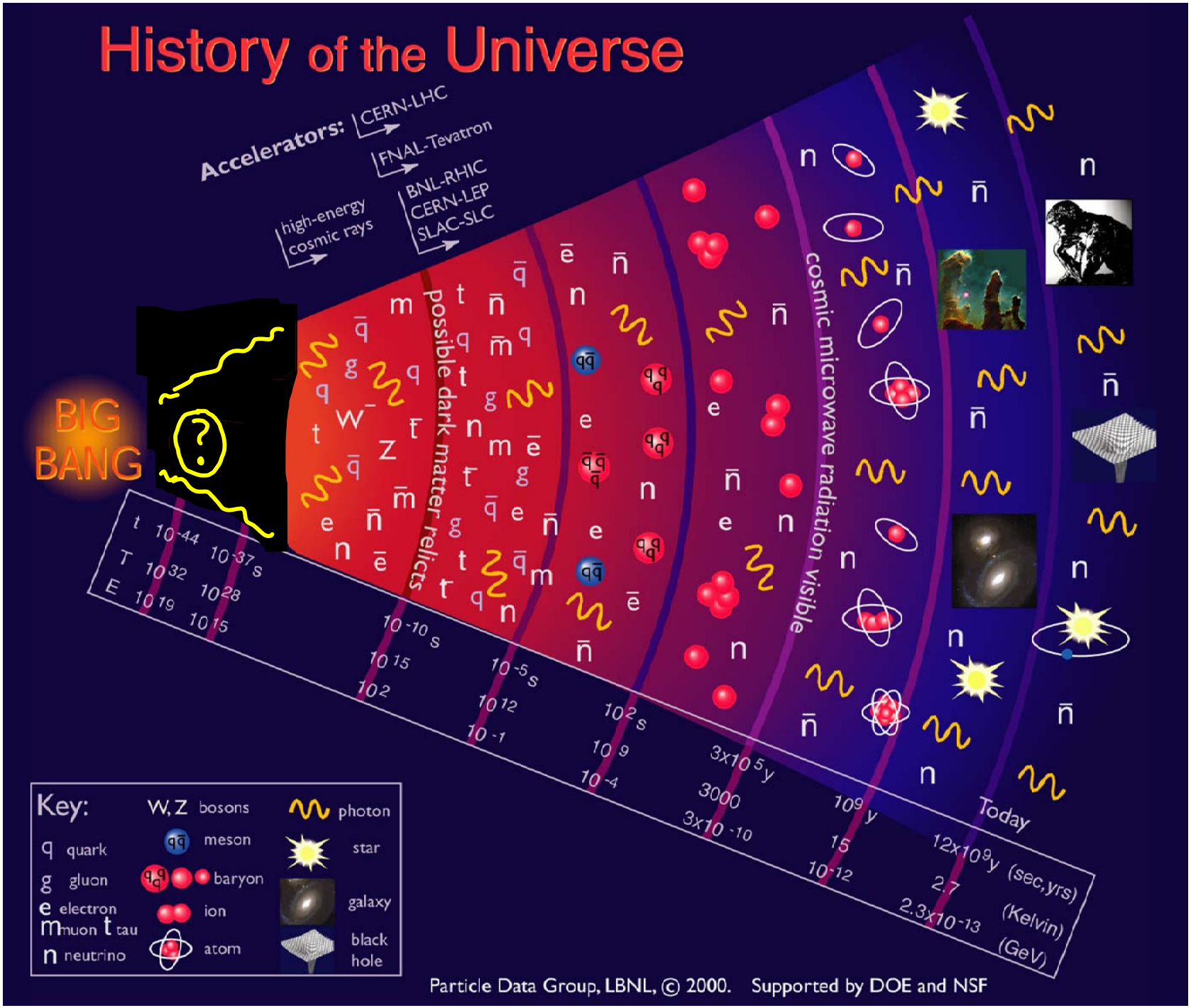
Physics 102 - April 6, 2011

- Friday recitation section cancelled
  go to M or W if possible

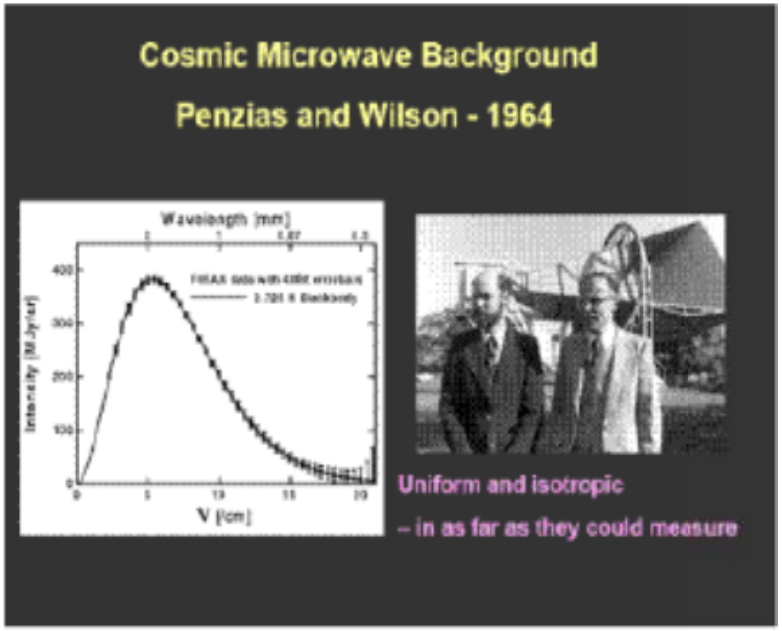
  Unable to find a good single time for the makeups

  Will probably do makeup Evening of Apr. 14

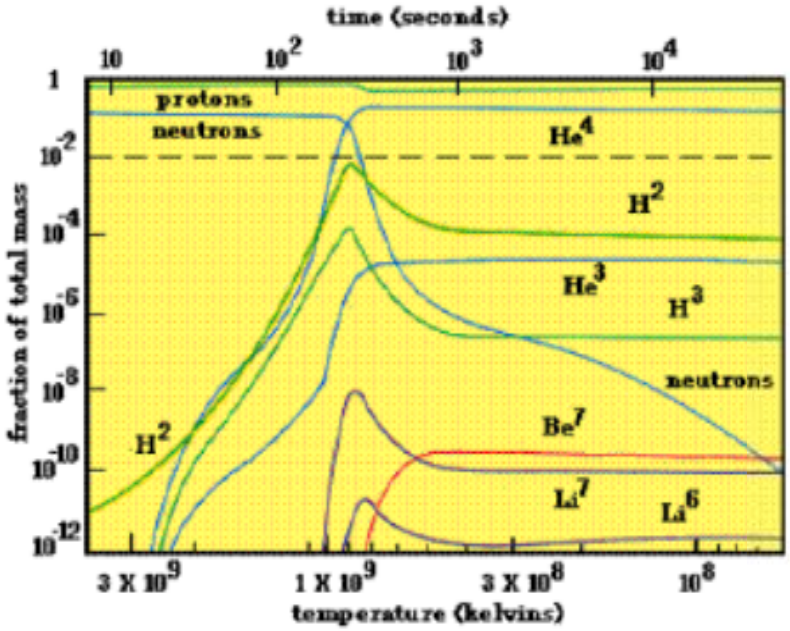

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 1032 1028
E 1019 1015
10-10 s
10 15
10 2
10-5 s
10 12
10 -1
102 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
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
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



- 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

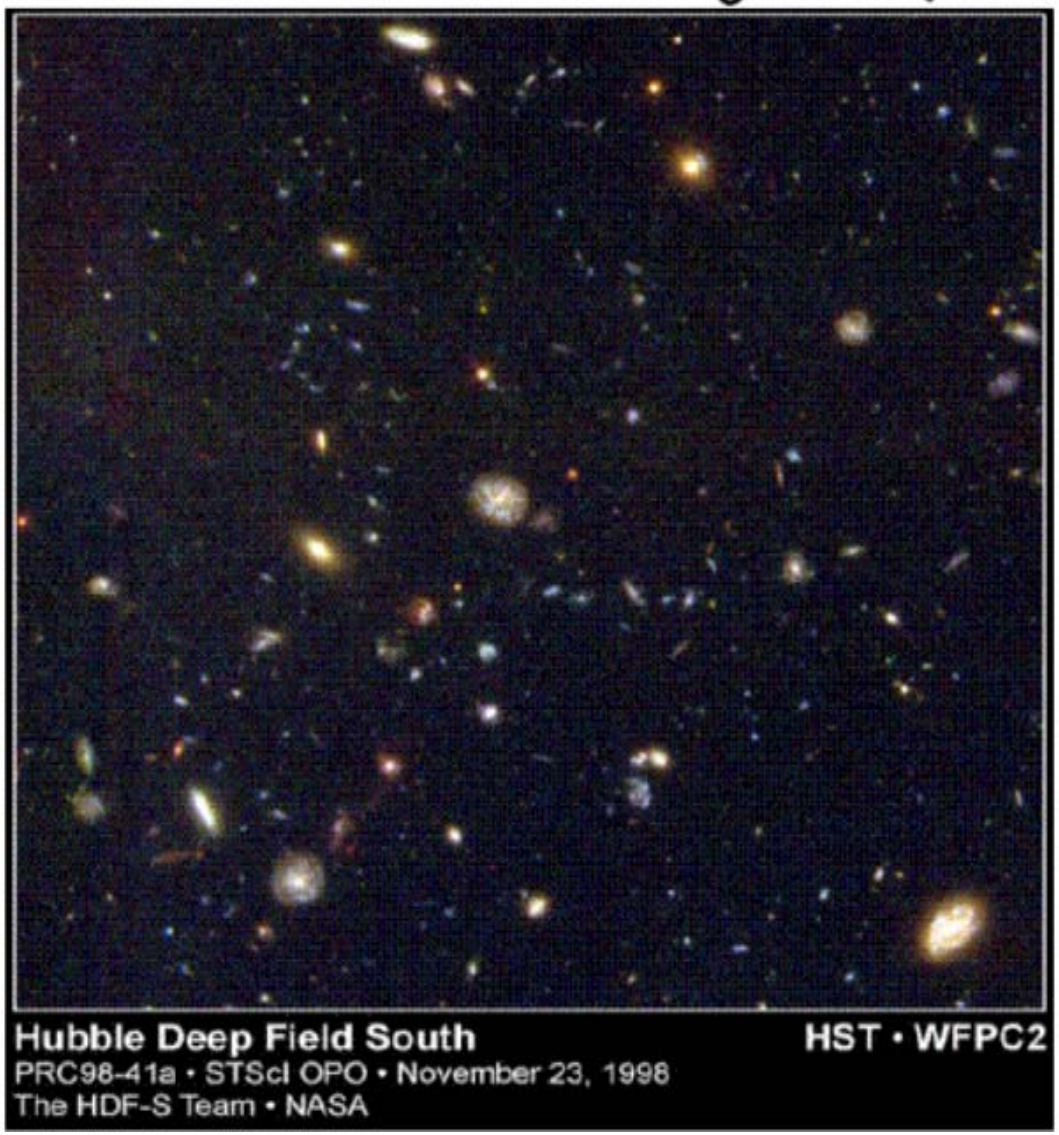
  only parts of universe as large as 400,000 light years could be causally connected

  yet all at same temperature??

