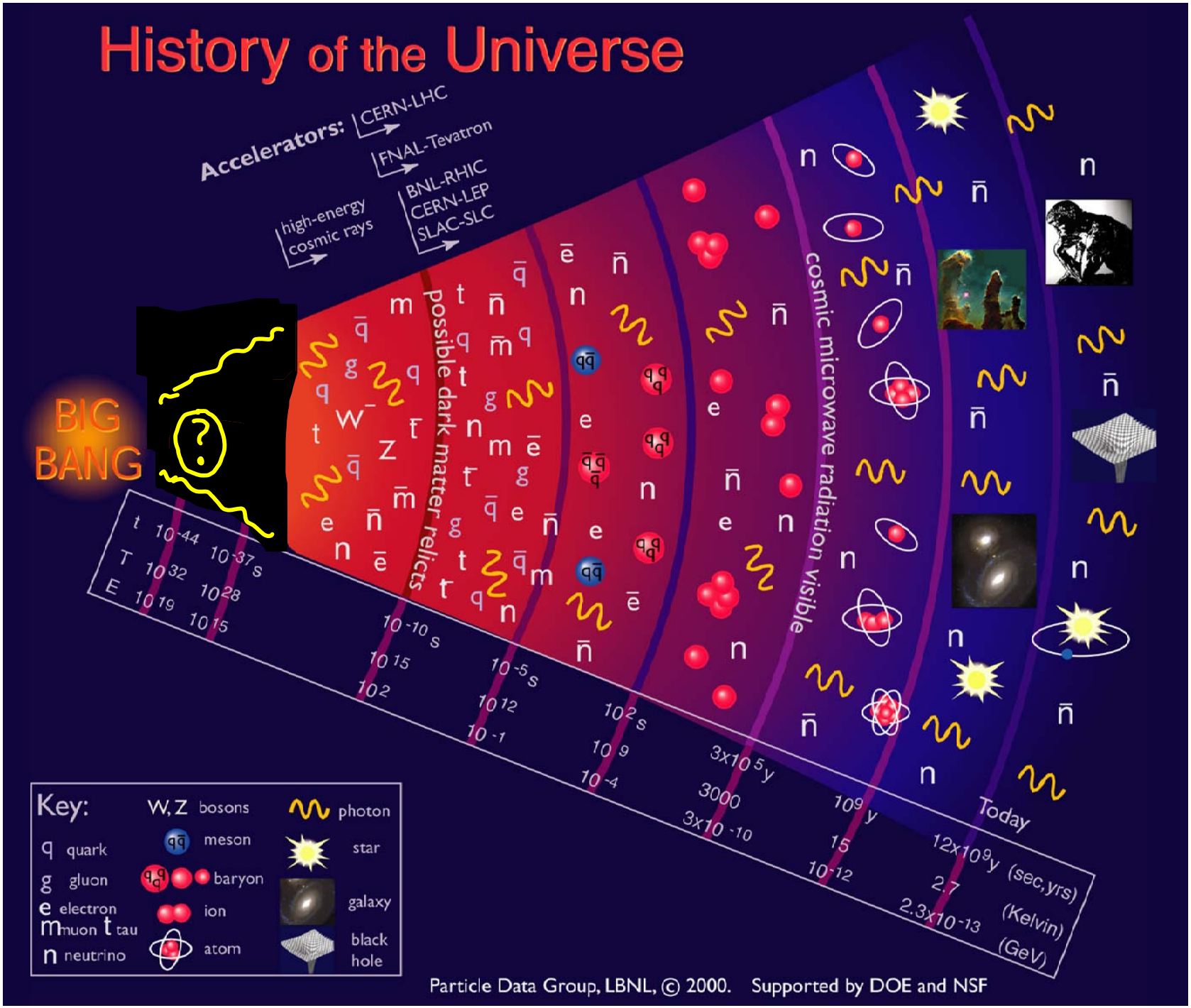
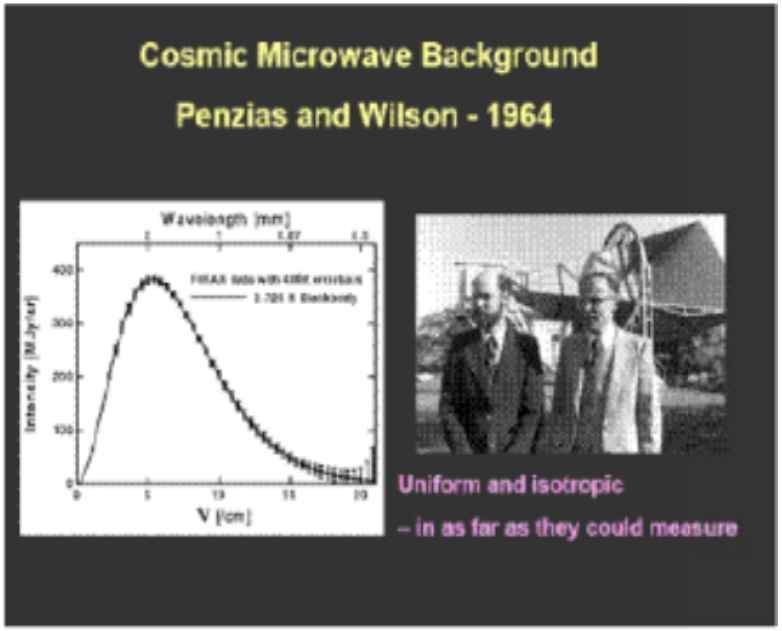
Cosmology has Arrived!

