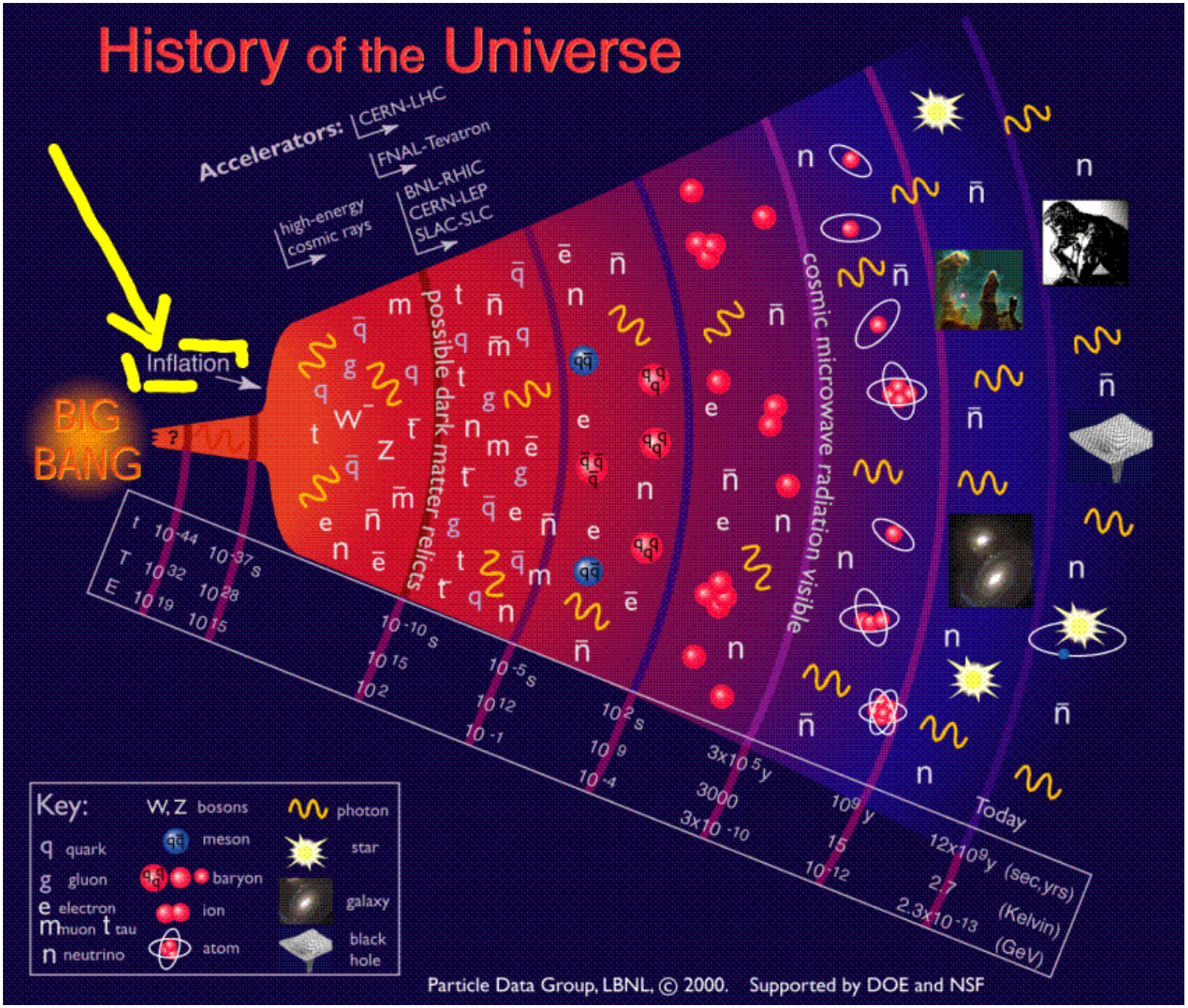
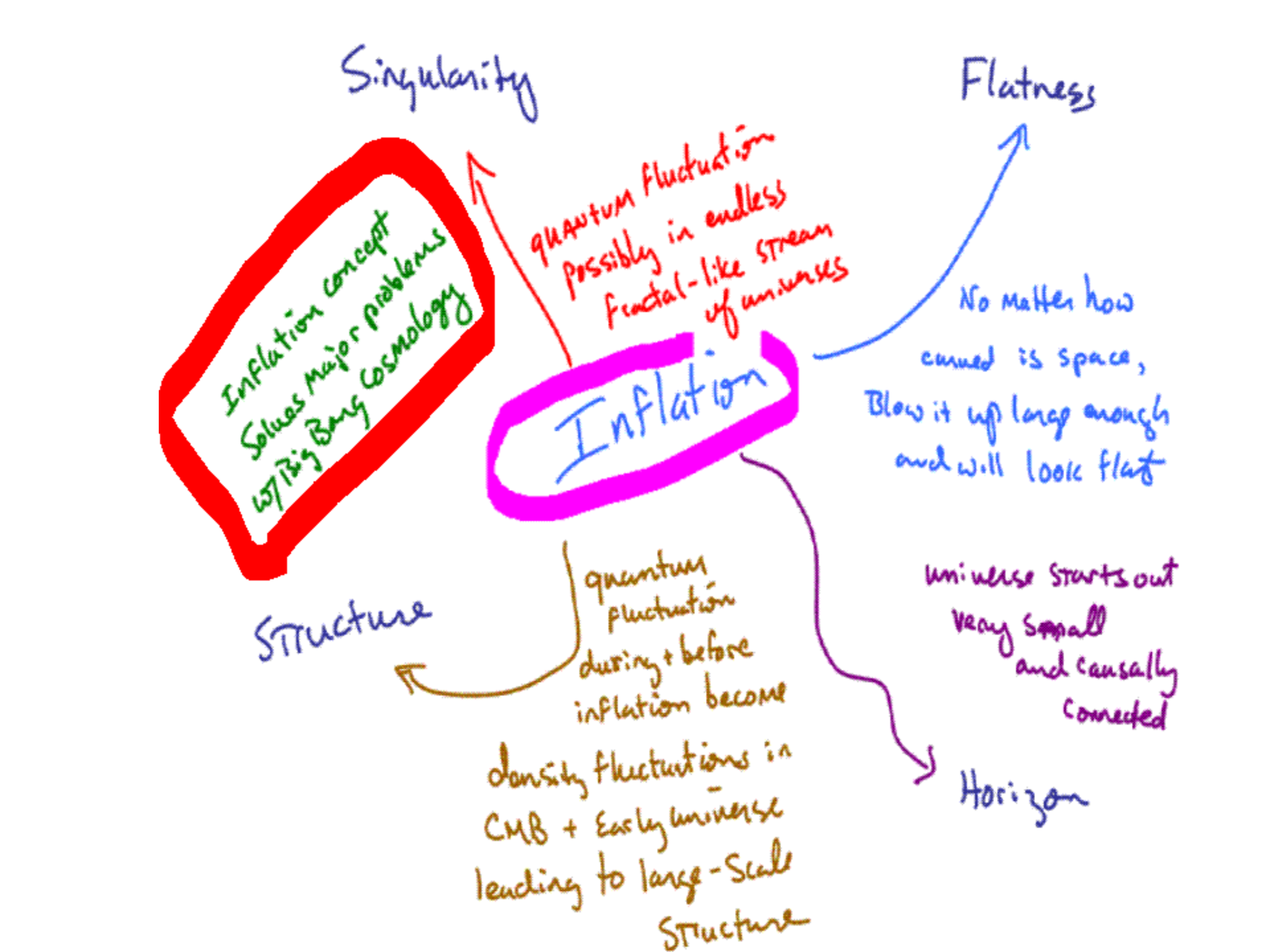
Physics 102 - November 30, 2009

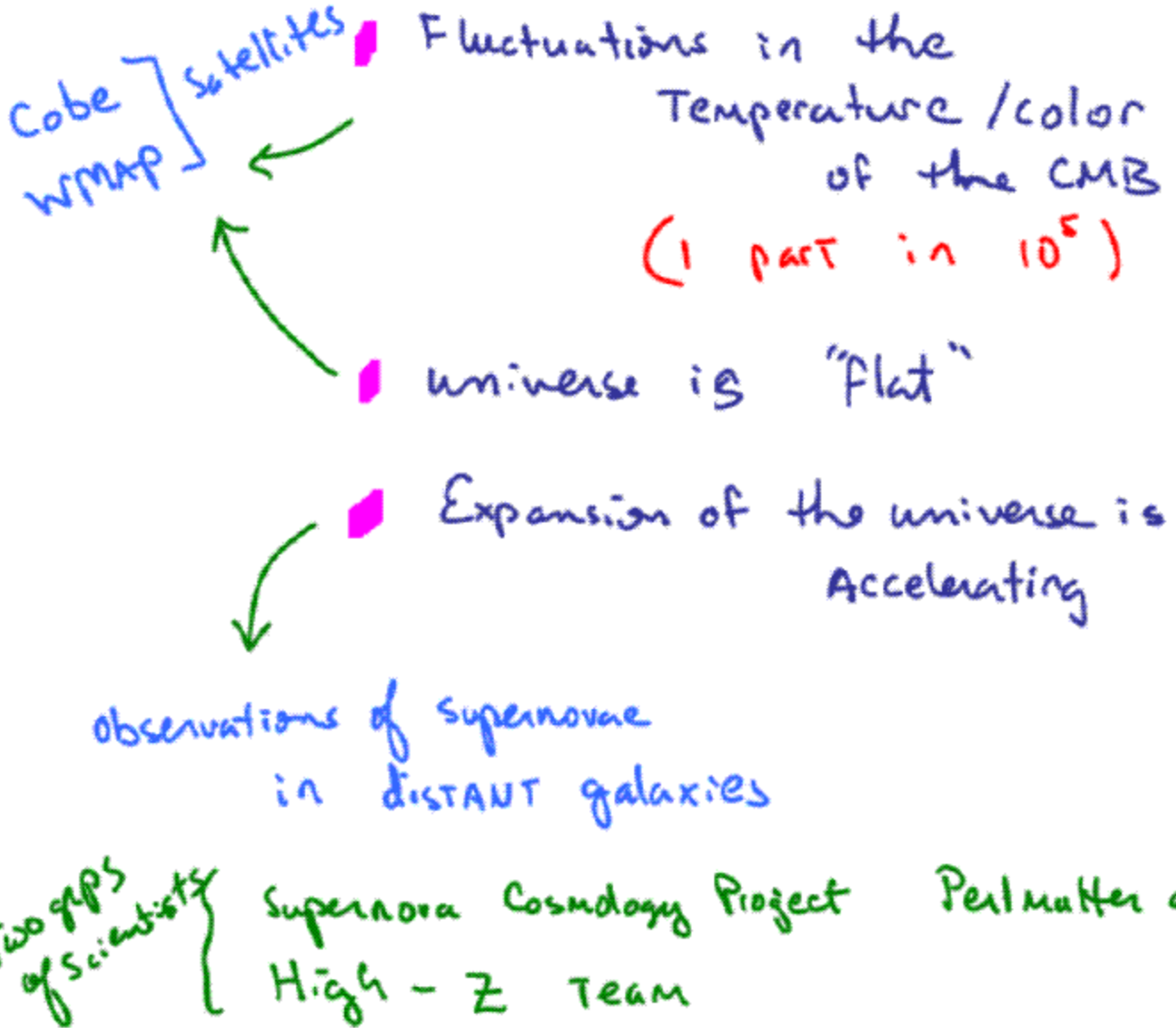
- No Recitation today
- Much reading posted
- Projects
- Exam graded