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

  Requires fine tuning of basic Model

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



Andrei Linde (Stanford)

Cosmic Inflation ~1979

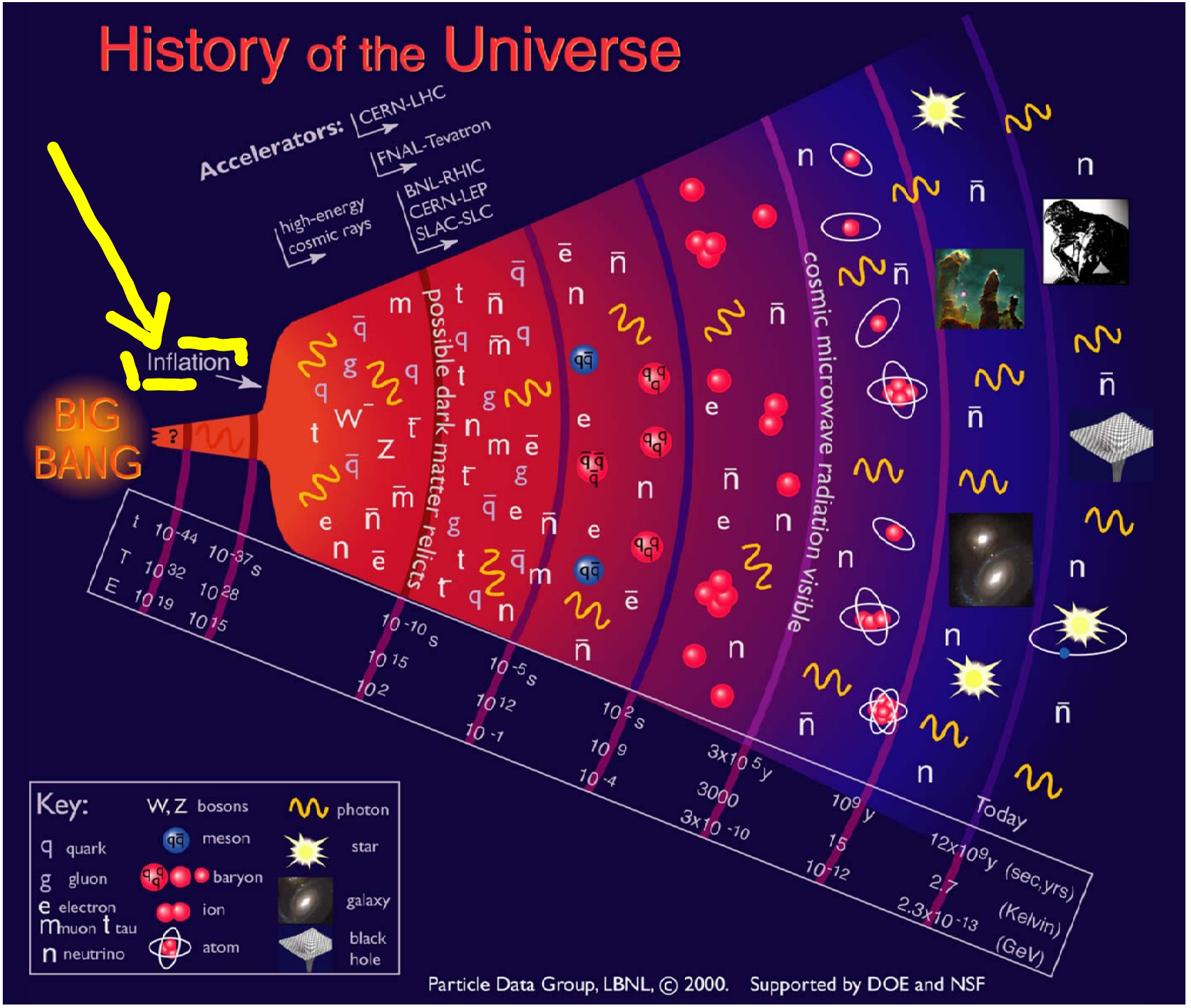
Paul Steinhardt (Princeton)