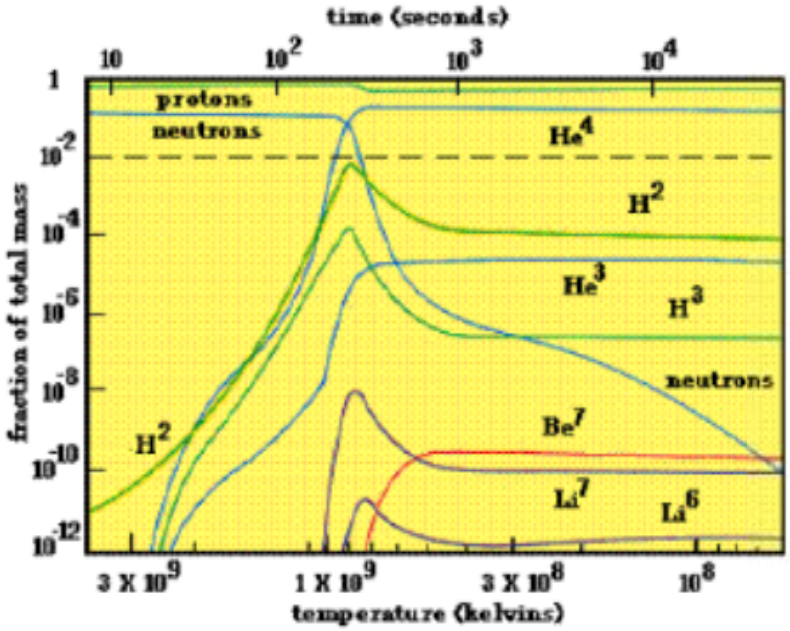

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 1032 1028
E 1019 1015
10-10 s
10 15
10 2
10-5 s
10 12
10 -1
102 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
109 y
15
10-12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10-13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
qq meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

- Observe light from Time universe became transparent
  T ~ 400,000 years

- Perfect blackbody all directions in sky



- Amount of light nuclei in interstellar / intergalactic space agrees w/ expectation from Big Bang Nucleosynthesis
  T ~ 3 minutes



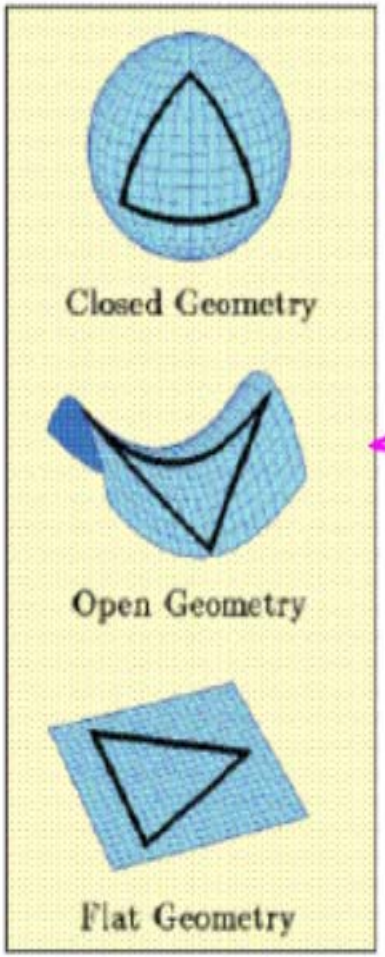
Problems w/ Big Bang

nonstatic universe expected from Relativity

Relativity allows space to have different curved geometries ?