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
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
1015
102
10-5 s
1012
10-1
102 s
109
10-4
3x105 y
3000
3x10-10
109 y
15
10-12
12x109 y (sec, yrs)
2.7
2.3x10-13
(Kelvin)
(GeV)
Today
Key:
W, Z bosons
q quark
g gluon
e electron
m muon t tau
n neutrino
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

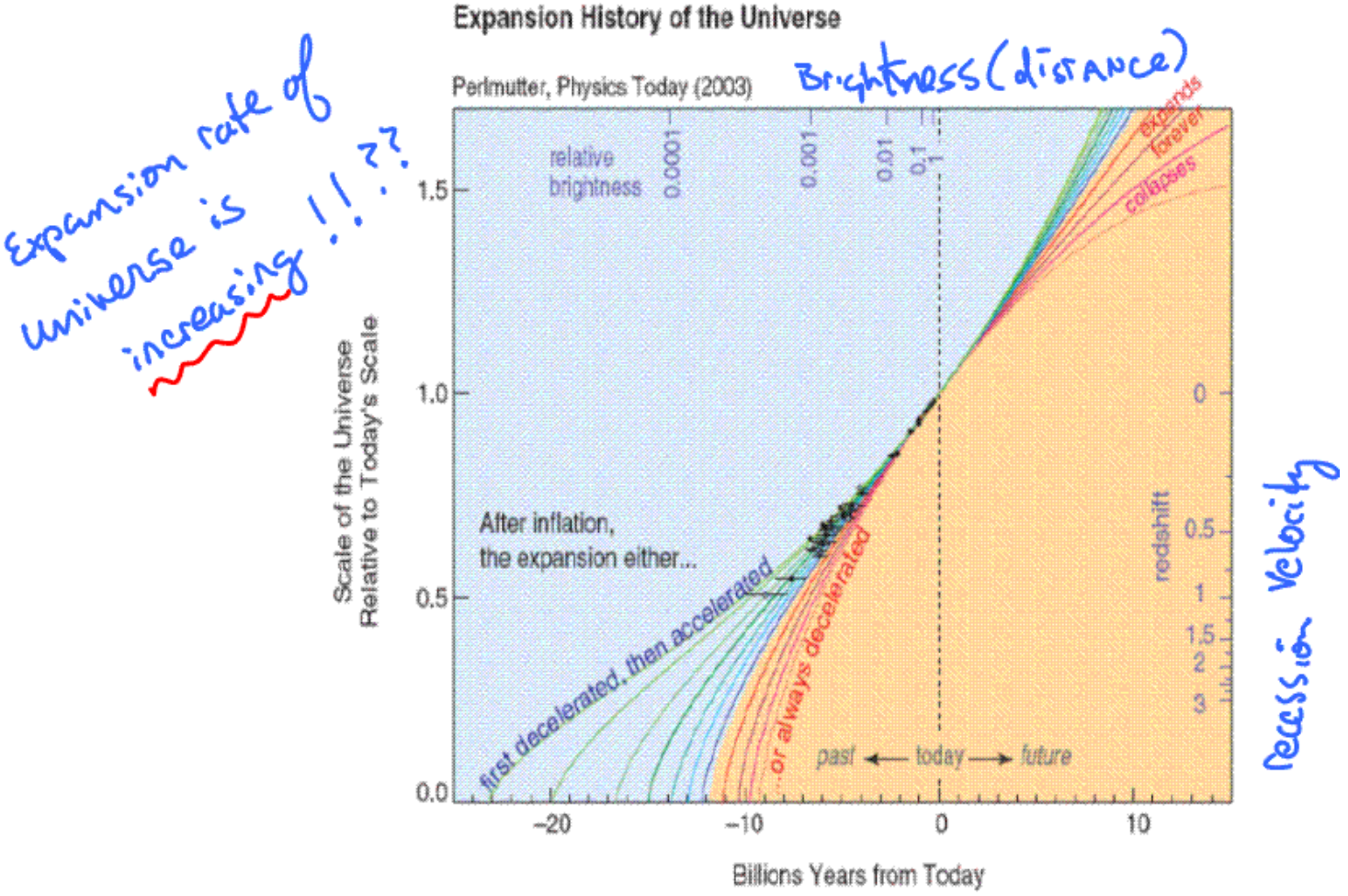
Cosmology Has Arrived!


Singularity
Flatness
Inflation concept
Solves major problems
w/ Big Bang Cosmology
quantum fluctuations
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

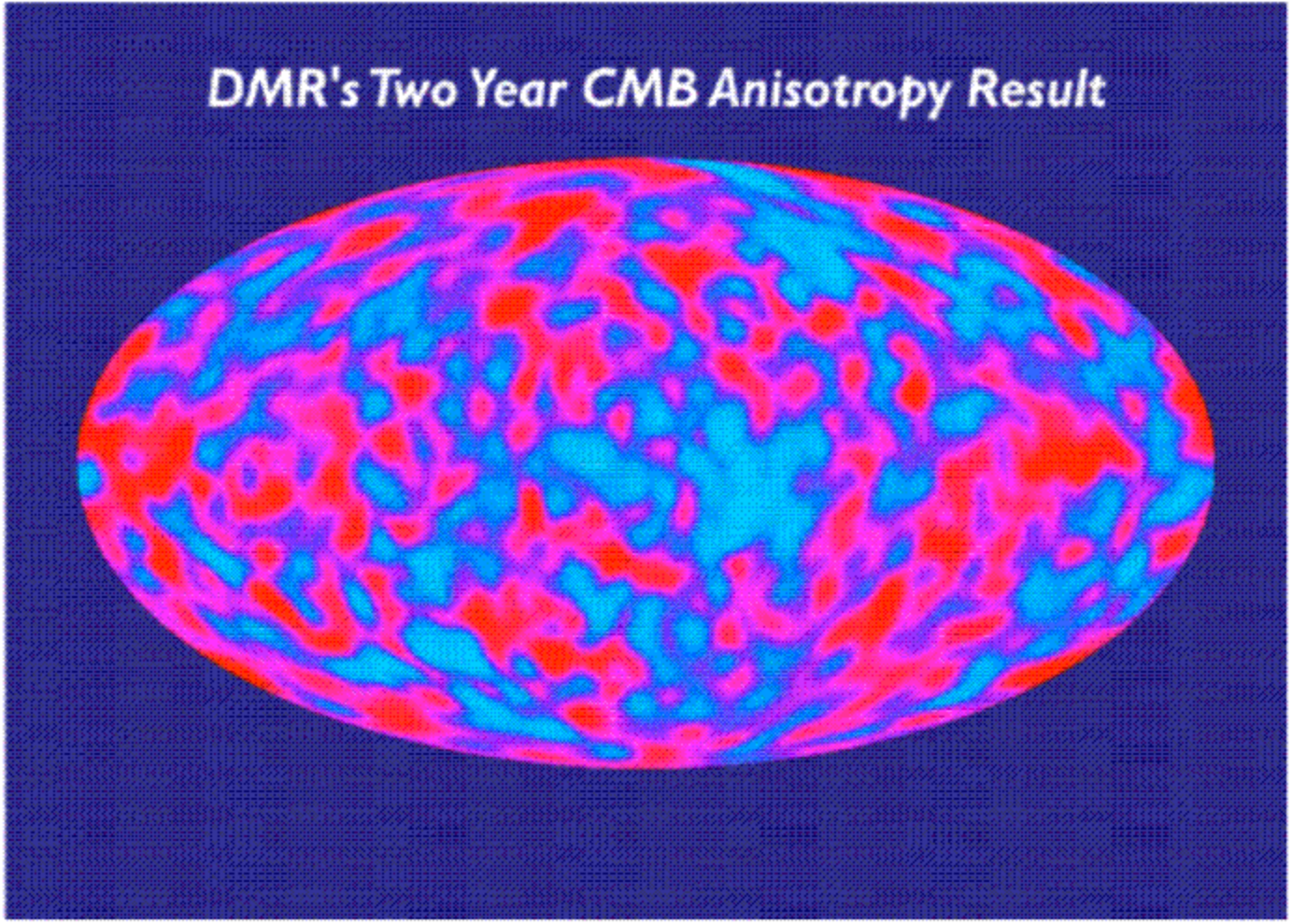
Incredible new data in the last 10 years



Do "Hubble" study velocity vs. distance over vast distances (Time) by using Supernovae as "standard candles"



Expansion rate of Universe is increasing!!??