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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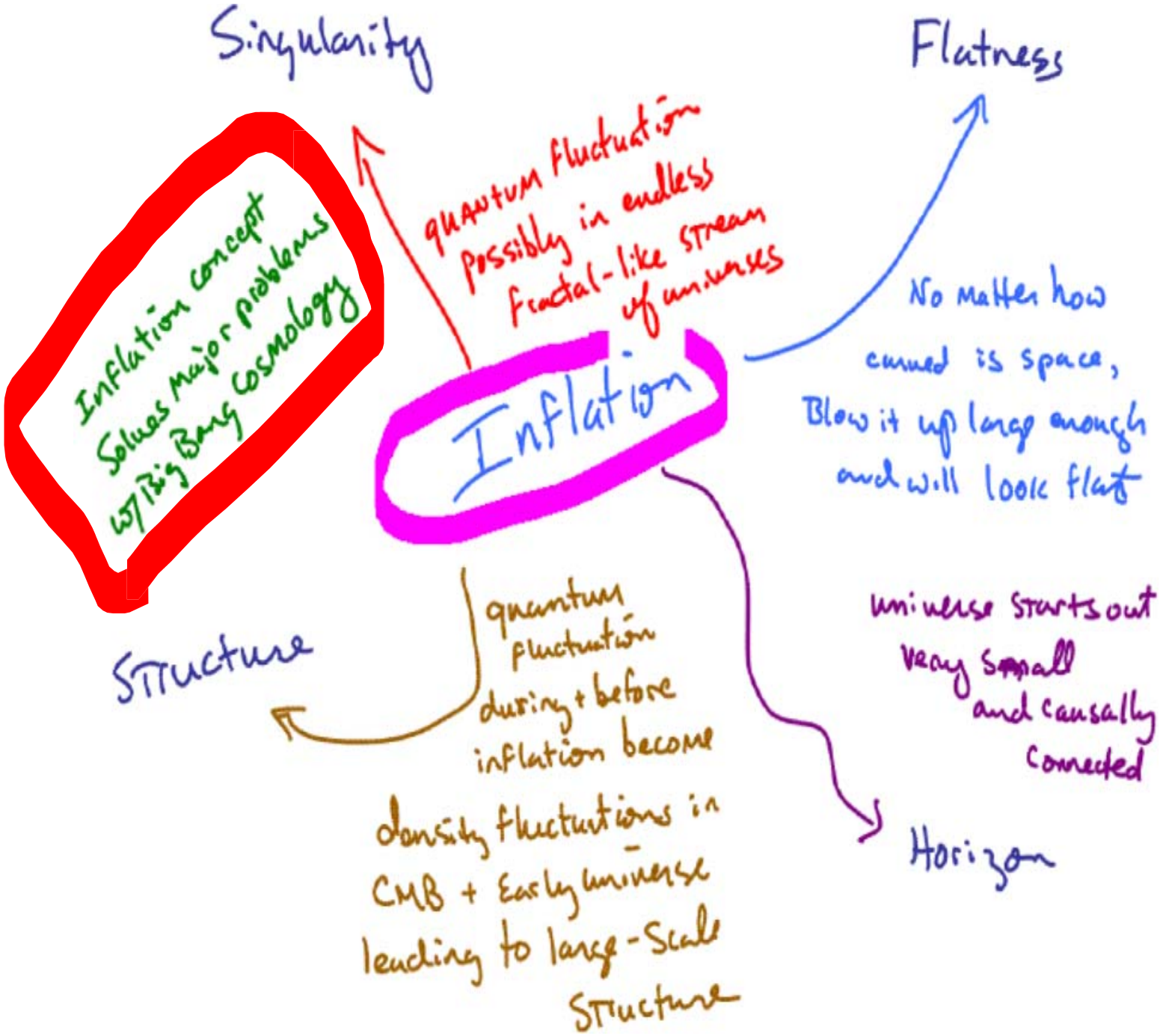
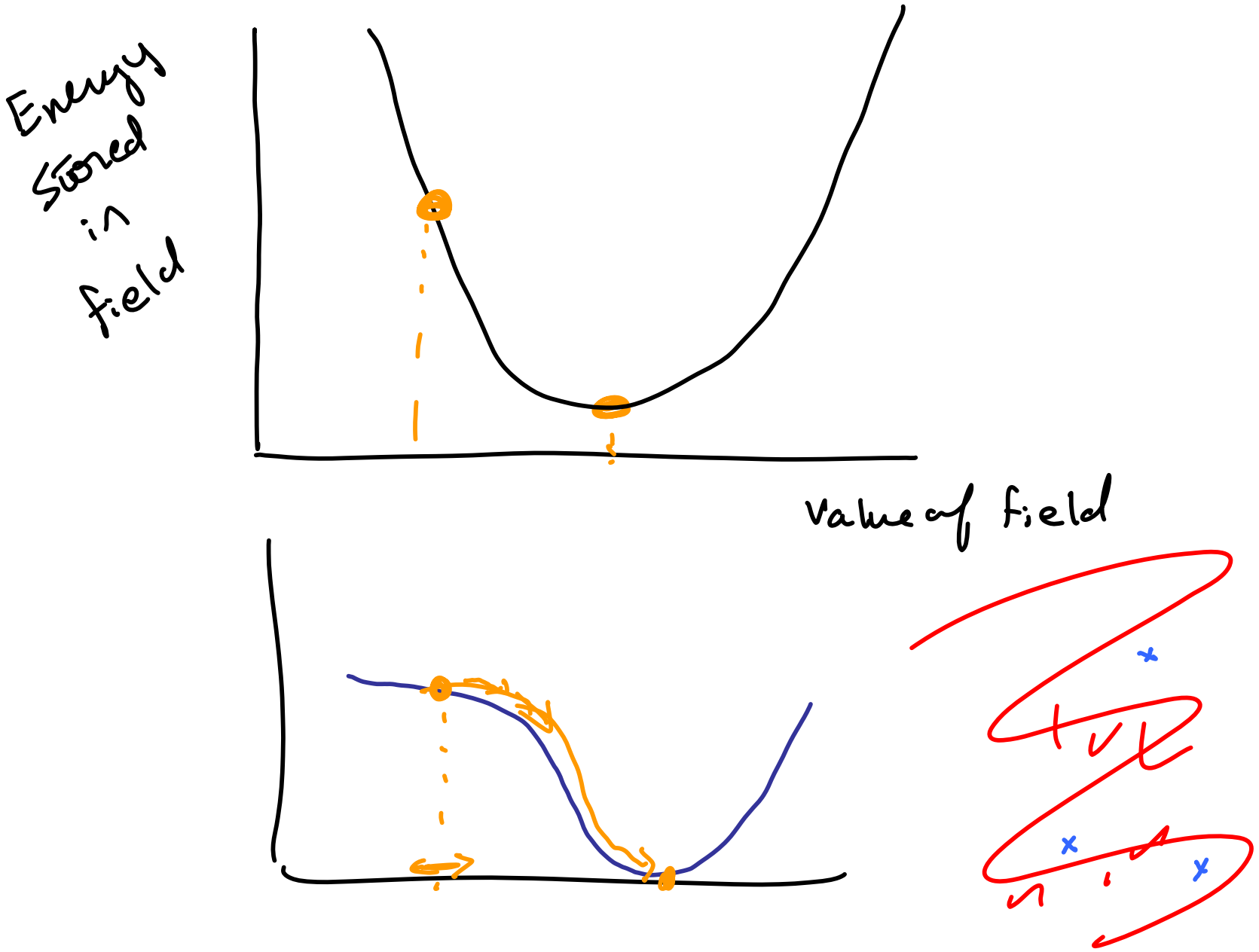
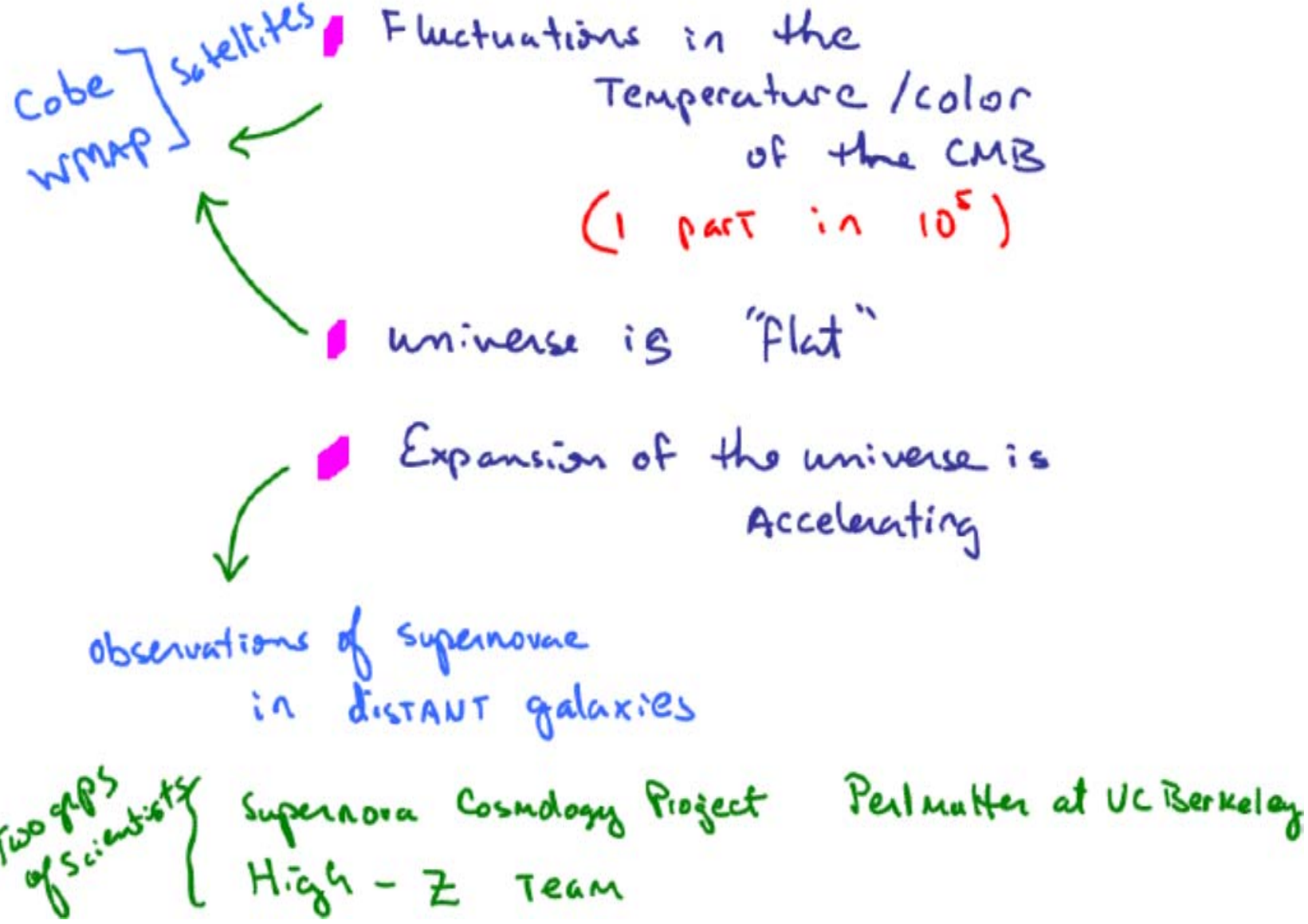
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

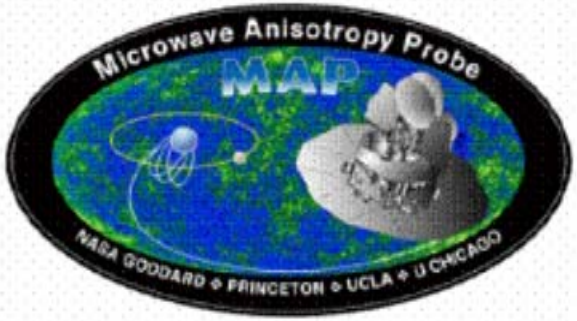

Singularity
Flatness
Inflation concept
Solves major problems
w/ Big Bang Cosmology
quantum fluctuation
possibly in endless
fractal-like stream
of universes
Inflation
No matter how
curved is space,
Blow it up large enough
and will look flat
Structure
quantum
fluctuation
during + before
inflation become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

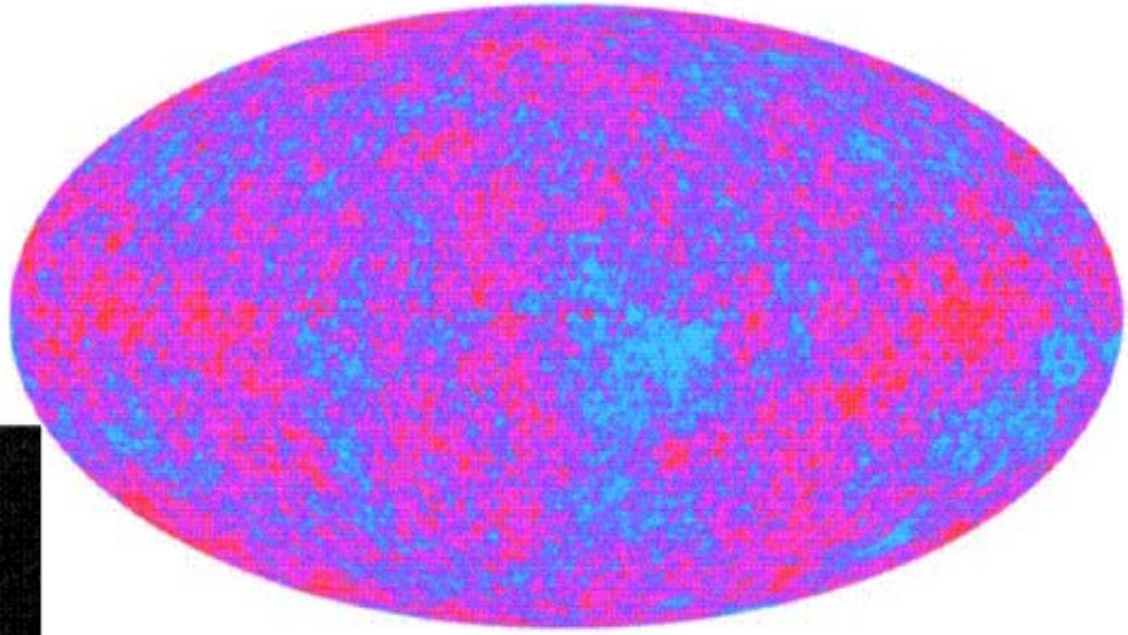

Energy stored in field
Value of field

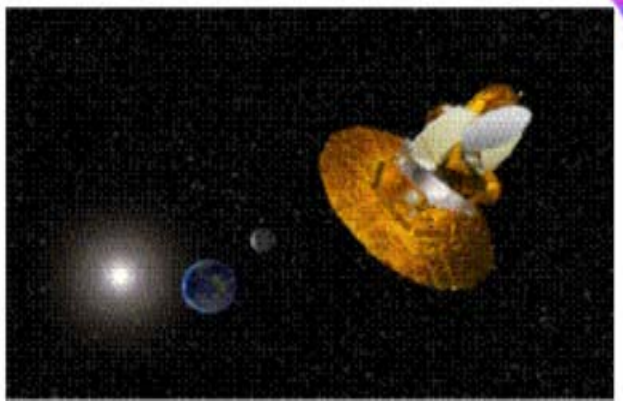
Incredible new data in the last 10 years