Which is our universe?

Flat space is A very special case!



Sum of angles in triangle

$>180^\circ$

← universe expands... slows down + collapses

$<180^\circ$

← universe expands forever

$=180^\circ$

← universe expands to a stop

Very special case

- Singularity Problem – Yikes!! All of the universe at a Point?

- Horizon Problem – Why is universe so smooth and isotropic on large scales?

  Why CMB so smooth and isotropic

  at T = 400,000 yrs

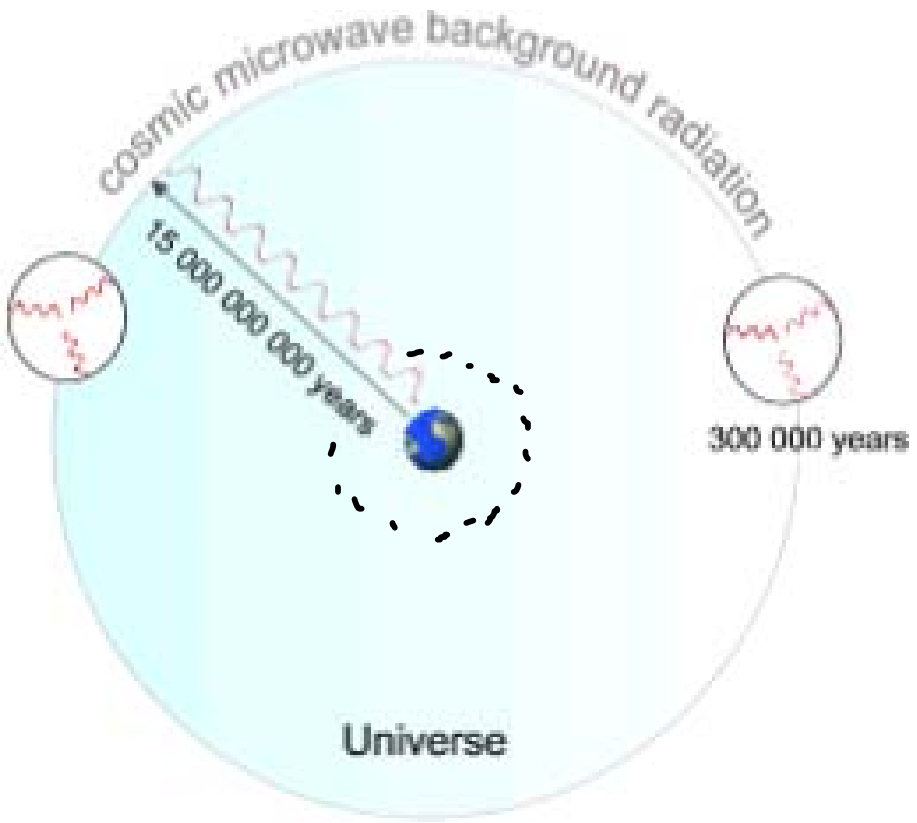
  only parts of universe as large as 400,000 light years could be causally connected

  yet all at same temperature??

- Flatness problem – universe appears to be very close to "flat" ... very special case.