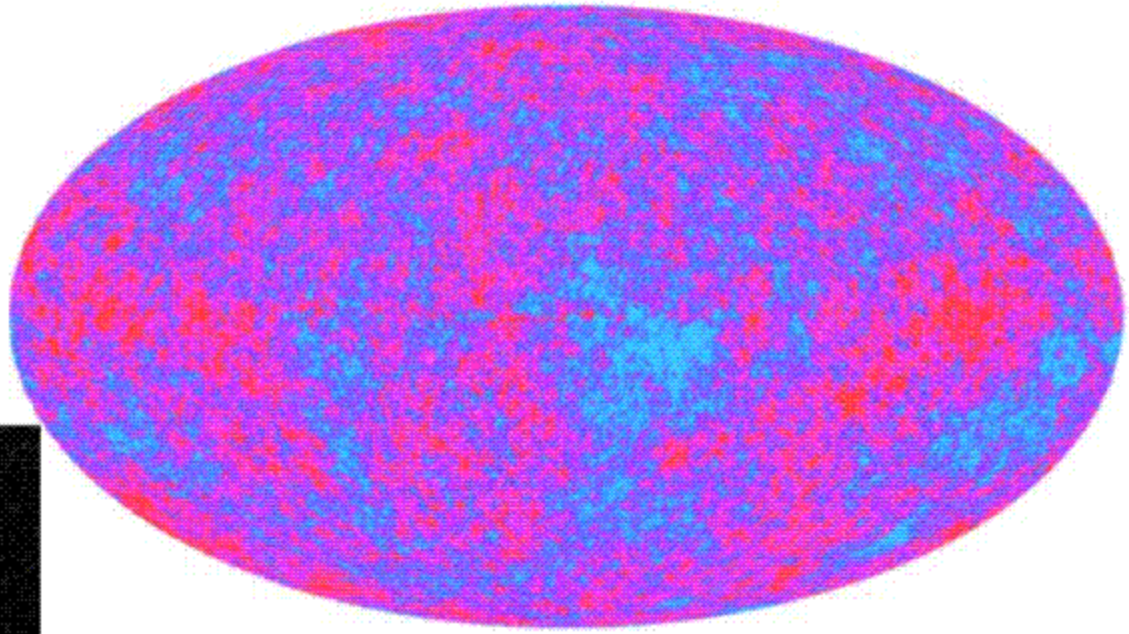
CMB "color" or Temperature seen to vary by 1 part in 100,000

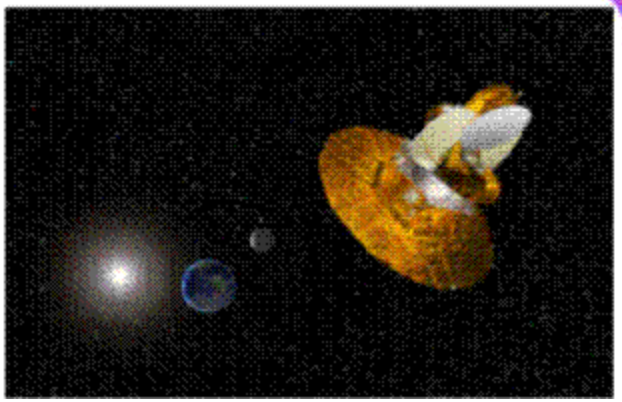
1992 COBE Satellite observation of CMB over all Sky

Cosmic Background Explorer

WMAp - Wilkinson Microwave Anisotropy Probe

(2003) High Resolution Study of CMB

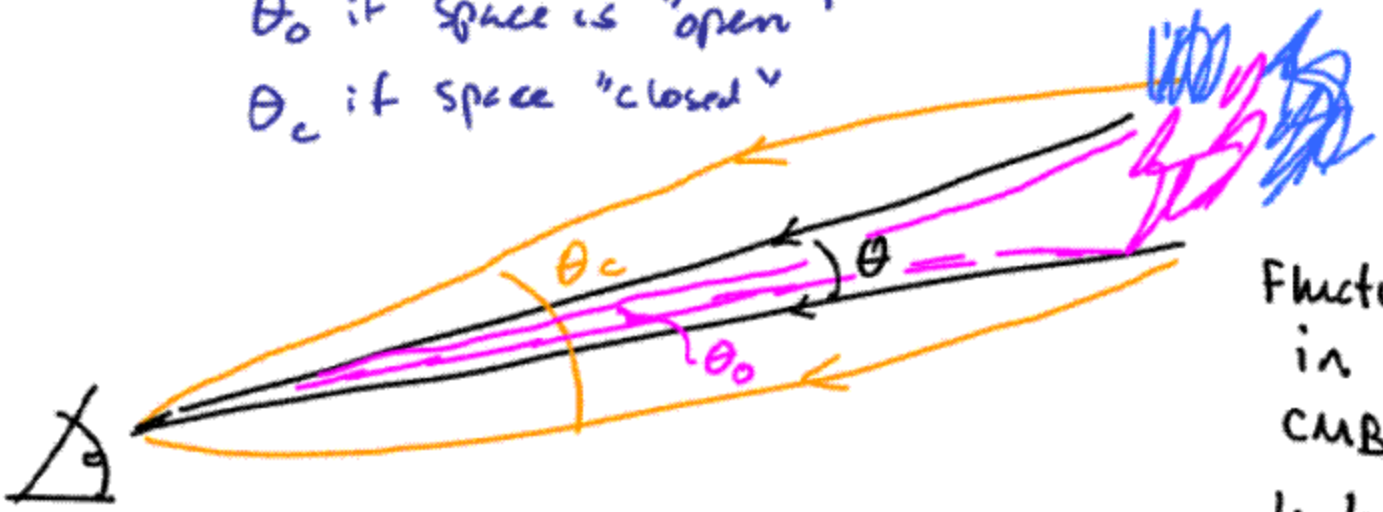




Measure θ_f if space is flat

θ_o if space is "open"

θ_c if space "closed"

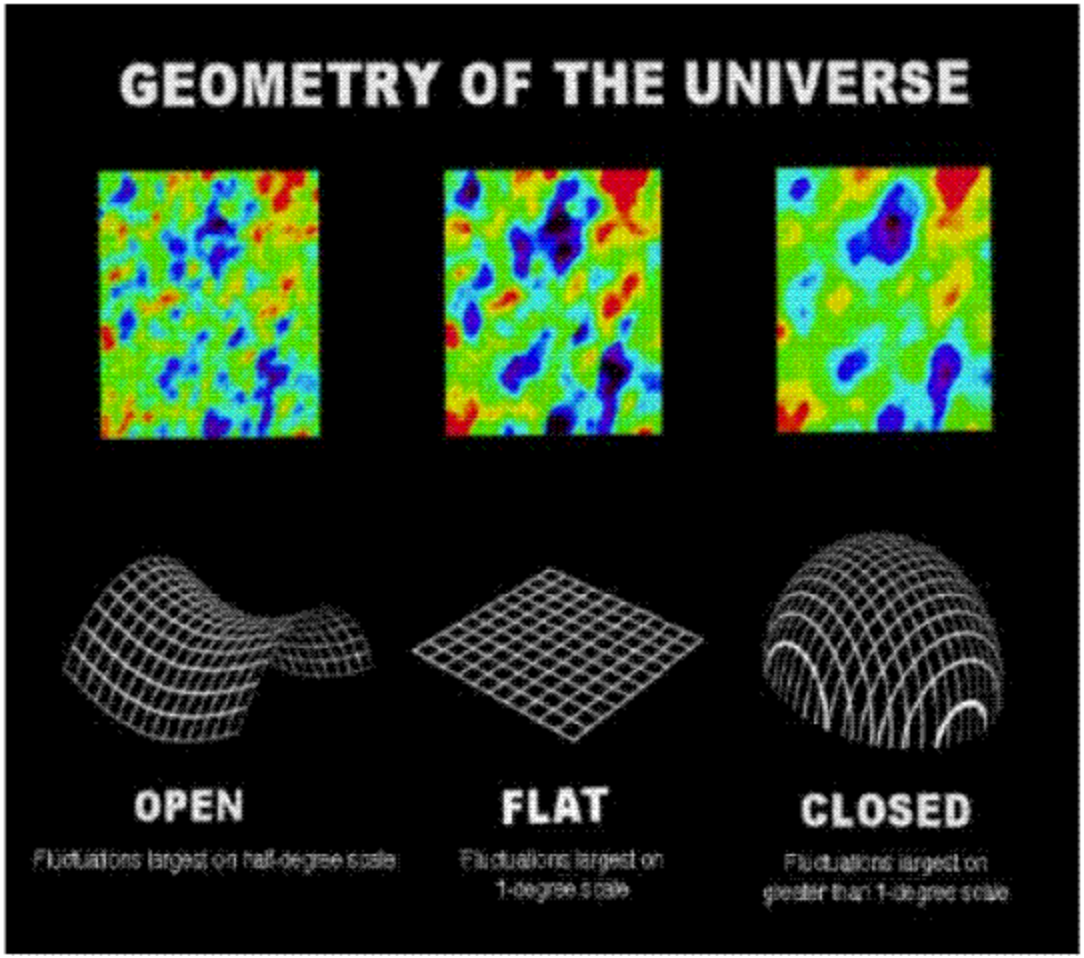


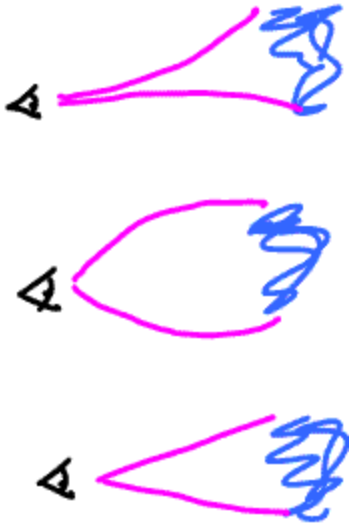
Fluctuations in CMB - light comes to us from DISTANCE of (Age of universe - 100,000) light years