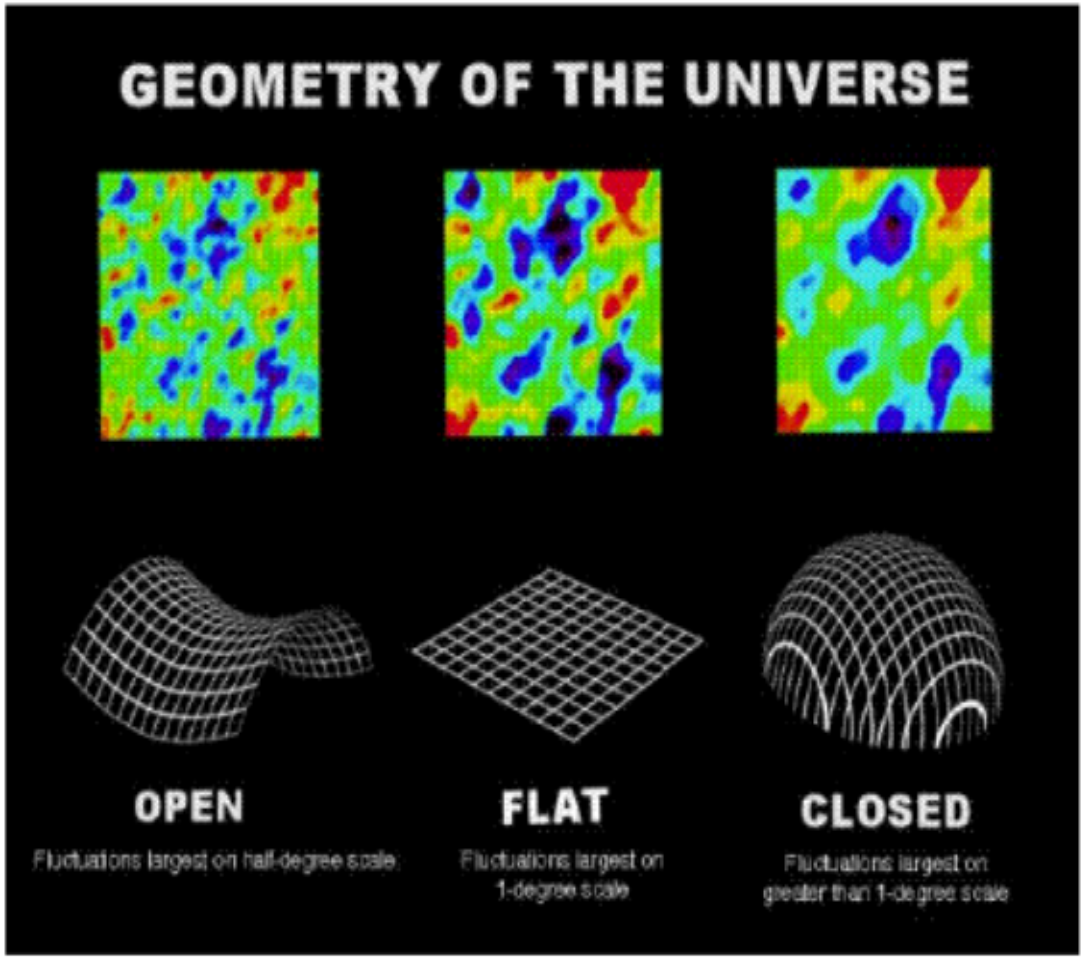
WMAp - Wilkinson Microwave Anisotropy Probe
(2003) High Resolution Study of CMB

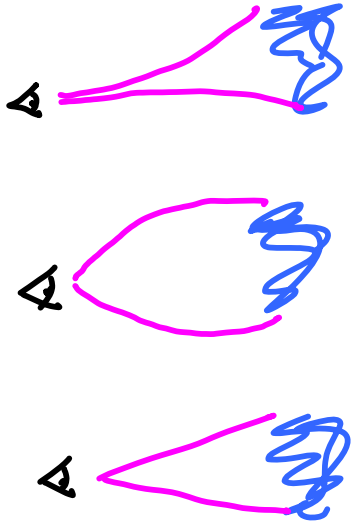


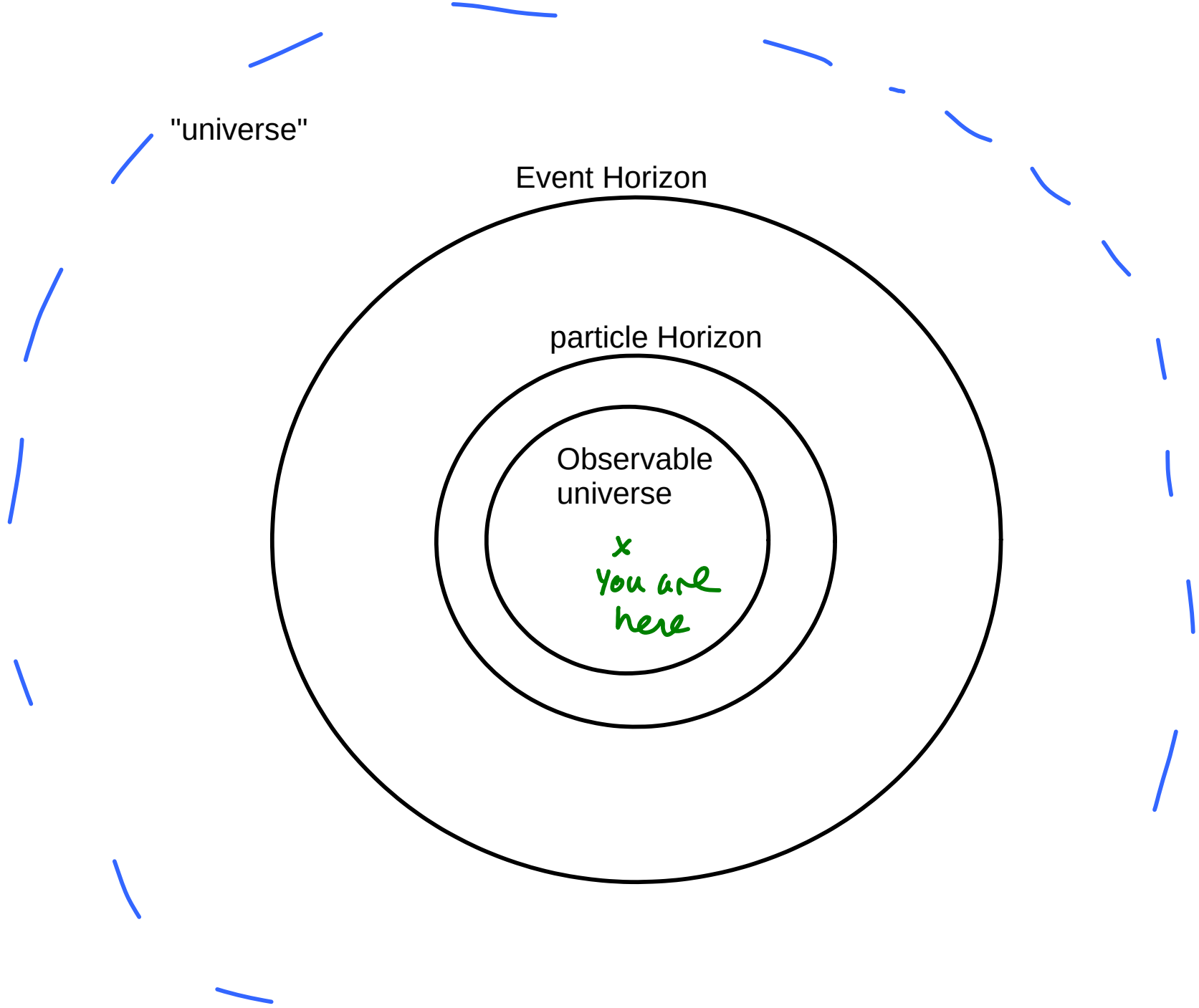




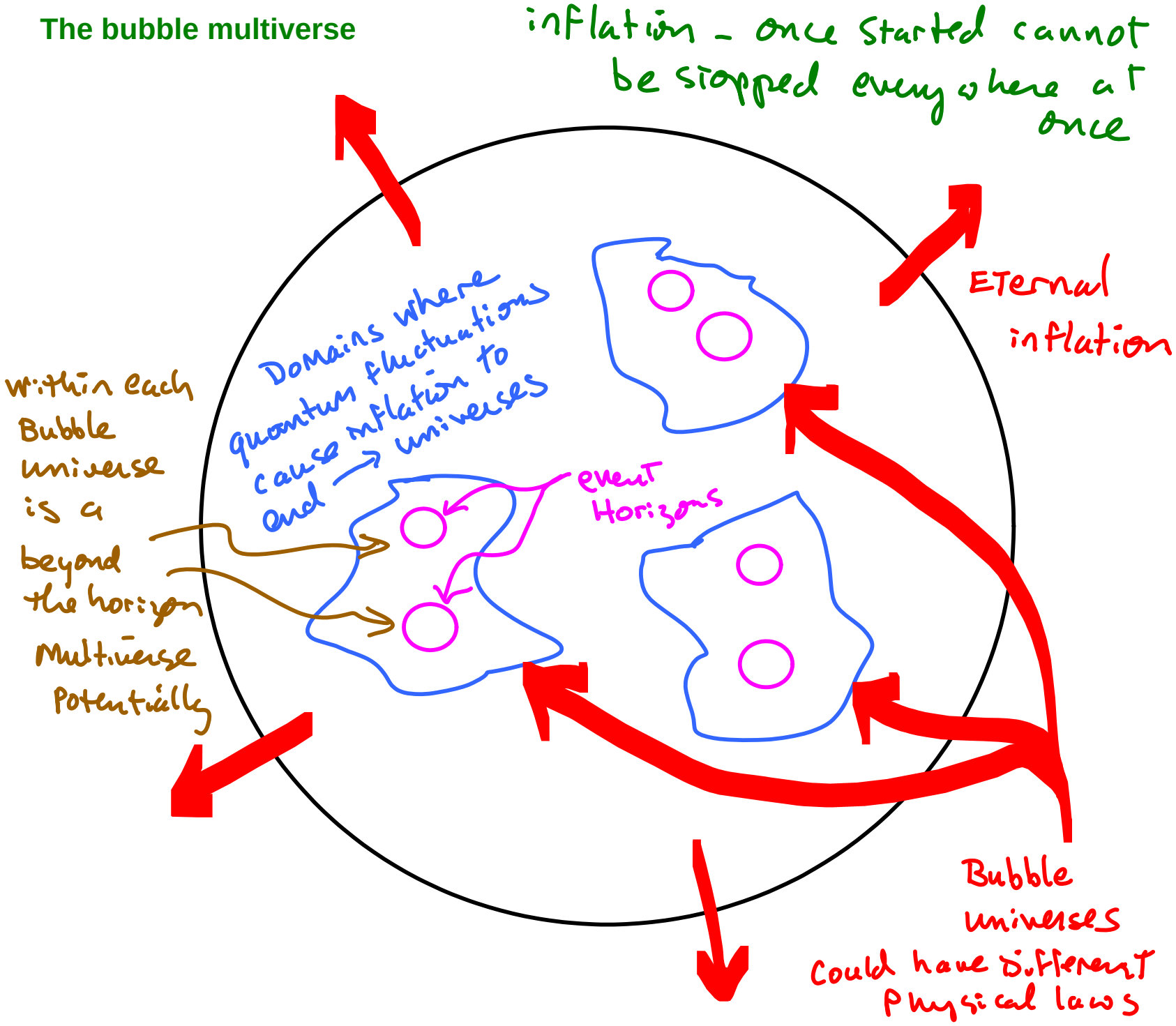
Size of fluctuations / structure in the CMB is sensitive to the geometry of the universe