  Requires fine tuning of basic Model

Horizon Problem



– drawing by
Theresa Knott
Taken from Wikipedia

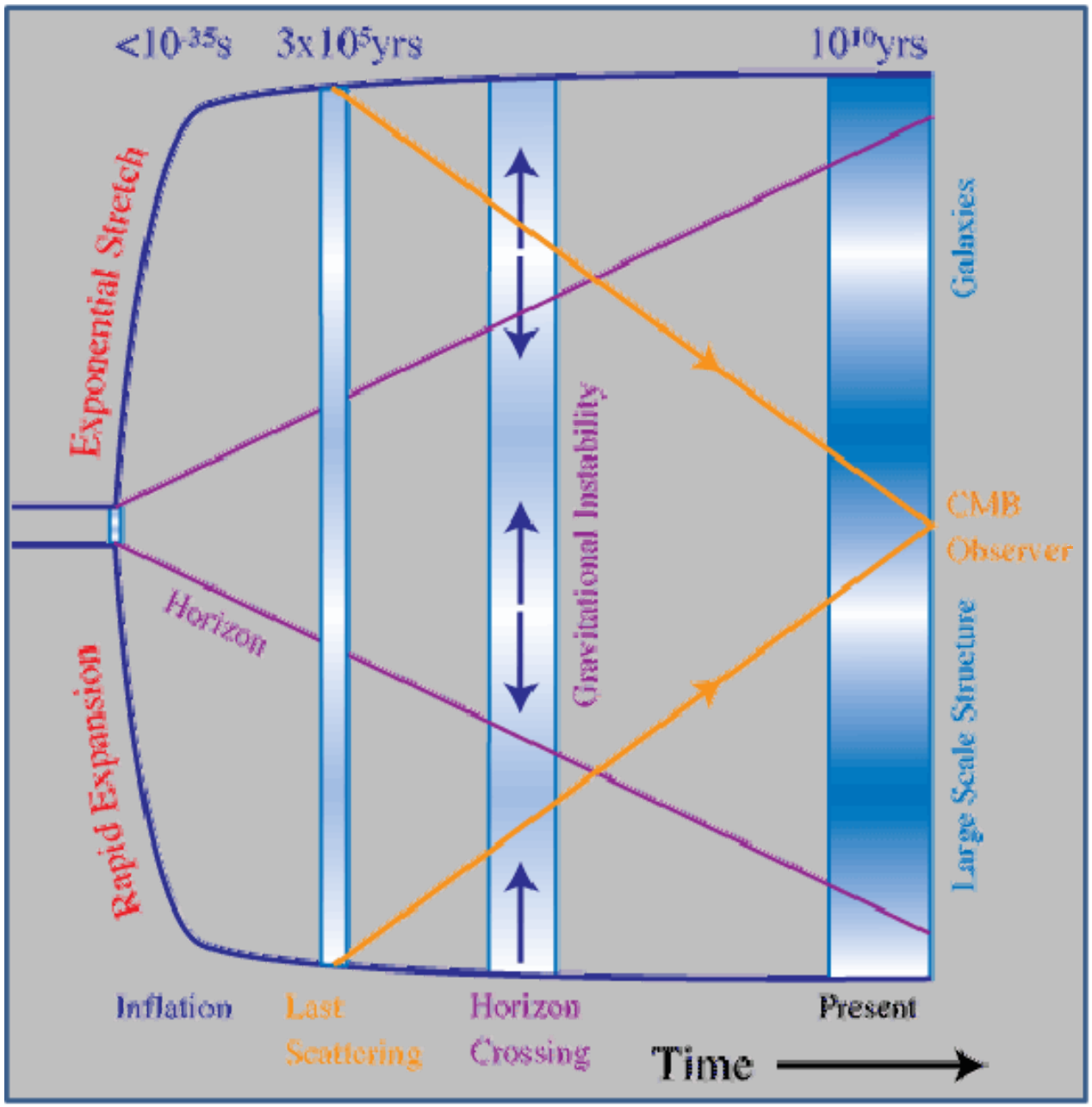
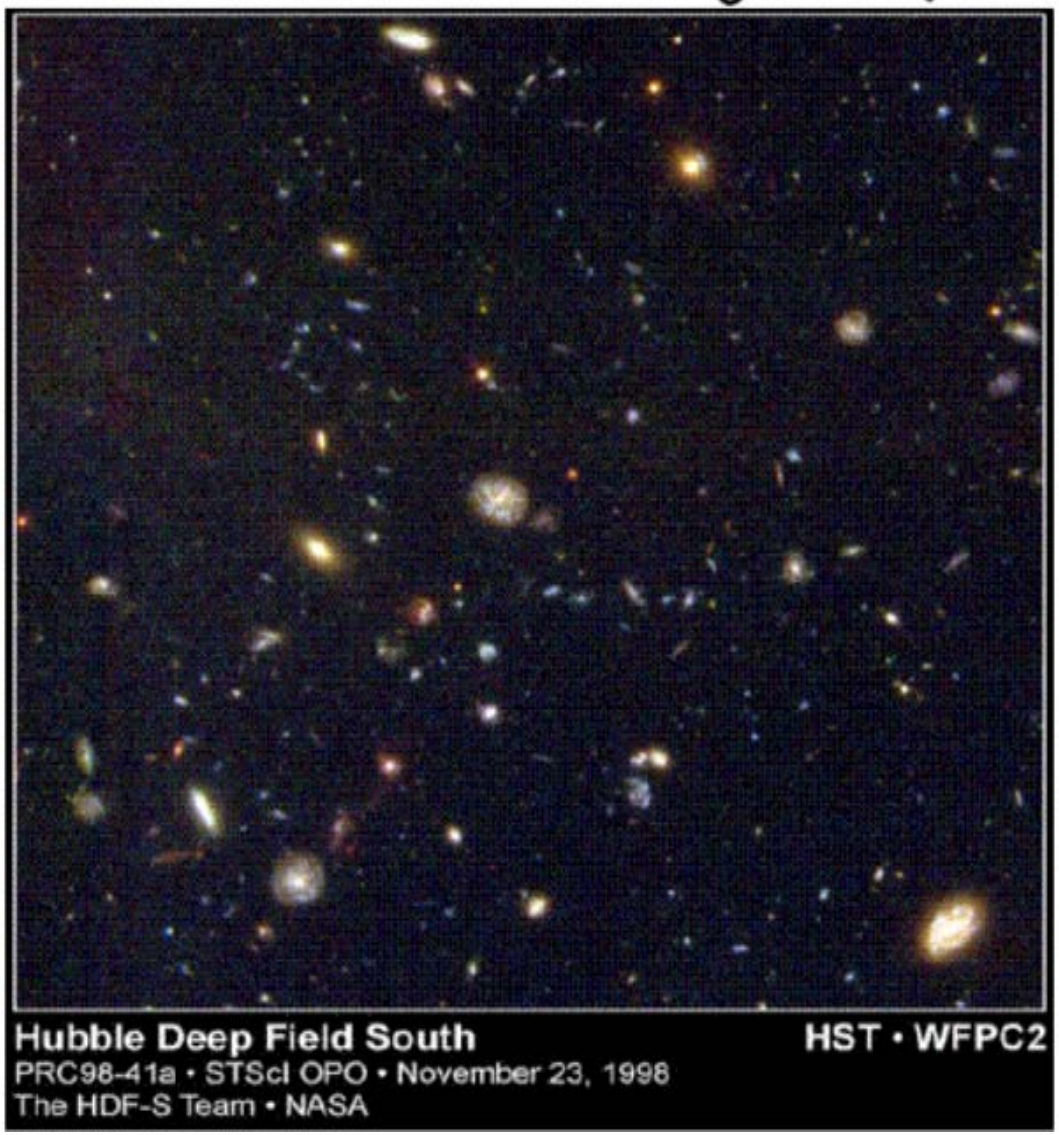