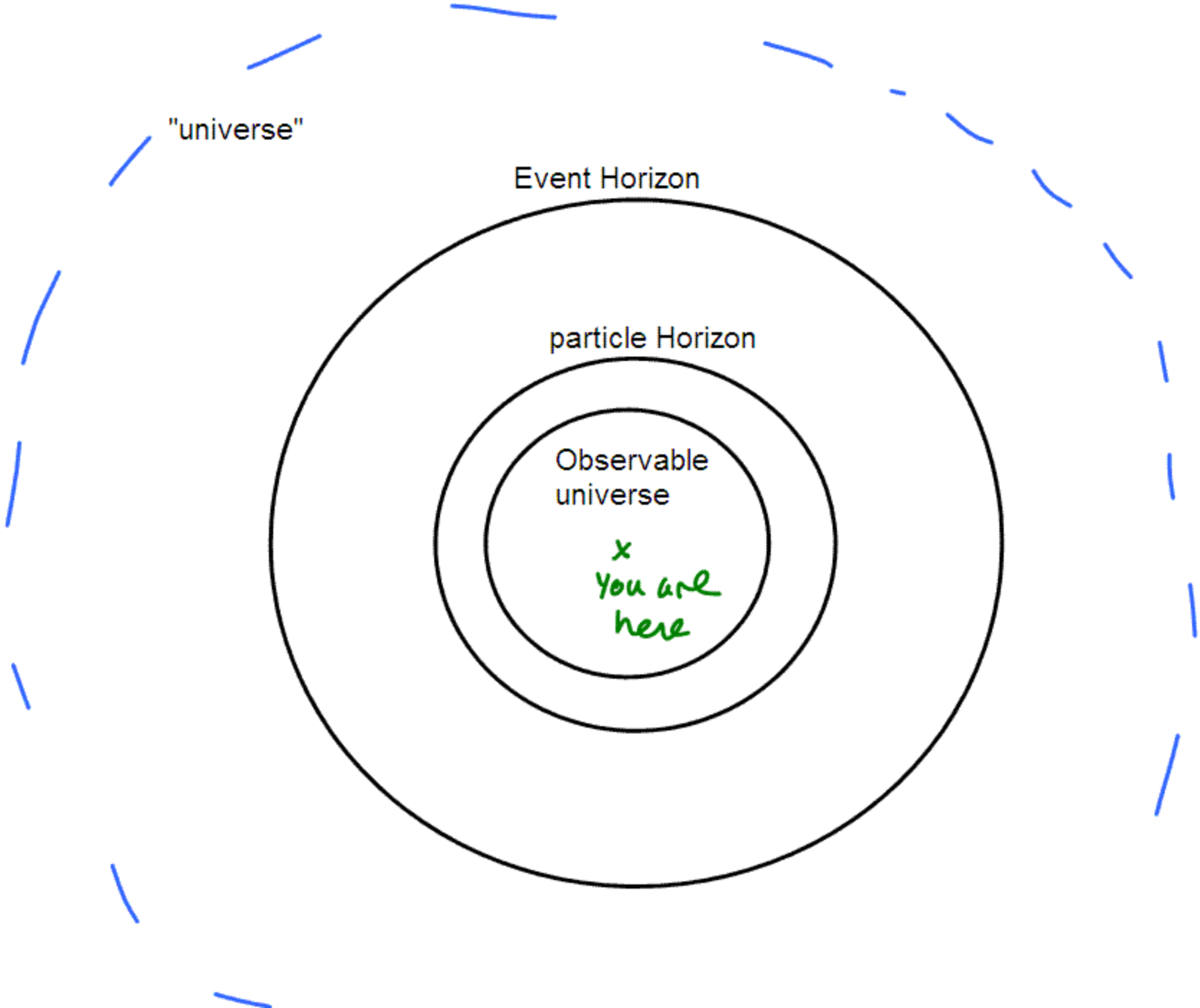
LOOK at Angular Size of fluctuations in CMB

PATH light takes depends on geometry of universe. We measure different Angular Sizes depending on geometry of space between

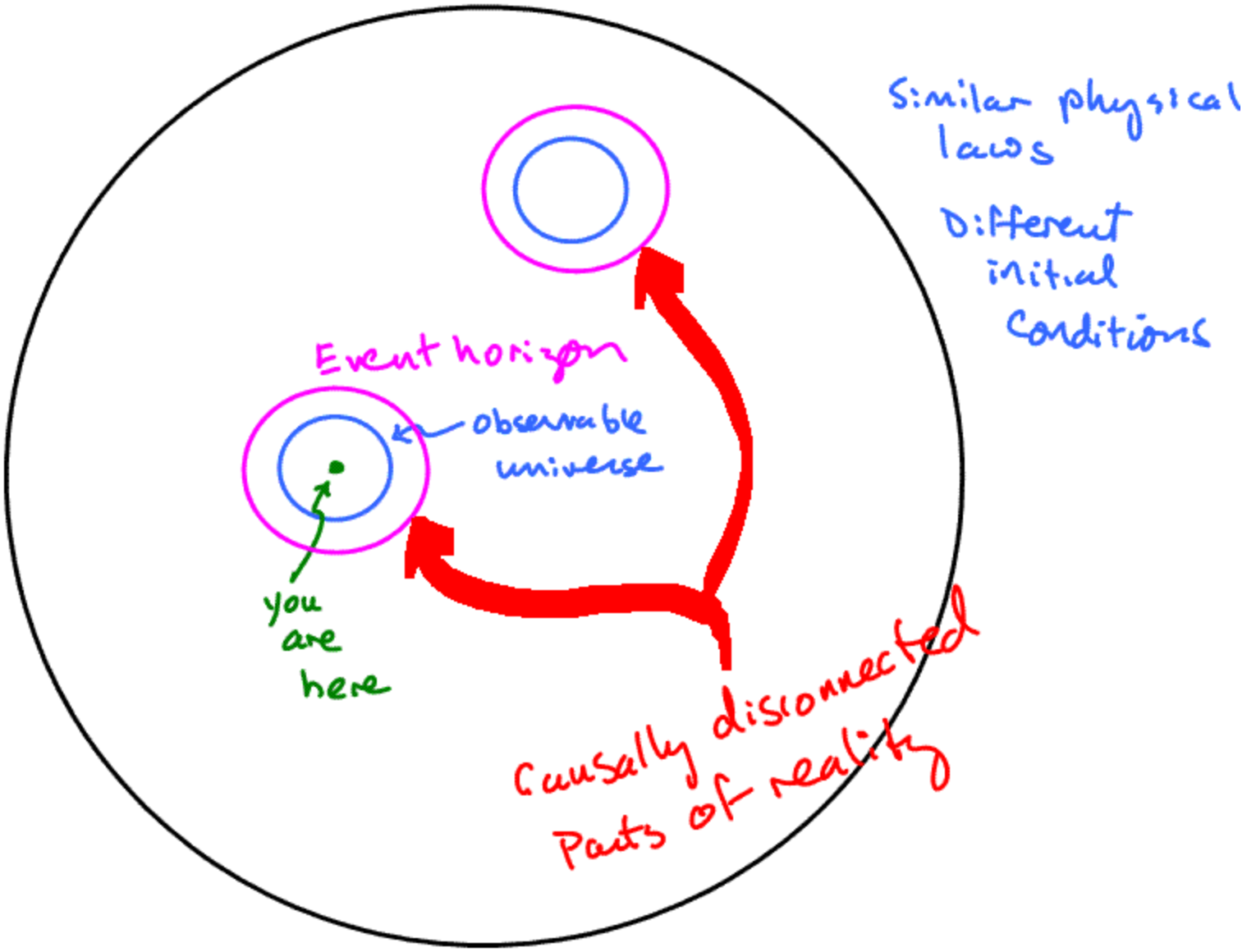
Size of fluctuations / structure in the CMB is sensitive to the geometry of the universe