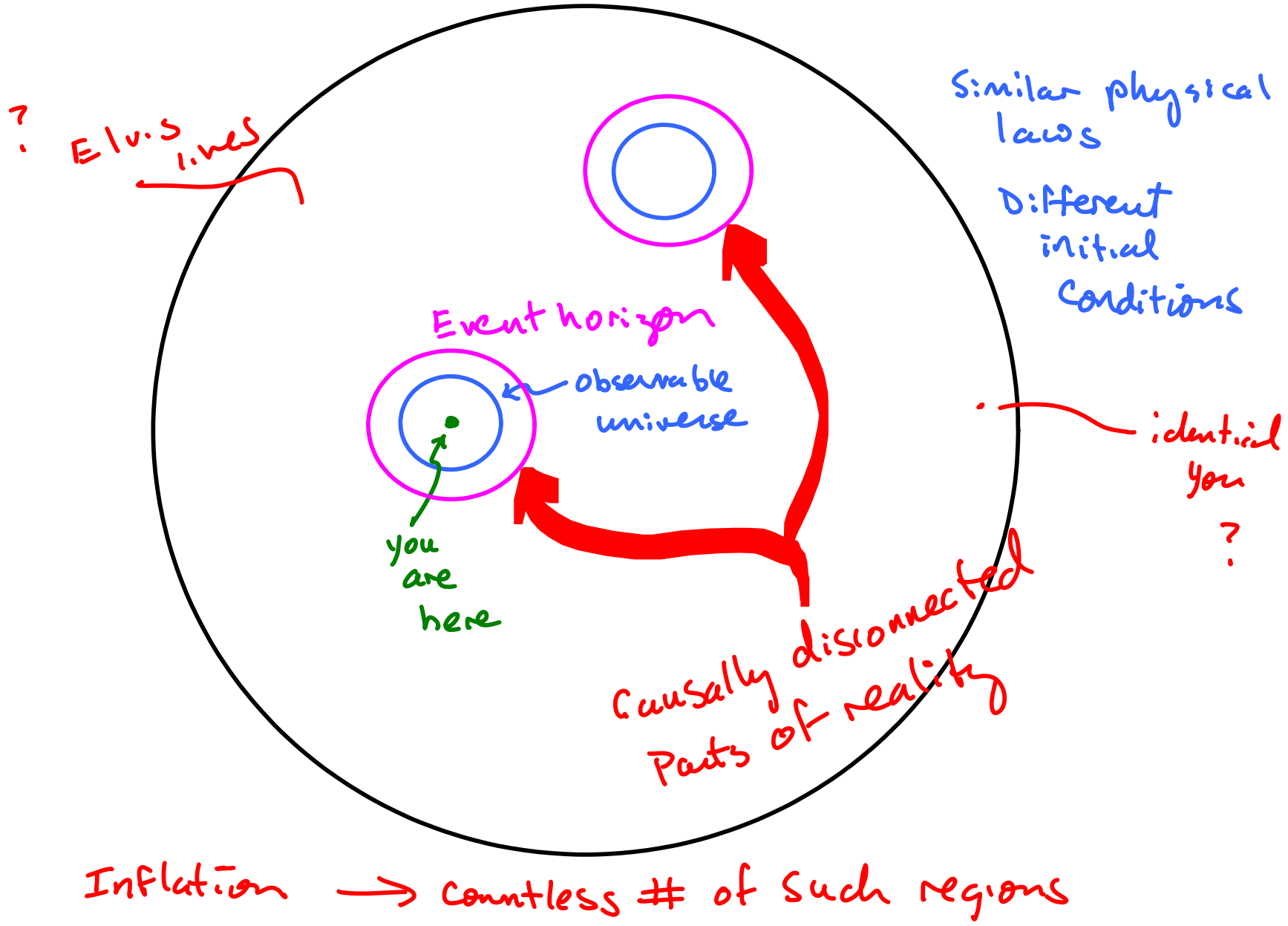



"universe"
Event Horizon
particle Horizon
Observable
universe
x
You are
here

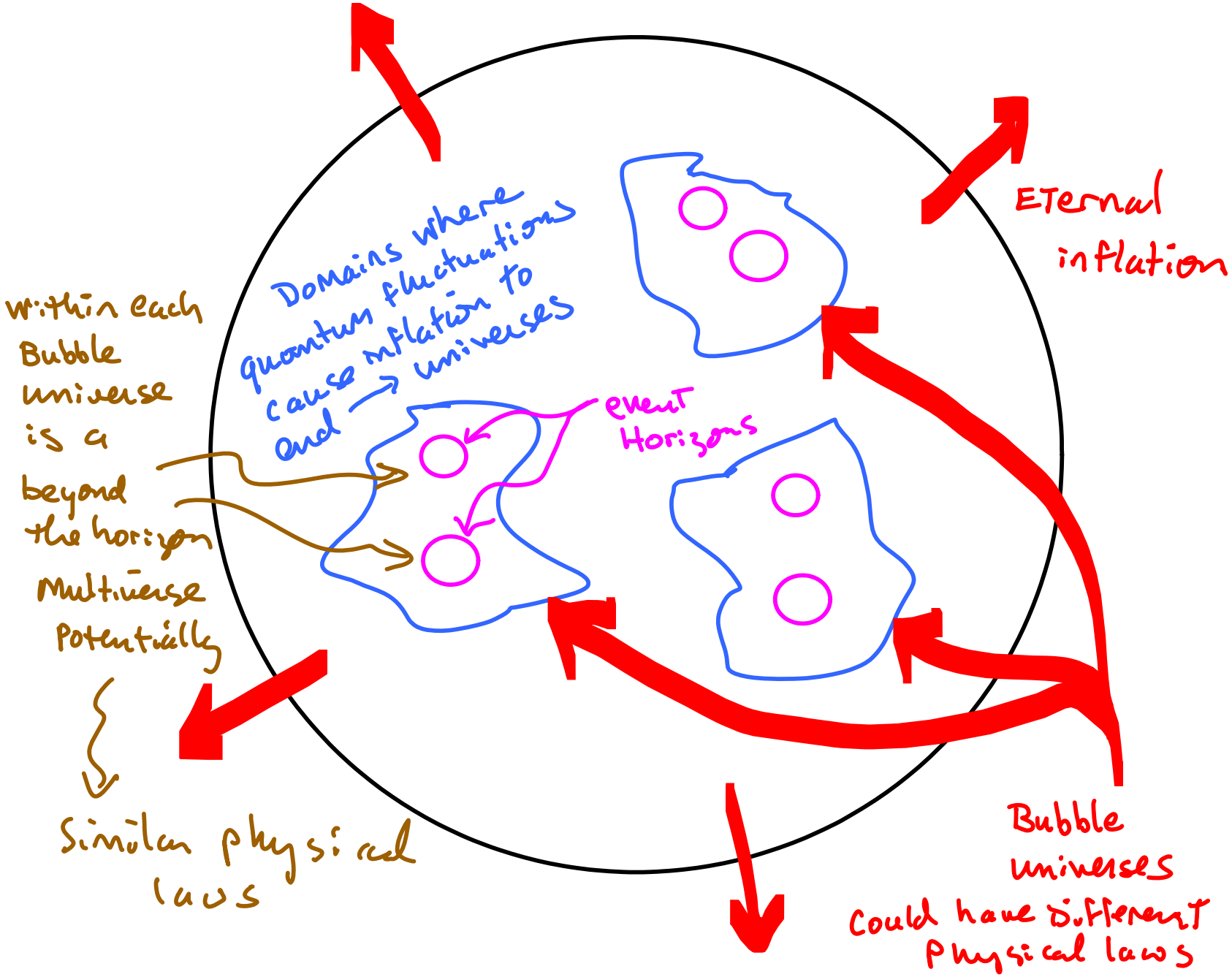
The bubble multiverse

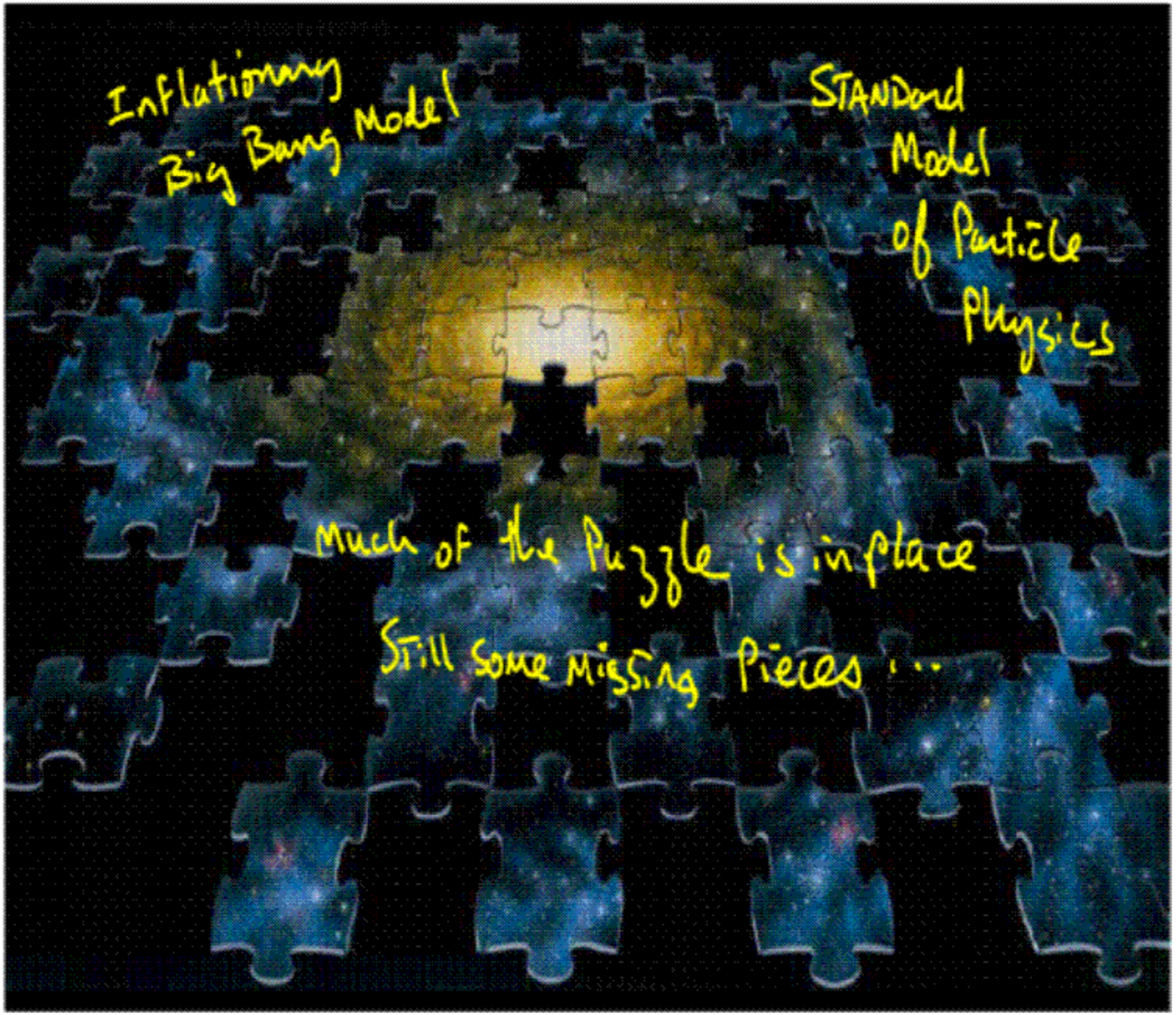


Beyond the horizon multiverse

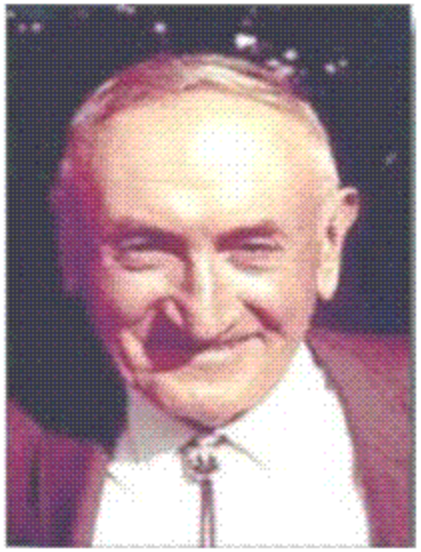


A multitude of Multiverses ....