Fig from Wayne Hu
CMB tutorials

- large scale structure problem – how do galactic structures form in a perfectly homogenous universe?



Andrei Linde (Stanford)

Cosmic Inflation ~1979

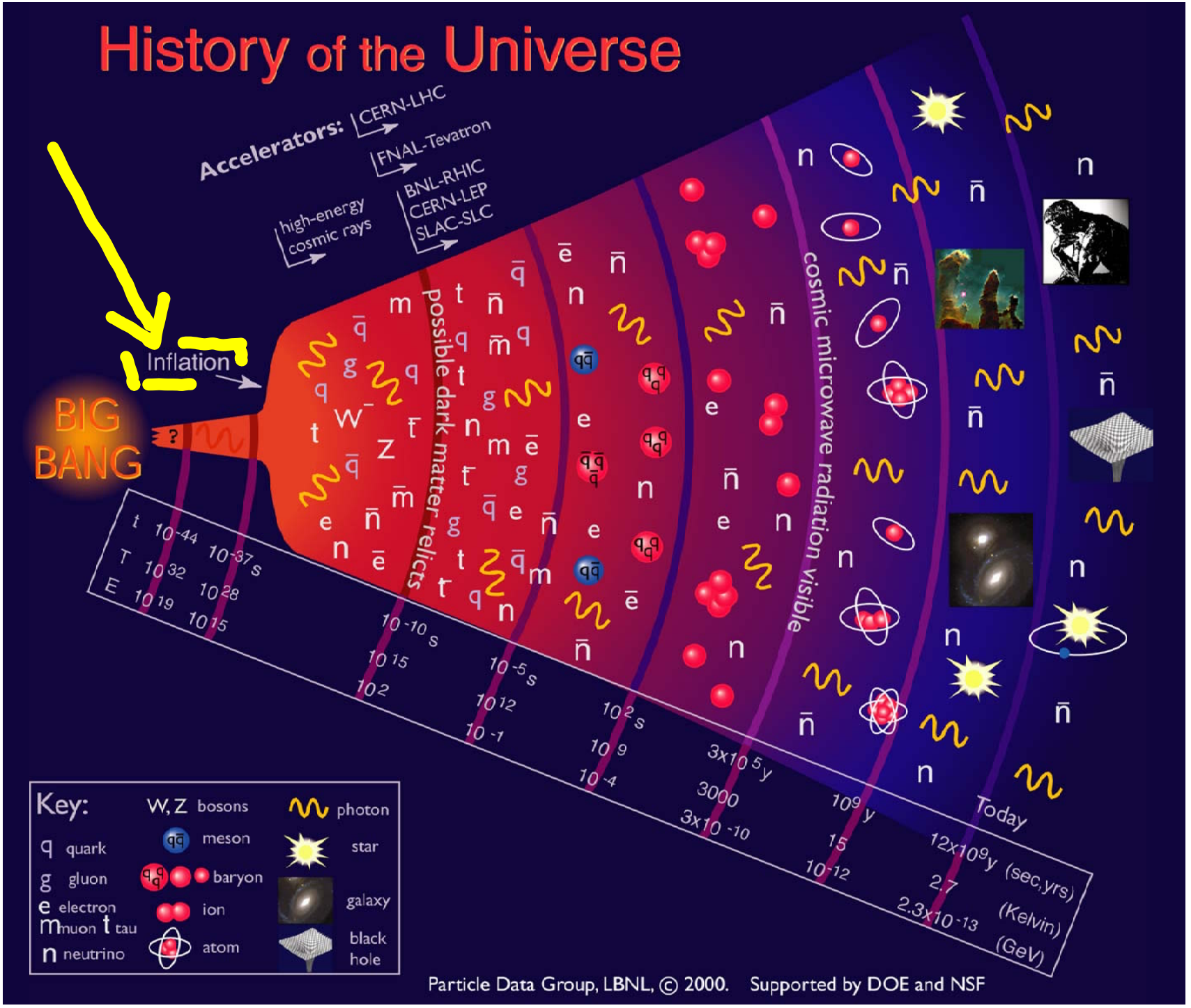
Paul Steinhardt (Princeton)

Andy Albrecht (UC Davis)

Idea used by many cosmological theories to solve Basic Problems w/ Big Bang Model

Inflationary Big Bang Models

Alan Guth (MIT)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Inflation

- Universe starts very small
- Perhaps as a tiny fluctuation in a spacetime foam of tiny fluctuations
  maybe $\sim 10^{-26}$ M in size

- Properties of such a fluctuation can be constructed so as to create an unstable repulsion filling the space of the fluctuation — some "field" of particle is created in a quasi-stable excited state → inflaton What was it exactly?
- Leads to inflation — The ultimate understatement!

  Vast exponential superluminal expansion of the universe as inflaton "relaxes" expansion slows. Energy Driving inflation Dumped into matter + radiation and we have initial conditions for Big Bang Model as we know it

But what about energy conservation?