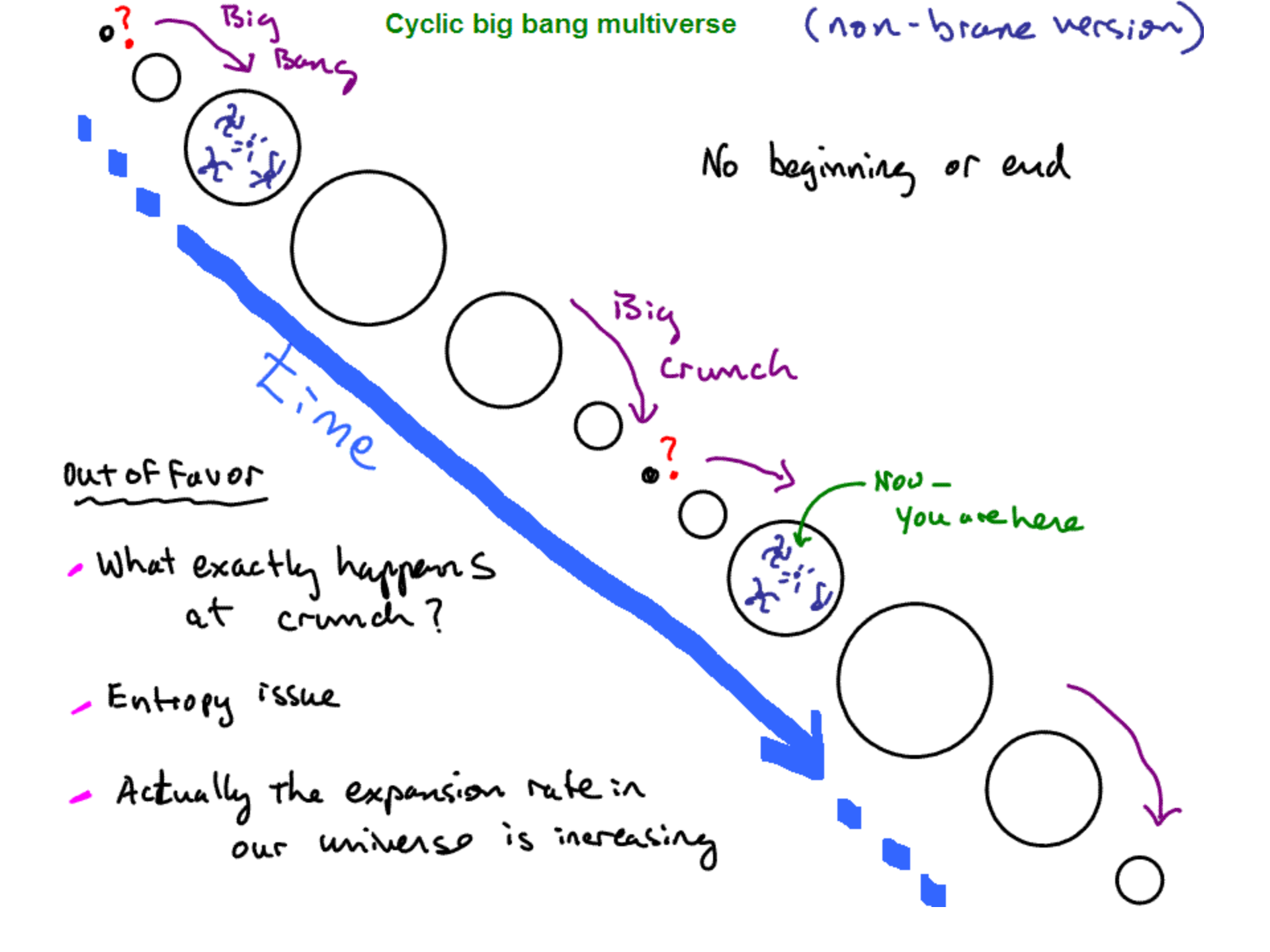



"universe"
Event Horizon
particle Horizon
Observable
universe
x
You are
here

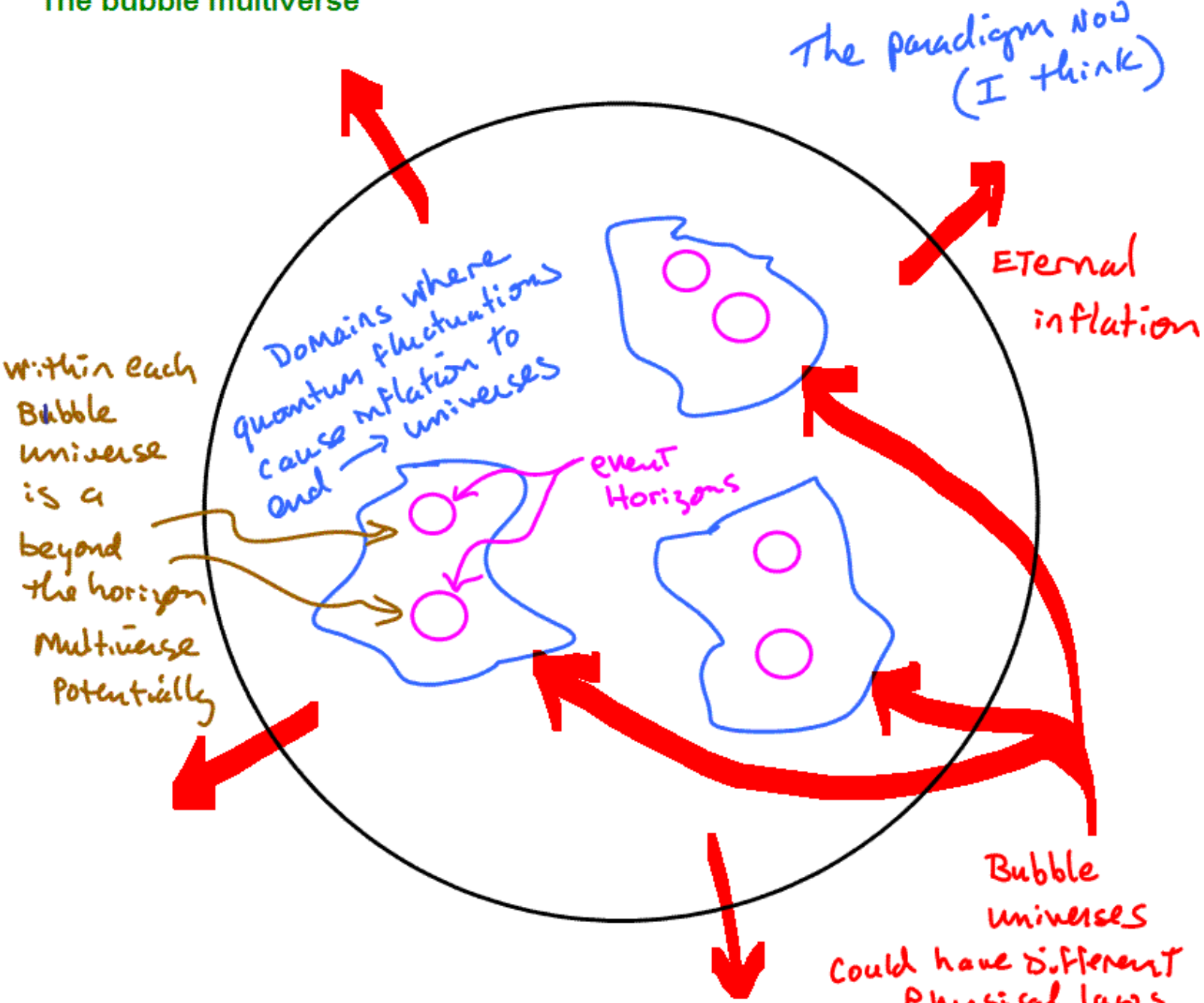
Beyond the horizon multiverse



Inflation → countless # of such regions


Cyclic big bang multiverse
(non-brane version)
?
Big Bang
No beginning or end
Time
Big crunch
?
Now – You are here
Out of favor
- What exactly happens at crunch?
- Entropy issue
- Actually the expansion rate in our universe is increasing

The bubble multiverse

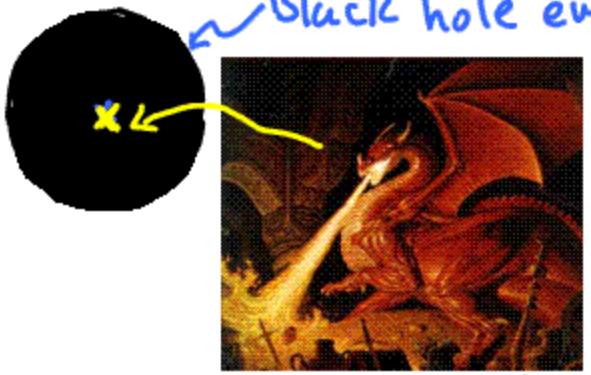


The bouncing black hole multiverse - cosmological natural selection

Also Fecund universes
↑ Fruitful in offspring

Lee Smolin
"The Life of the Cosmos"
Oxford Univ. Press 1997

What happens inside a Black hole?

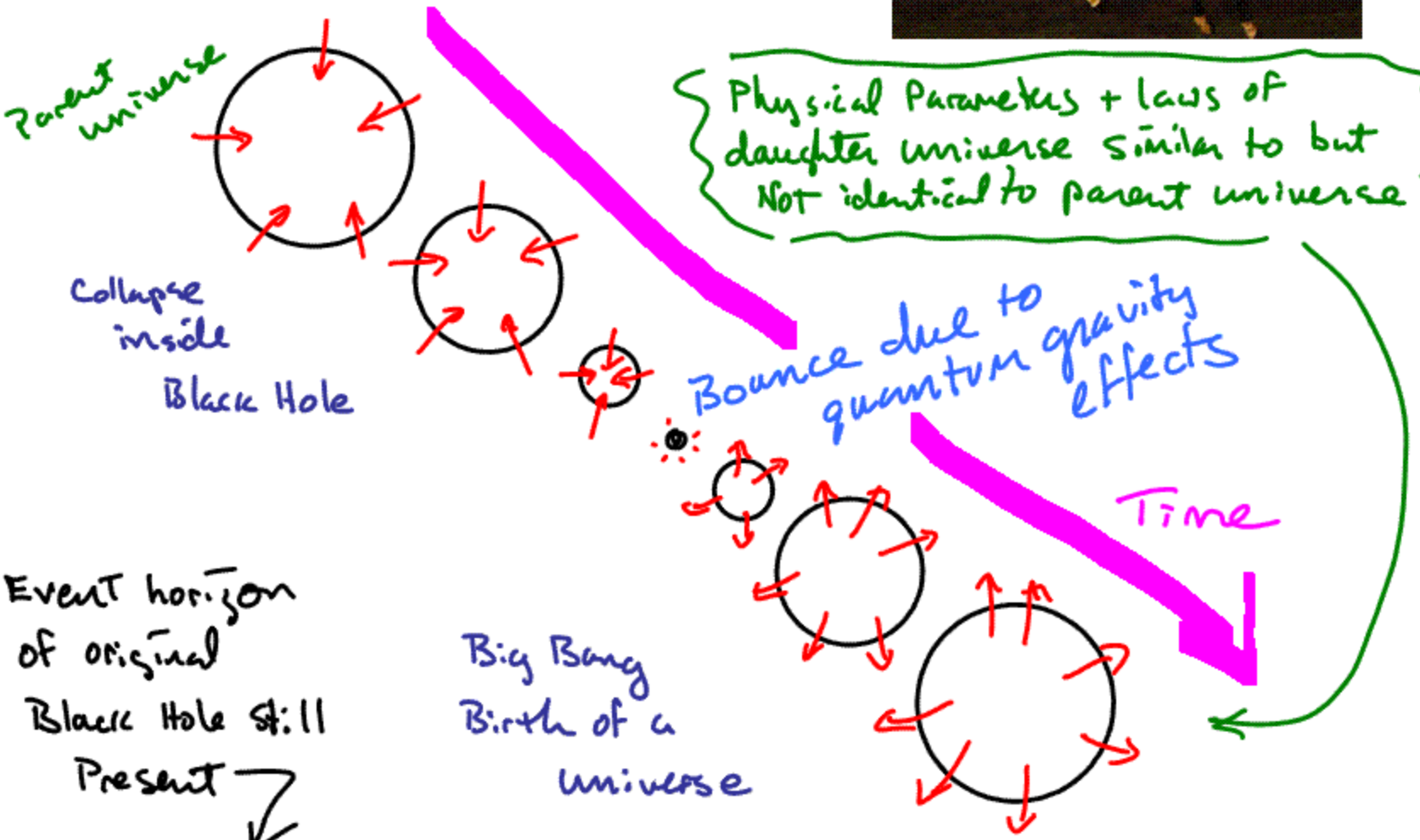


Beasts Dwell here
→ Singularity

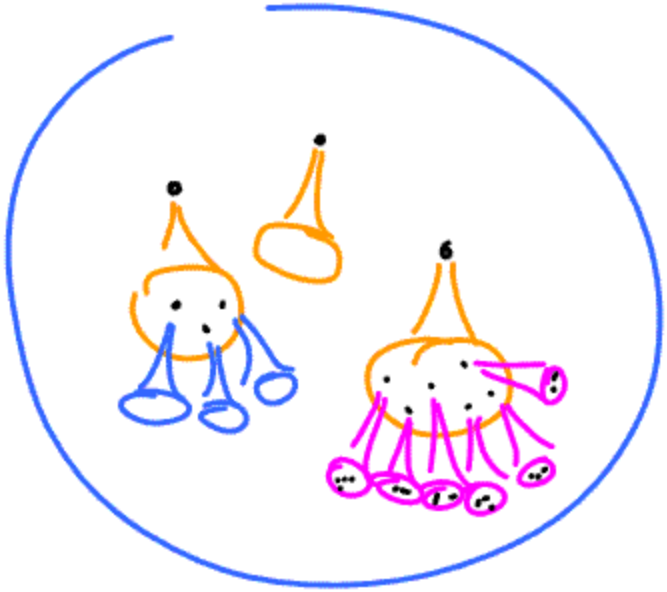
Classical general relativity:
curvature of spacetime is ∞
Physics as we know it ends

Quantum gravity to the rescue?

Physical Parameters + laws of daughter universe similar to but NOT identical to parent universe?