Inflationary Big Bang Model
STANDard Model of Particle Physics
Much of the Puzzle is in place
Still some Missing Pieces ...

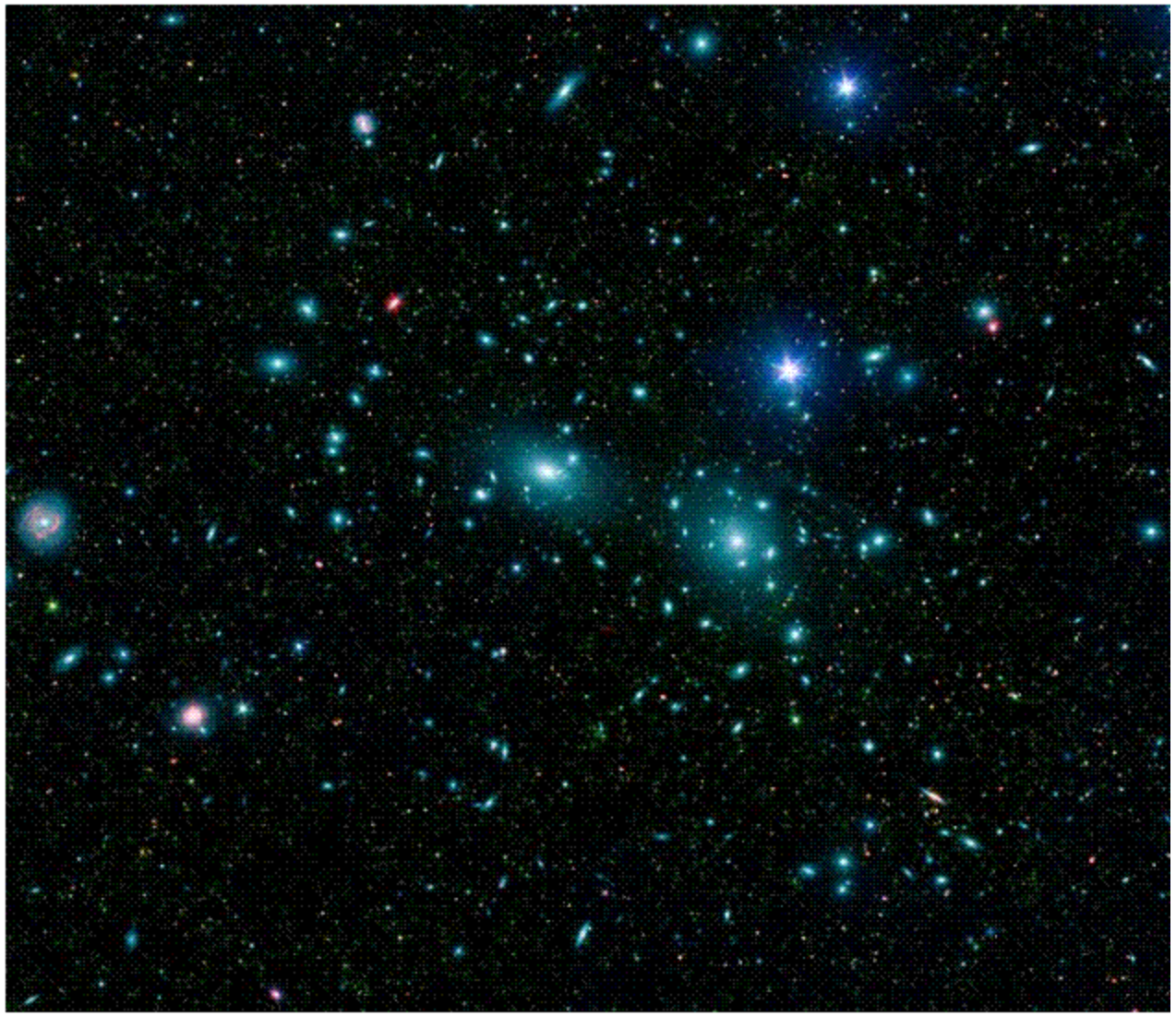
DARK MATTER



Fritz Zwicky (1898-1974)
CalTech astrophysicist

- jet engines
- "Spherical bastard"
- Suggested galaxies could act as gravitational lenses
- Dark Matter