$V = 0$ Total energy $= 0$

$V \neq 0$

$+$ $-$

Δ Kinetic energy $+ \Delta$ grav. Potential energy $= 0$

As inflation happens energy stored in increasing gravitational Potential energy

"The universe is the ultimate Free lunch" – Guth

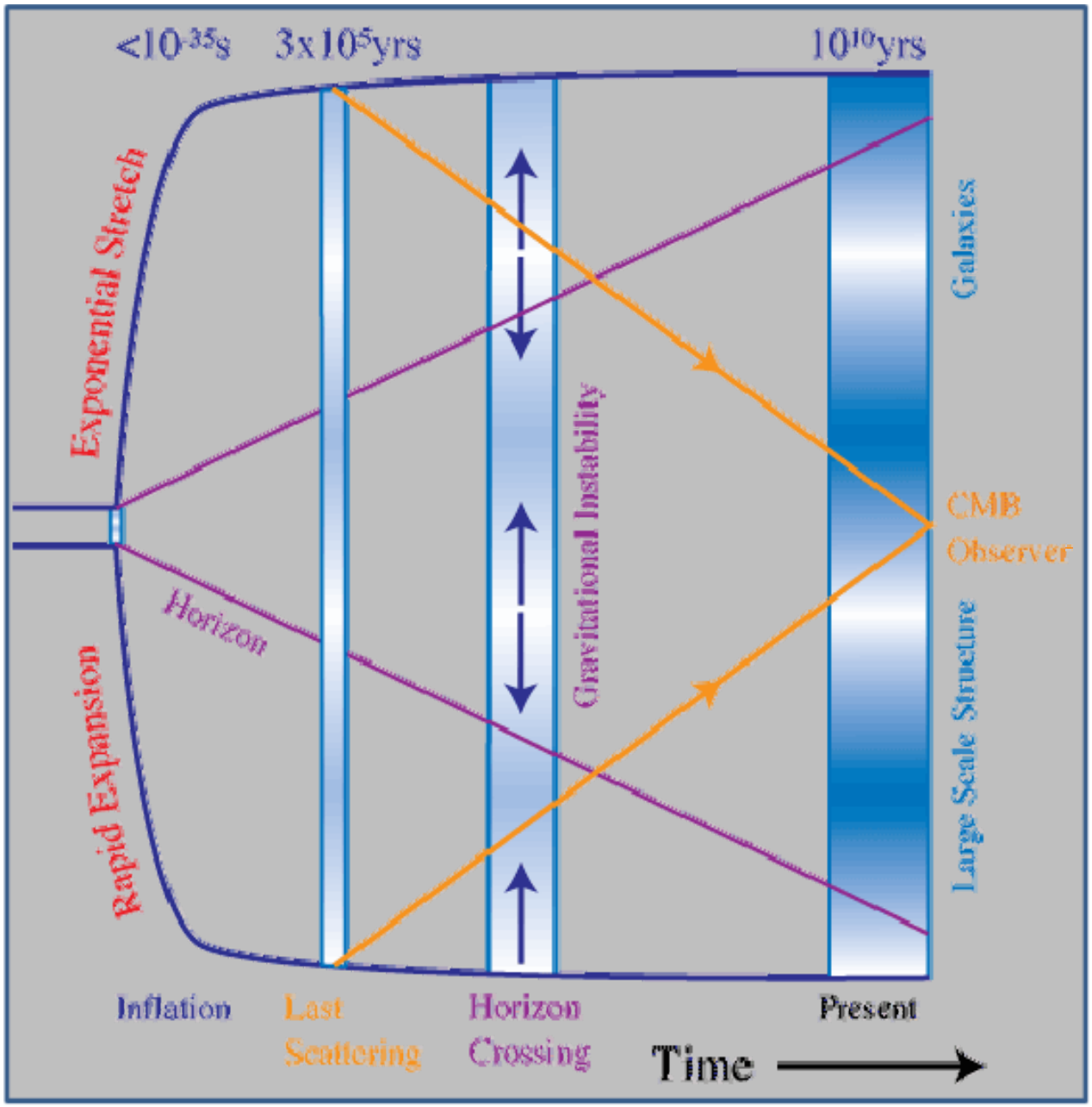
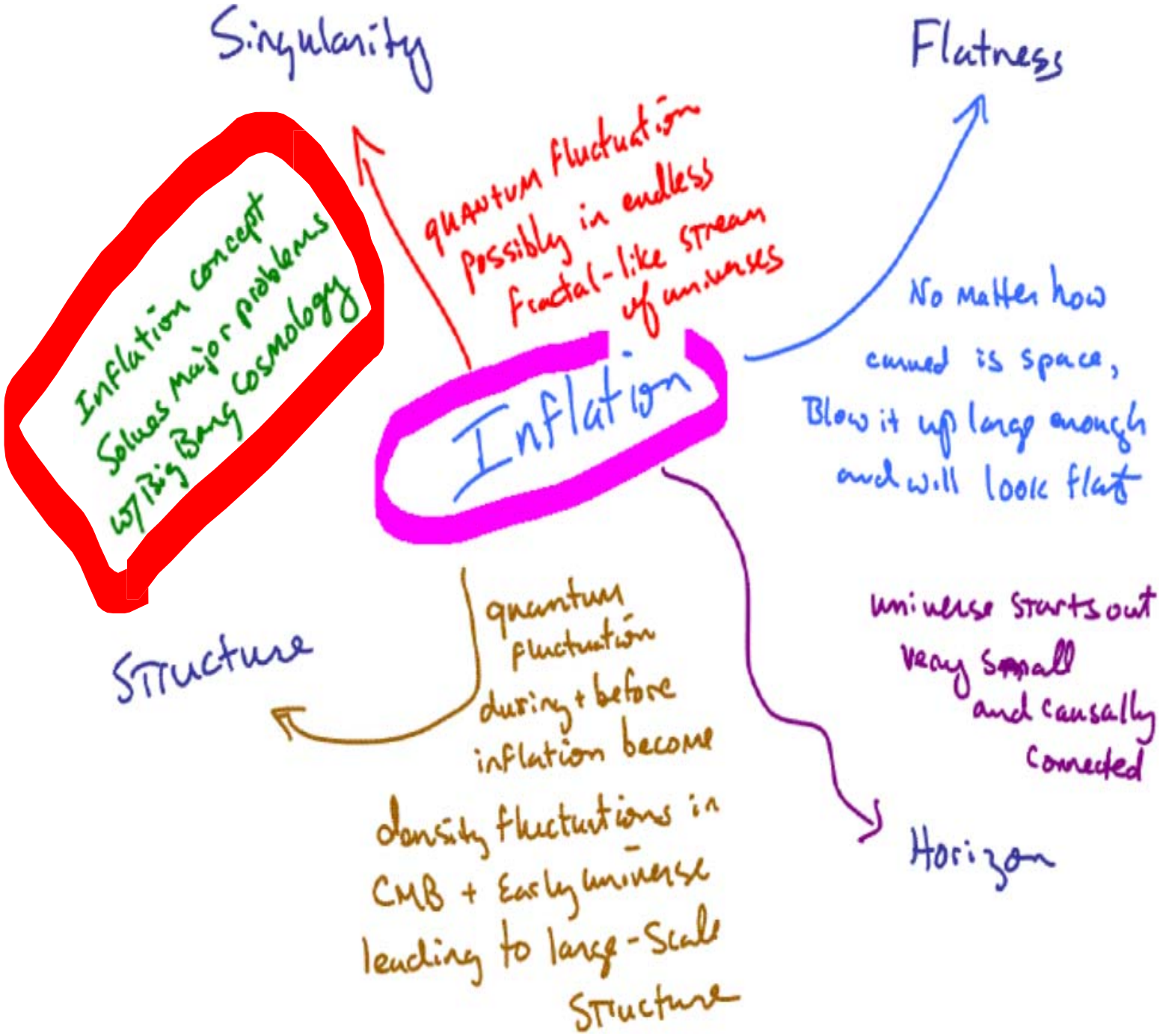


Fig from Wayne Hu
CMB tutorials


Singularity
Flatness
Inflation concept
Solves major problems
w/ Big Bang Cosmology
quantum fluctuation
possibly in endless
fractal-like stream
of universes
Inflation
No matter how
curved is space,
Blow it up large enough
and will look flat
Structure
quantum
fluctuation
during + before
inflation become
density fluctuations in
CMB + Early universe
leading to large-scale
structure
universe starts out
very small
and causally
connected
Horizon