Cosmological Natural selection



Parameters of universes in the greater cosmos will evolve toward optimal production of Black holes

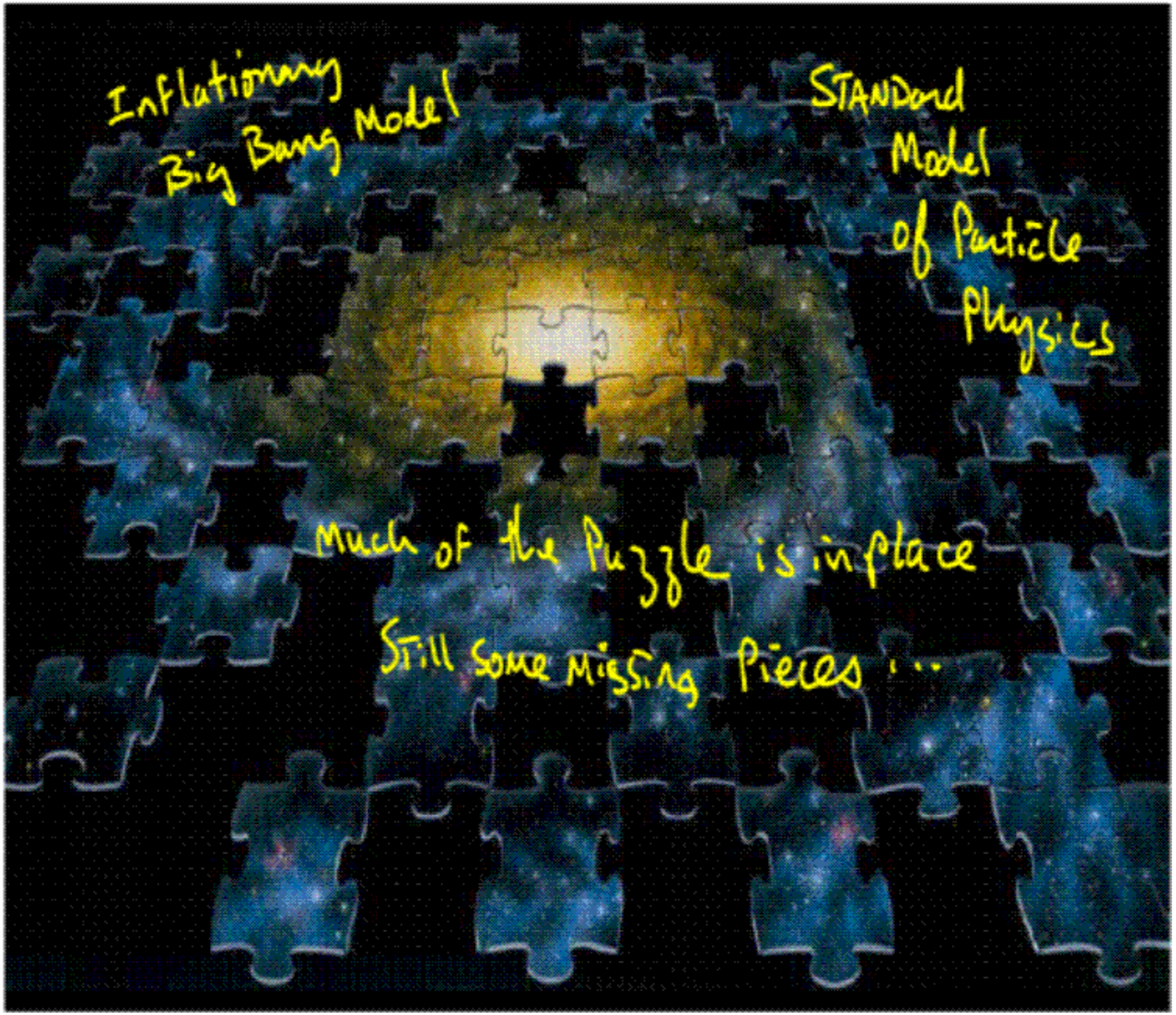
This type of universe will be predominant

Black holes → long life stars → also good for life as we know it

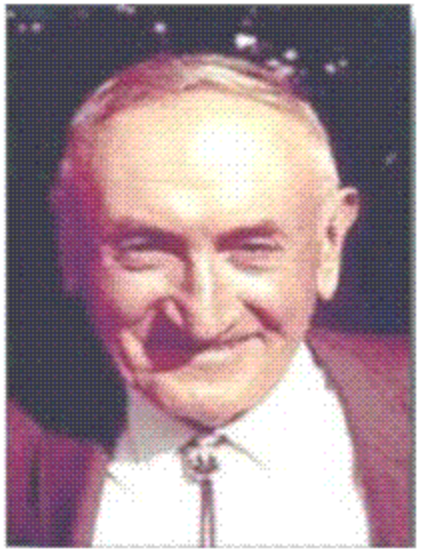
natural reason for Fine-tuning in our universe