Coma Cluster of galaxies

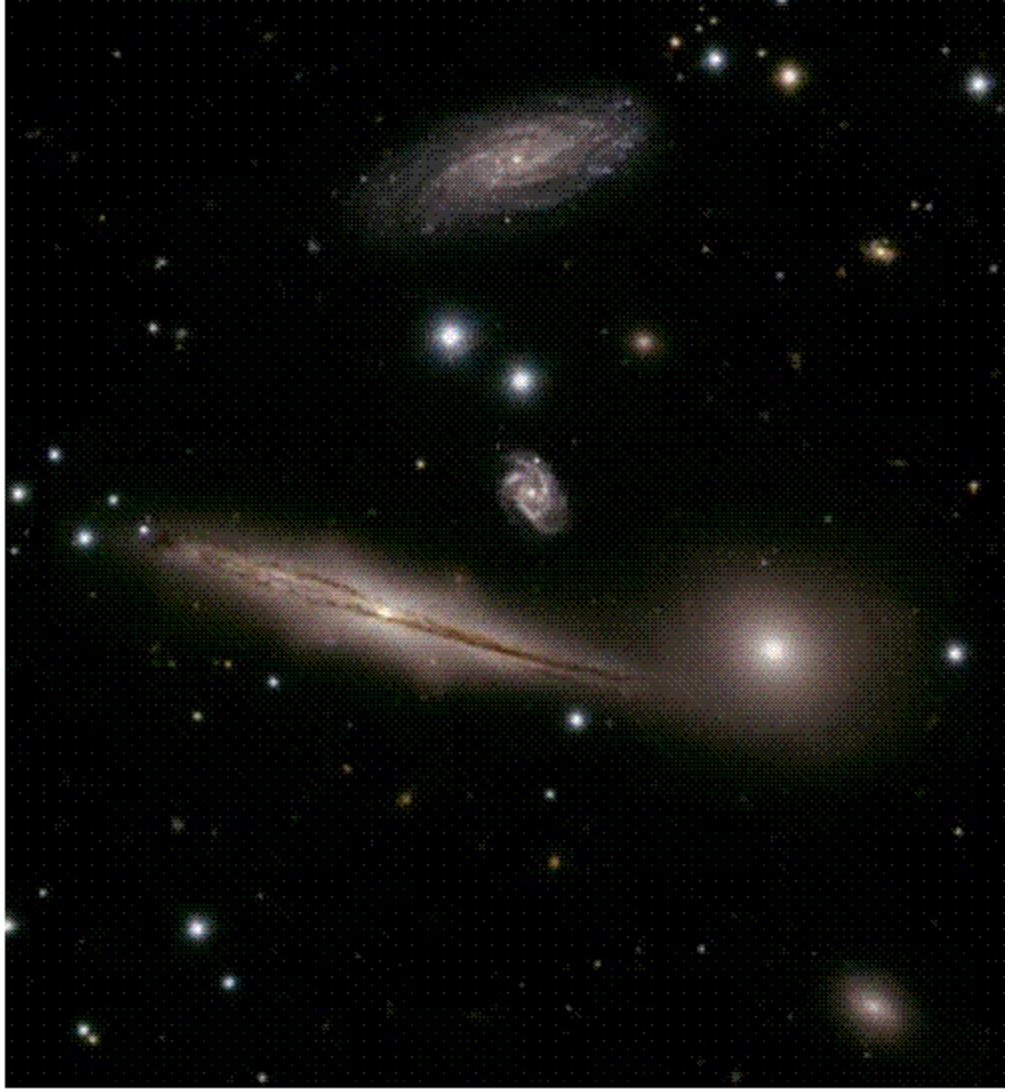


Nasa/JPL / Sloan Dig. Sky Survey

Zwicky compared mass of galactic cluster using two methods

① number + brightess of galaxies in cluster

② motion of galaxies at edge of cluster



galactic cluster

$Mass|_{method\ 2} >> Mass|_{method\ 1}$ → DARK Matter

1975

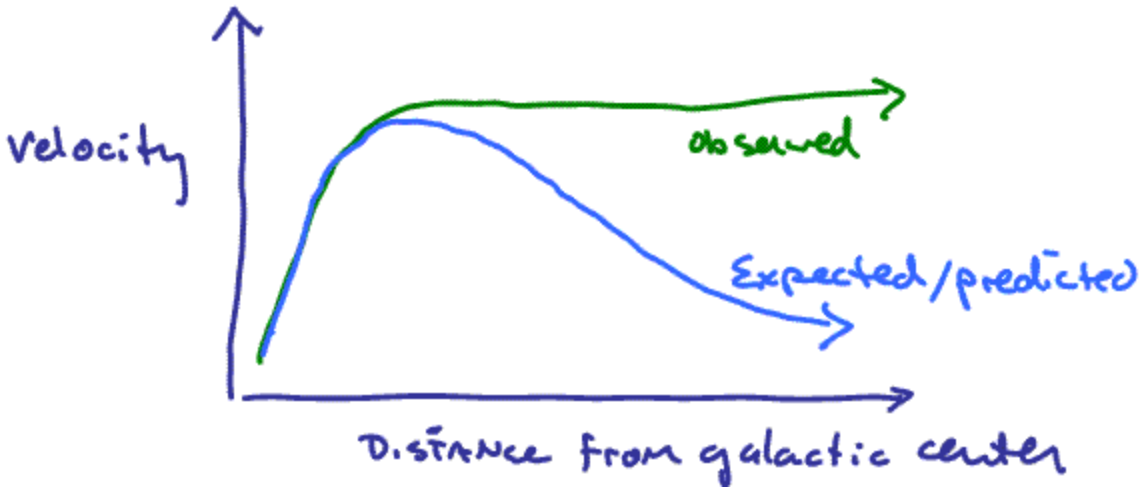
Vera Rubin

Kent Ford

Carnegie Institution of Washington

Vera Rubin

Measured velocities of stars in spiral galaxies



Dark Matter

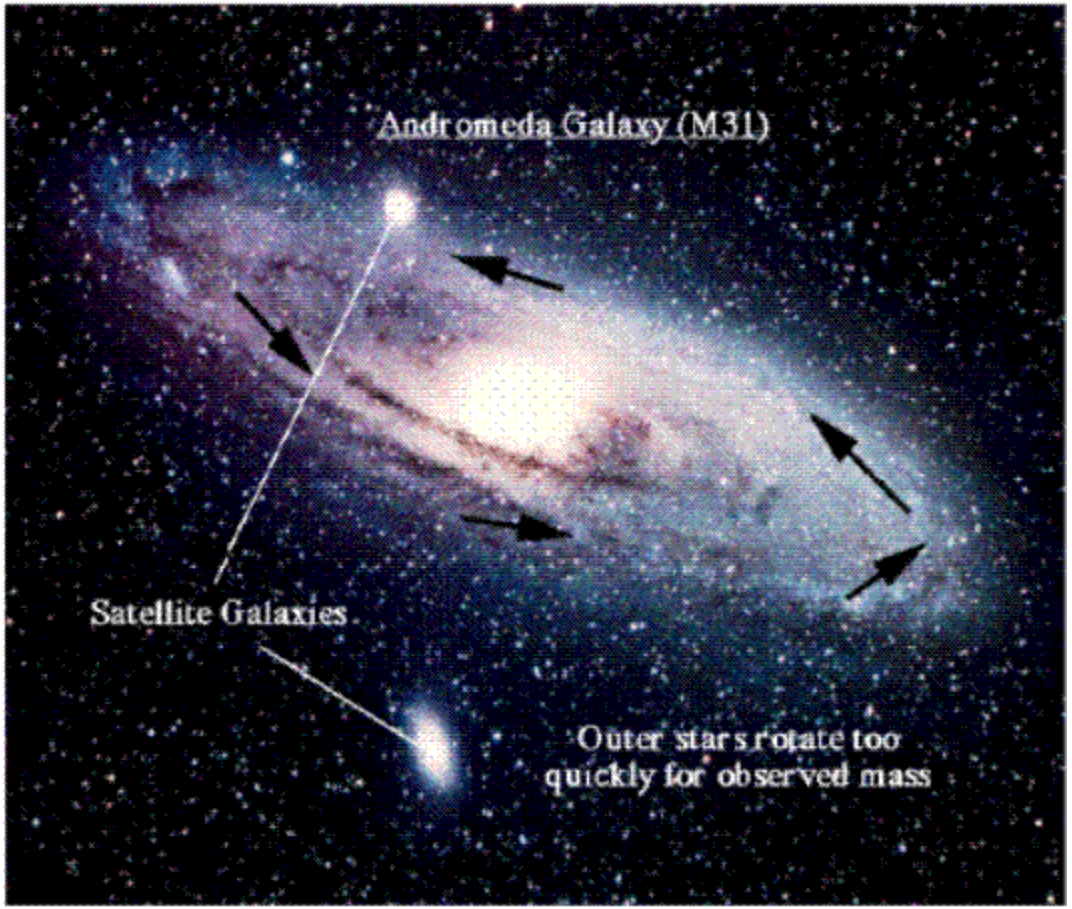
Orbits $F = \frac{mv^2}{R}$ $F = \frac{GMm}{R^2}$

Circular Motion

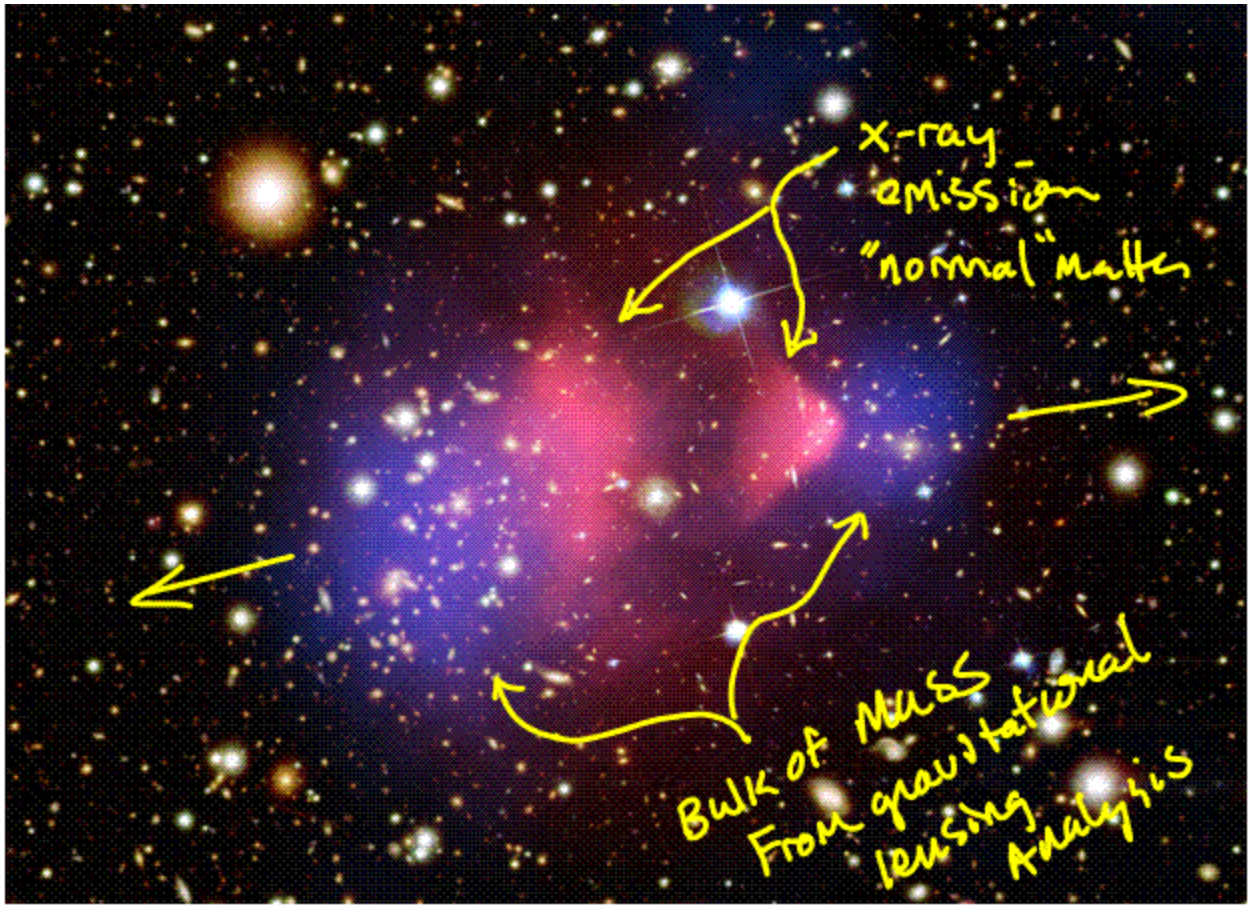
$\frac{mv^2}{R} = \frac{GMm}{R^2}$

Can relate velocity radius and force in orbits.

