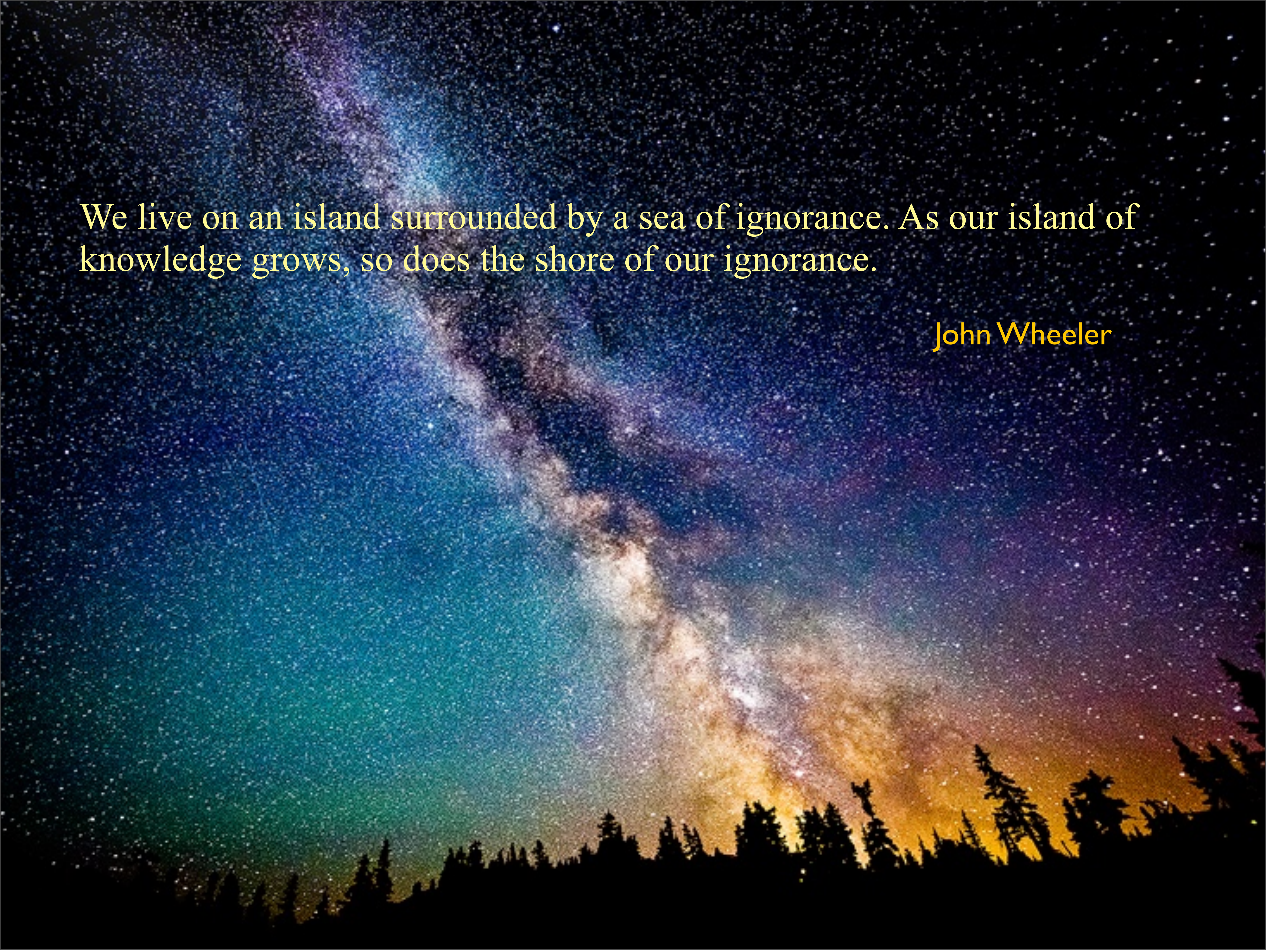
- even if existing, could never be counted. no way to be proved.
  therefore, it is not a scientific claim.

We have come a long way
from a rather speculative theory



to scientific cosmology ...

Paradigm Shifts in Cosmology, Naoshi Sugiyama, 2011


We live on an island surrounded by a sea of ignorance. As our island of knowledge grows, so does the shore of our ignorance.
John Wheeler