Anthropic selection

Falsifiable hypothesis


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

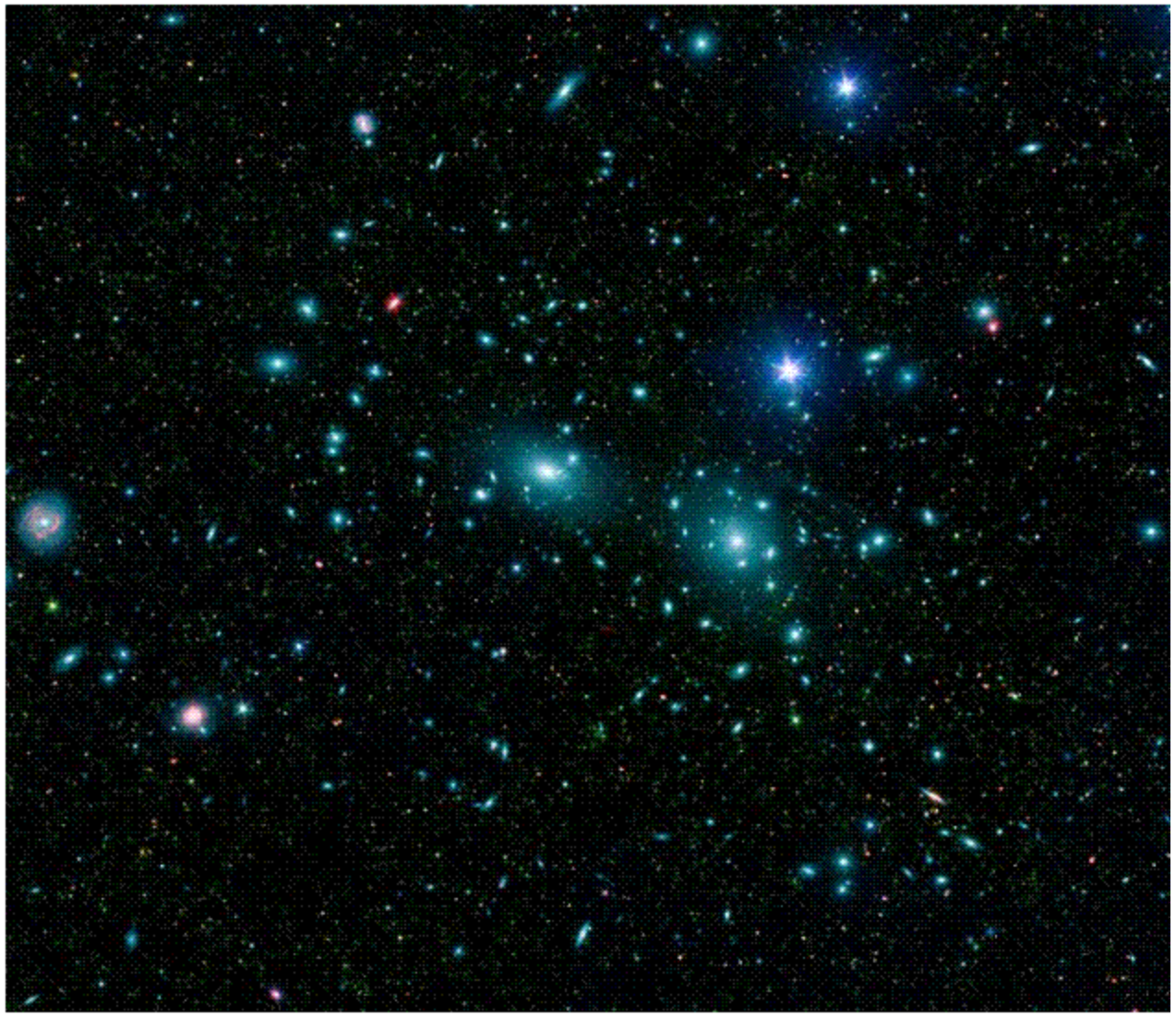
DARK MATTER



Fritz Zwicky (1898-1974)
CalTech astrophysicist

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

Coma Cluster of galaxies

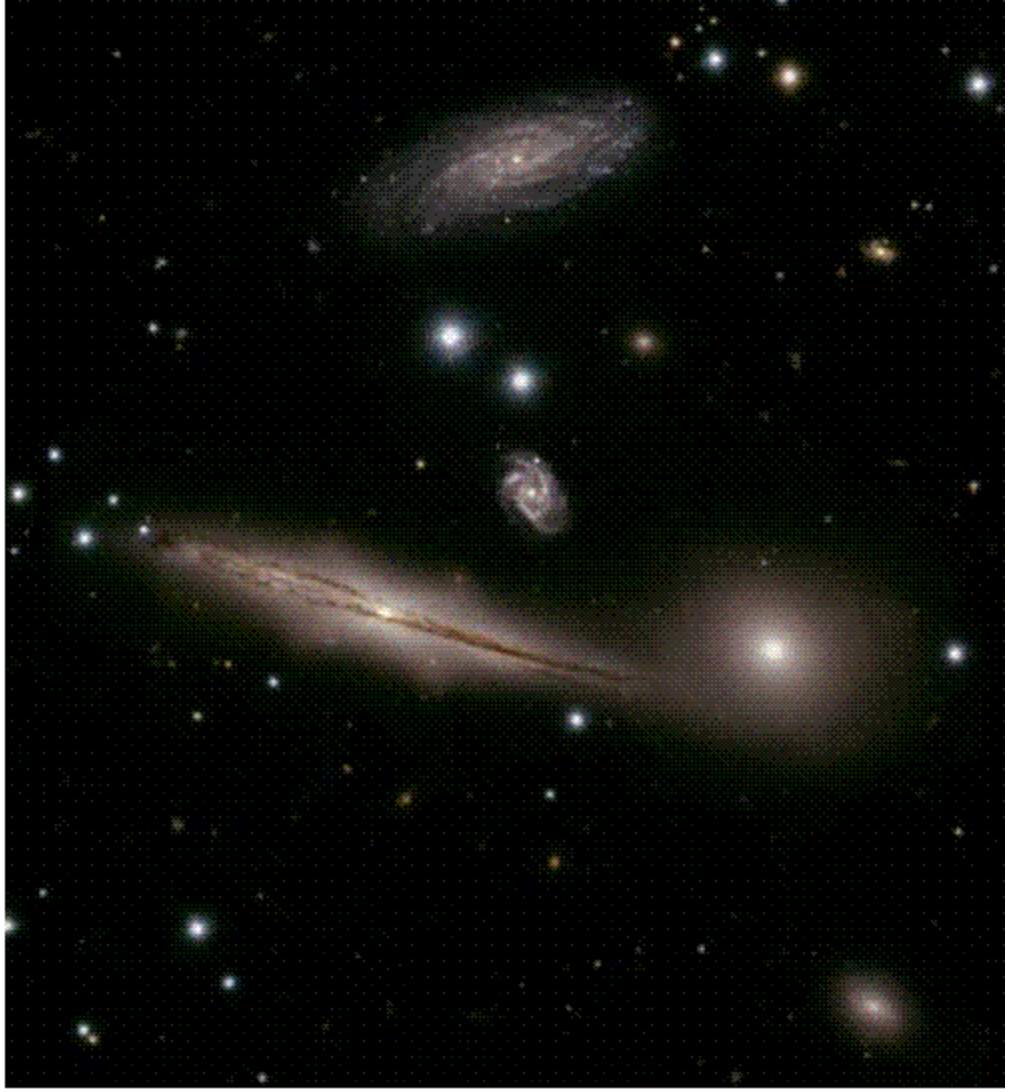


Nasa/JPL / Sloan Dig. Sky Survey

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

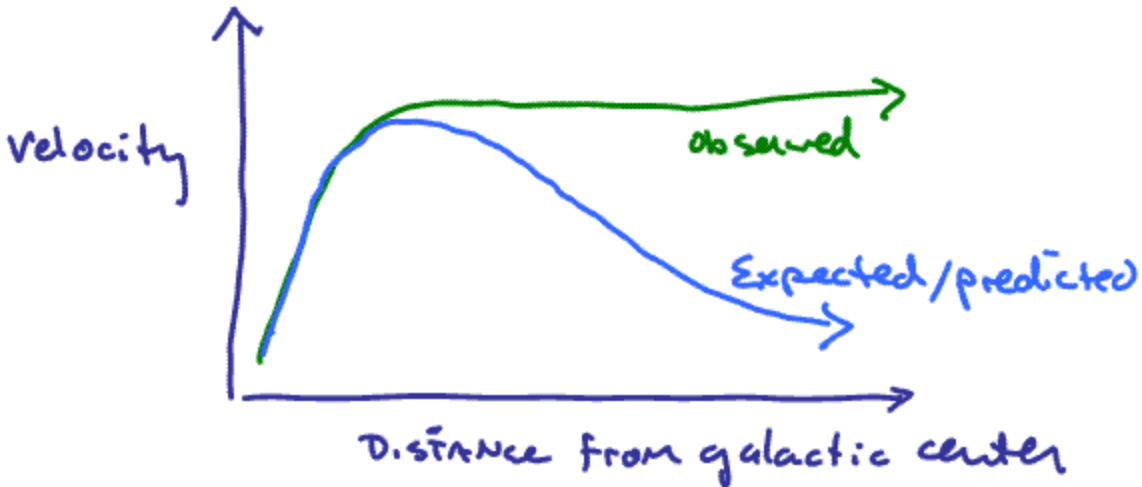
Vera Rubin

Kent Ford

Carnegie Institution of Washington

Vera Rubin

Measured velocities of stars in spiral galaxies



Dark Matter

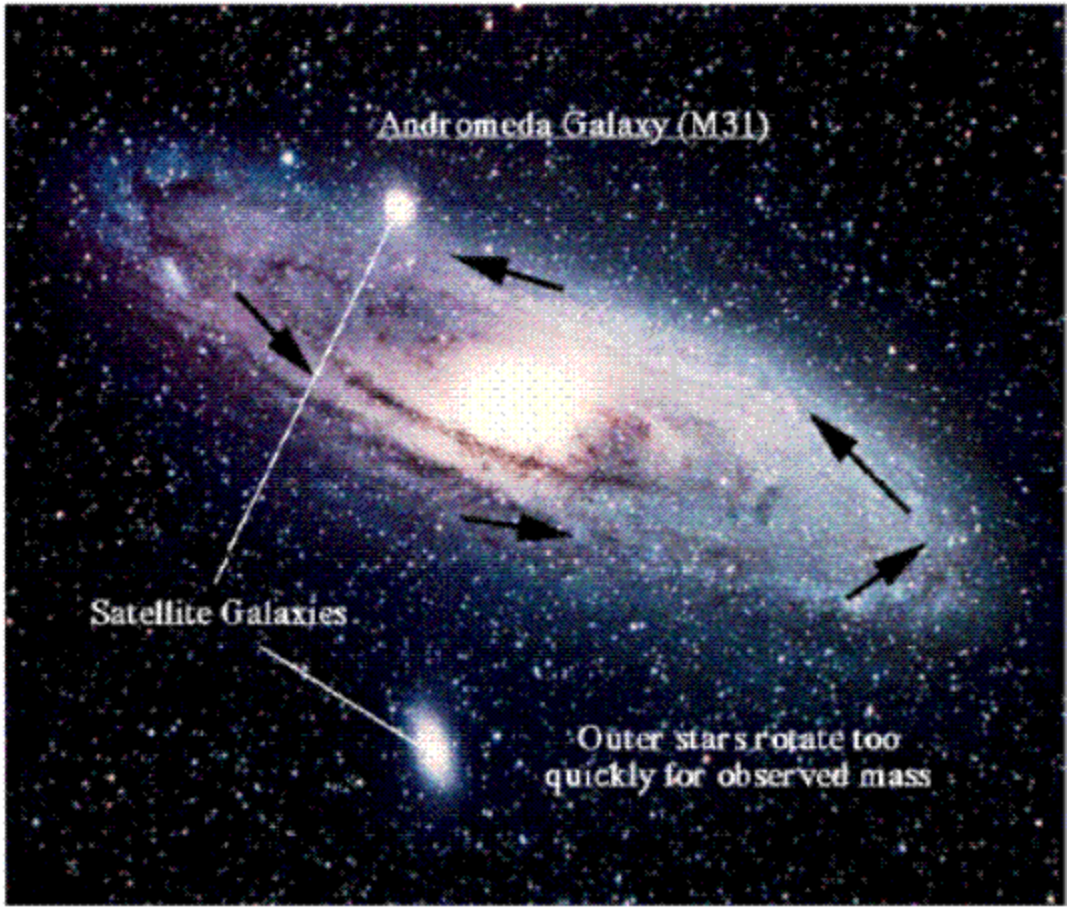
Orbits $F = \frac{mv^2}{R}$ $F = \frac{GMm}{R^2}$