Have seen that orbits in stars and galactic clusters Require Stronger Gravitational force than can be explained by conventional Observable "visible" matter



-P. Cashman

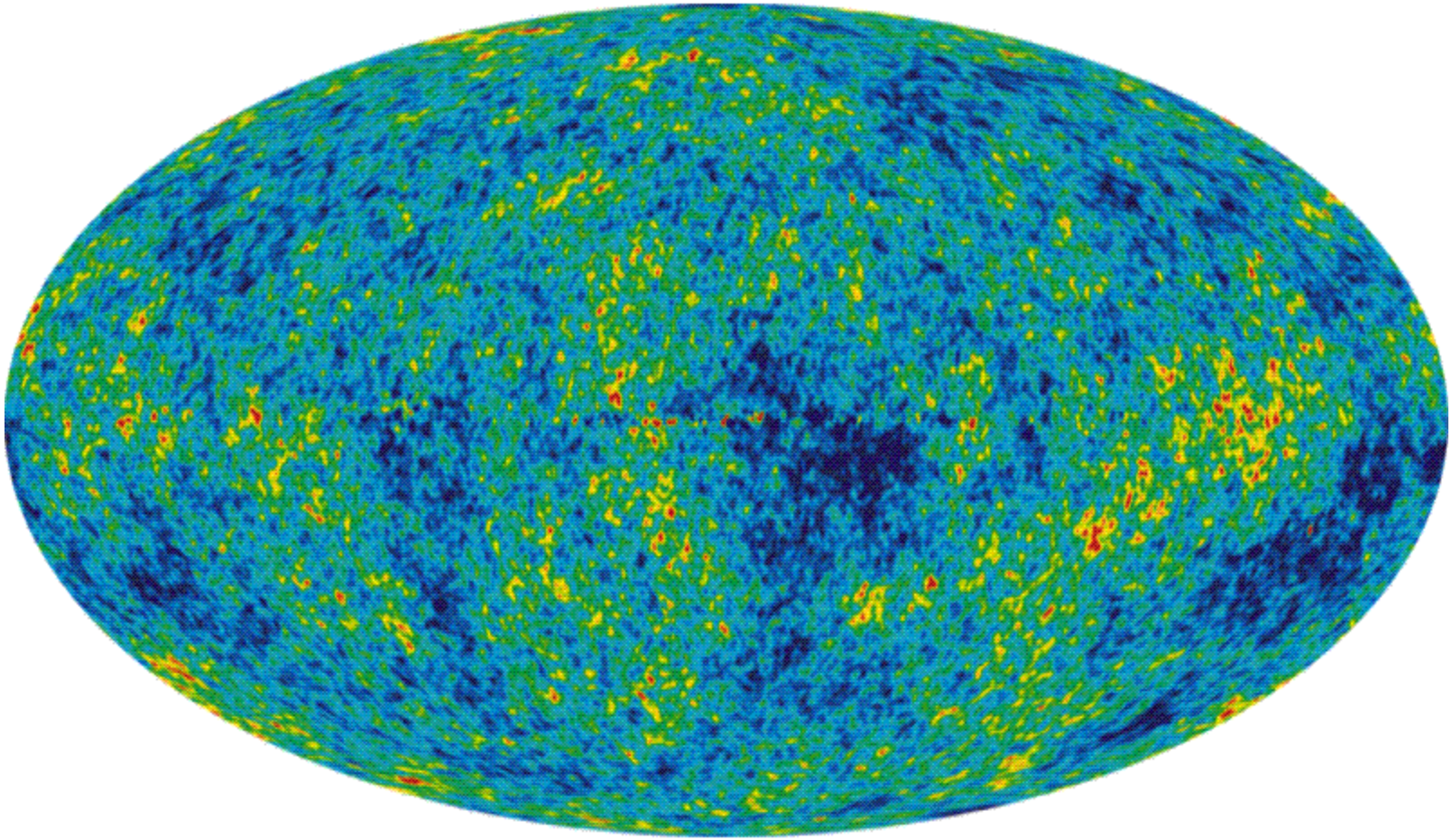


Bullet cluster
colliding galactic clusters

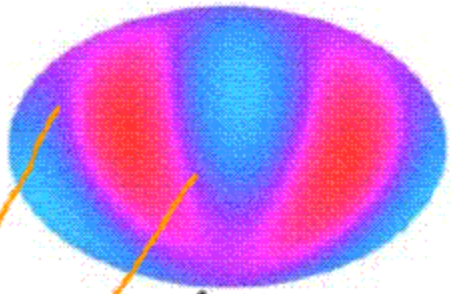
galaxies + Dark Matter
zip past

intergalactic gas slowed down

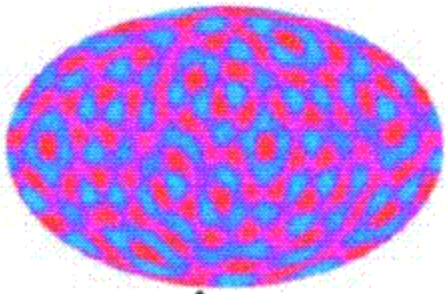
The universe at $t = 400{,}000$ years



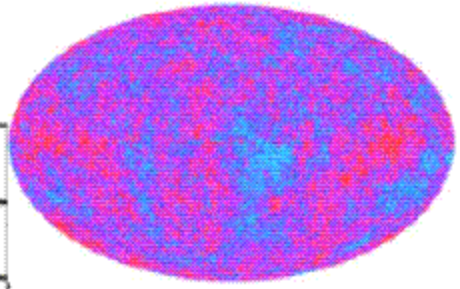
Cosmic Microwave Background from WMAP

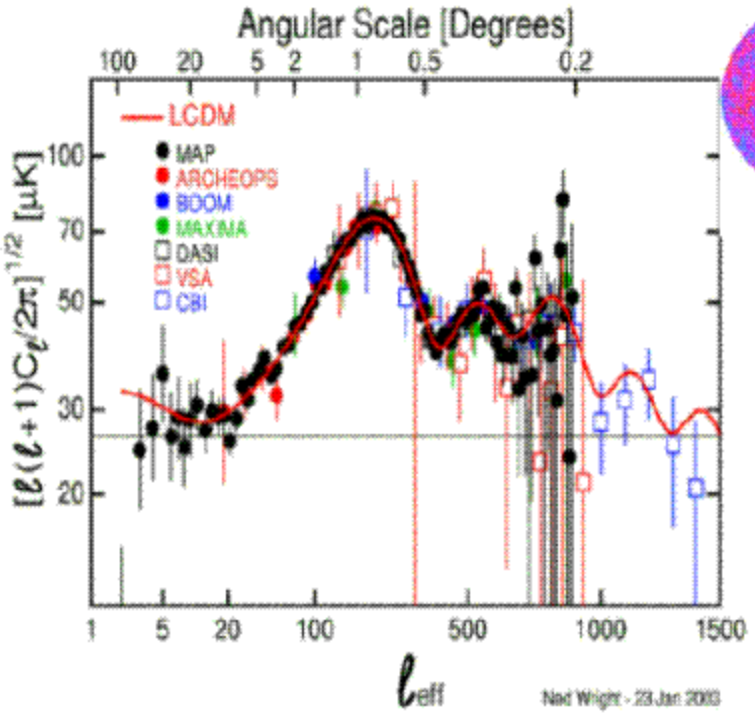


$\ell = 2$



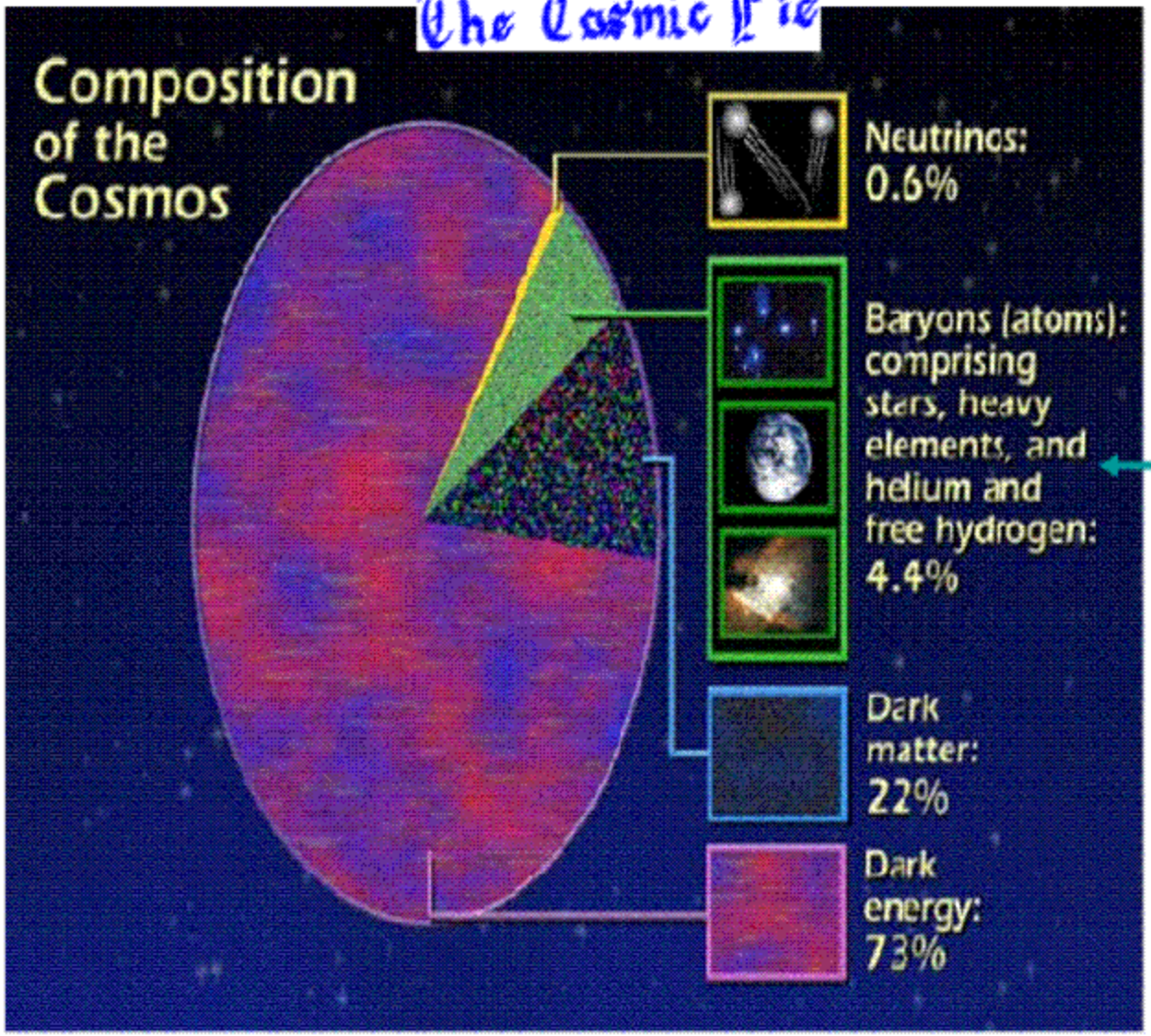
$\ell = 16$





"Power spectrum" (size) of temperature fluctuations sensitive to different matter/energy components of the universe

The Cosmic Pie



95% of the universe is unknown!

figure from E. Linder LBL