Circular Motion

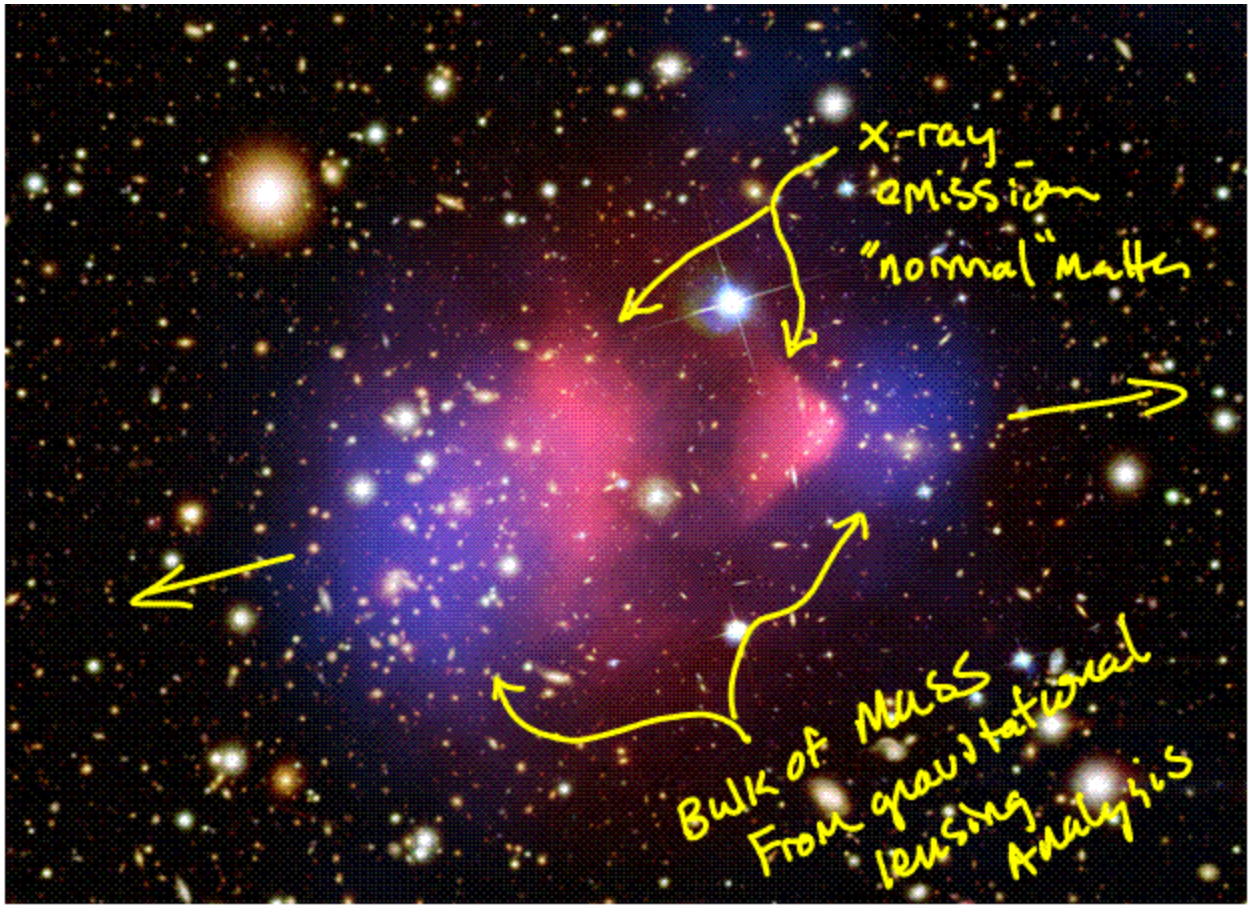
$\frac{mv^2}{R} = \frac{GMm}{R^2}$

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

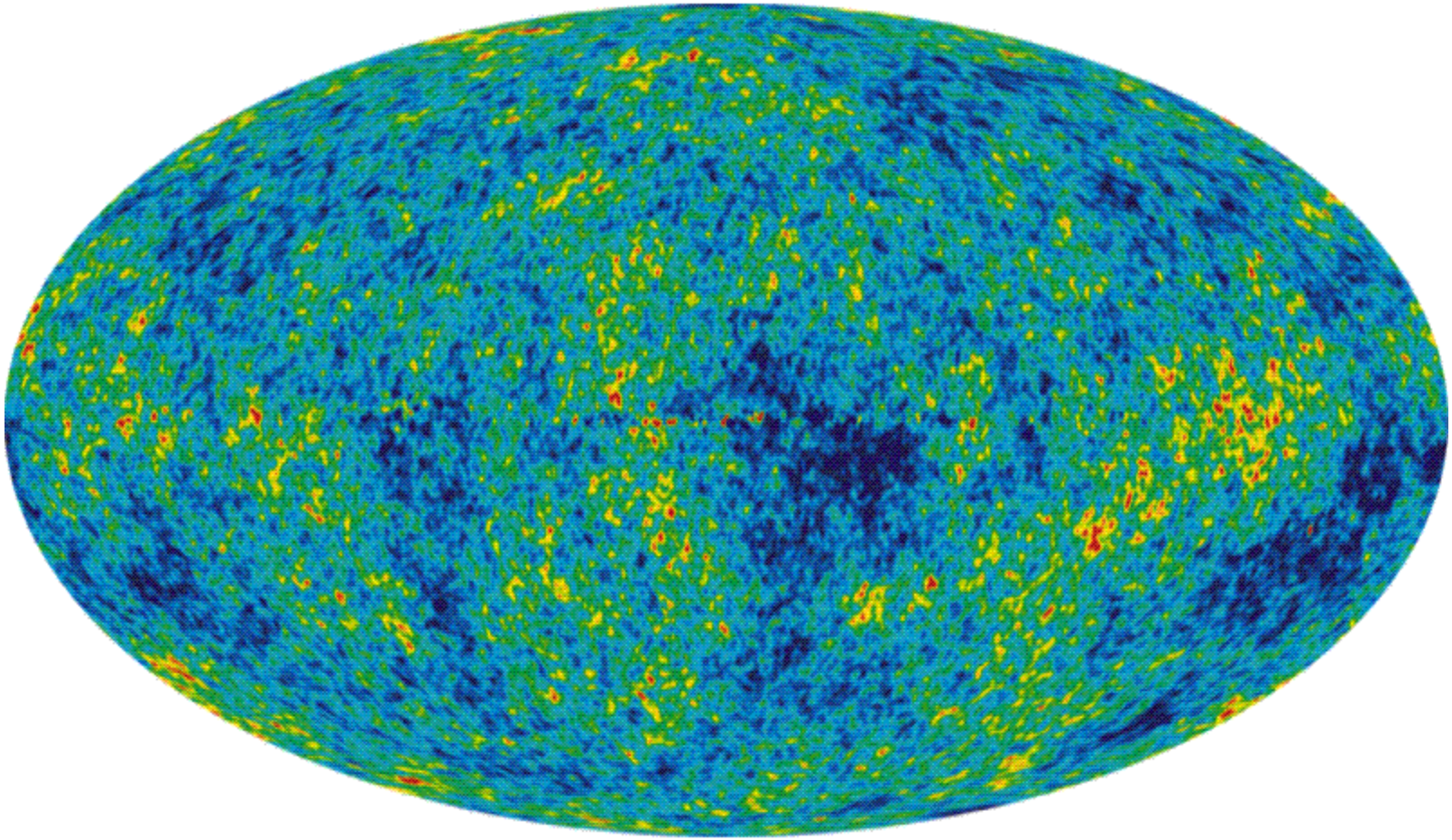


Bullet cluster
colliding galactic clusters

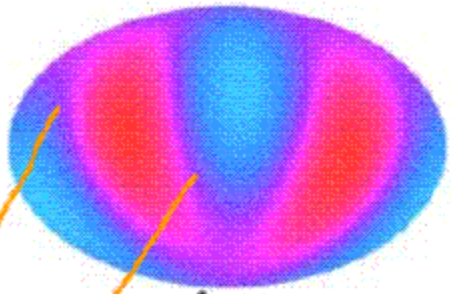
galaxies + Dark Matter
zip past

intergalactic gas slowed down

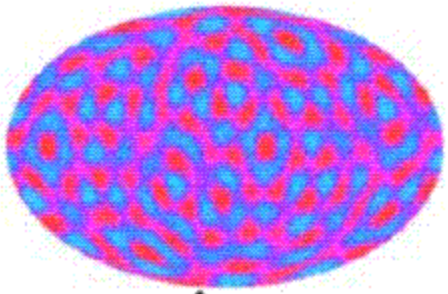
The universe at $t = 400{,}000$ years



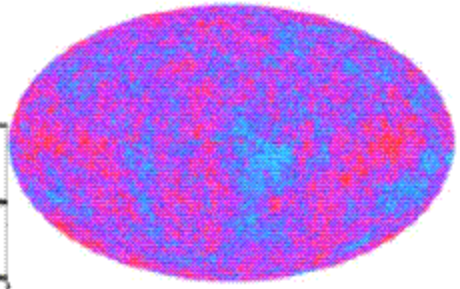
Cosmic Microwave Background from WMAP

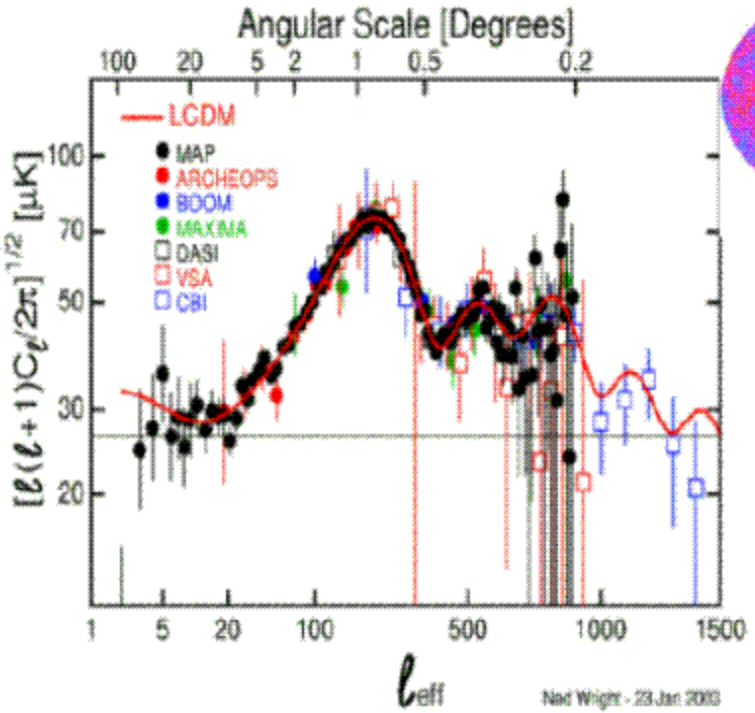


$\ell = 2$



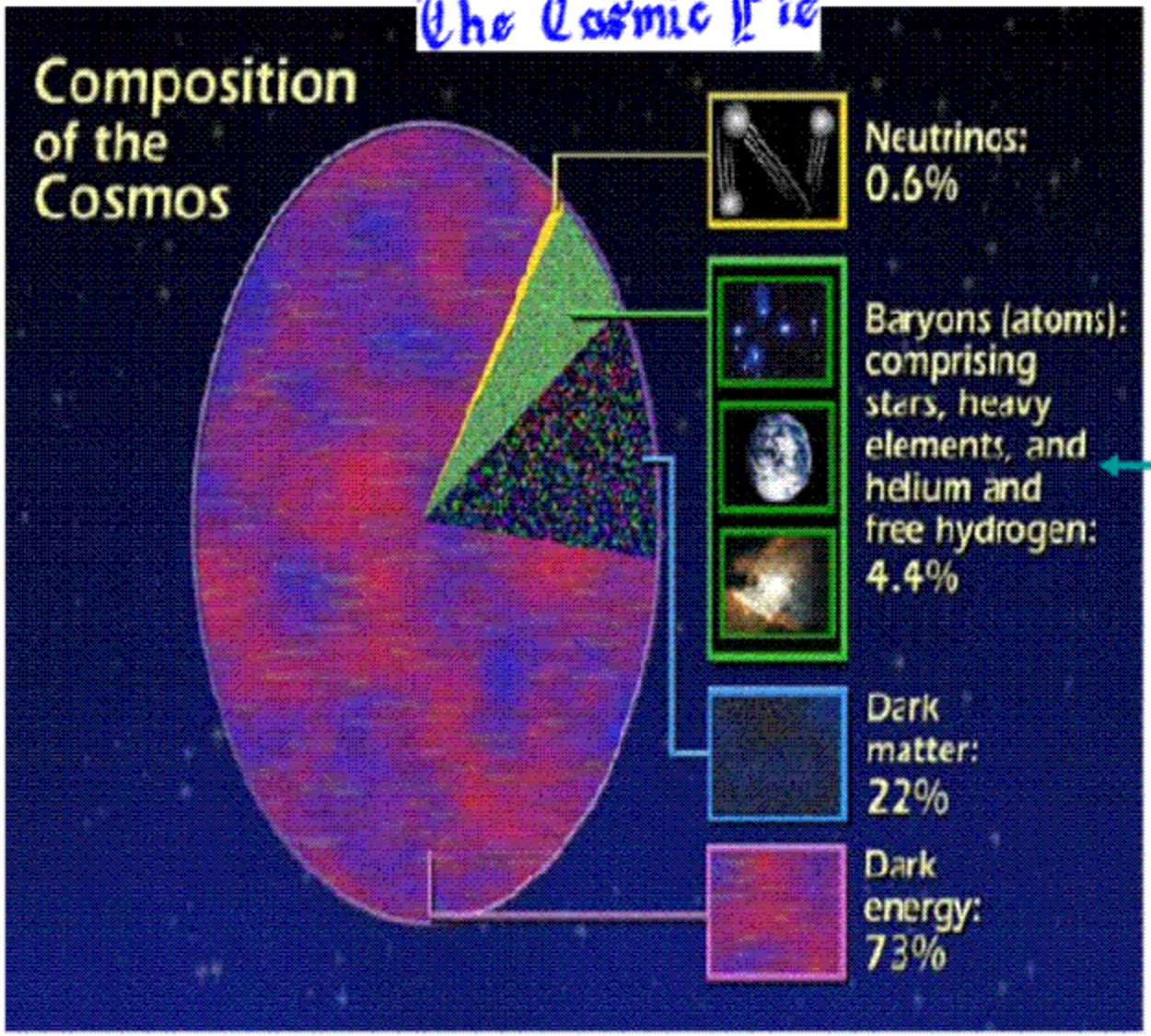
$\ell = 16$





"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