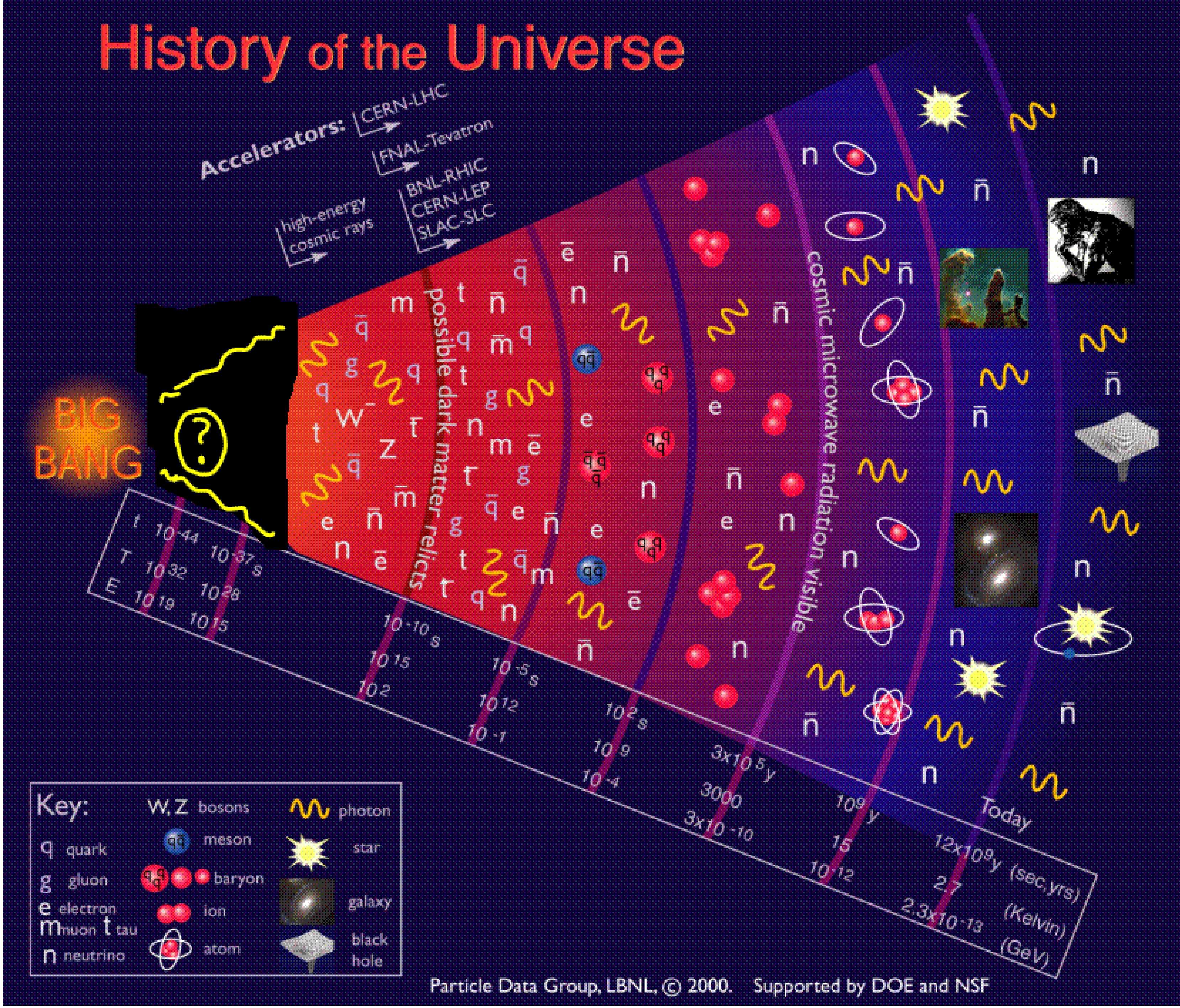
Physics 102 - April 4, 2011

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

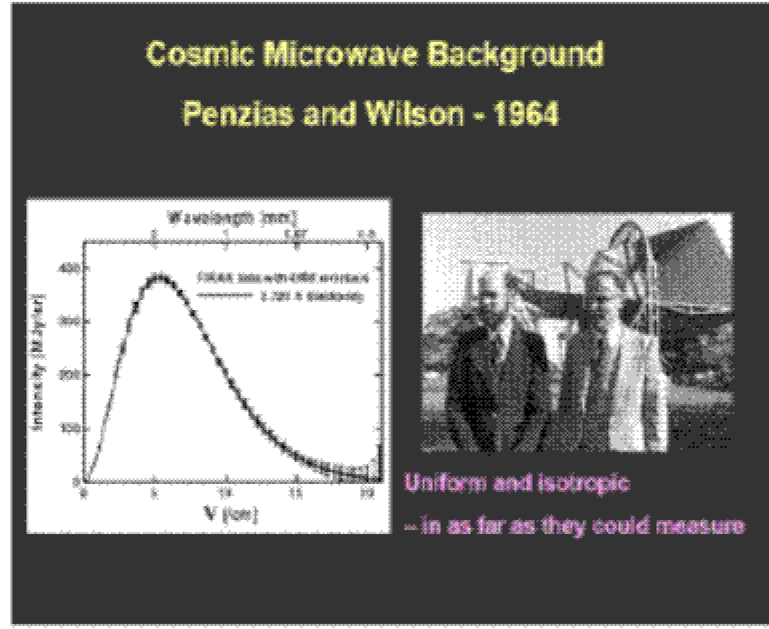
  Hoping to set up a Makeup . . .

Cosmology Has Arrived !

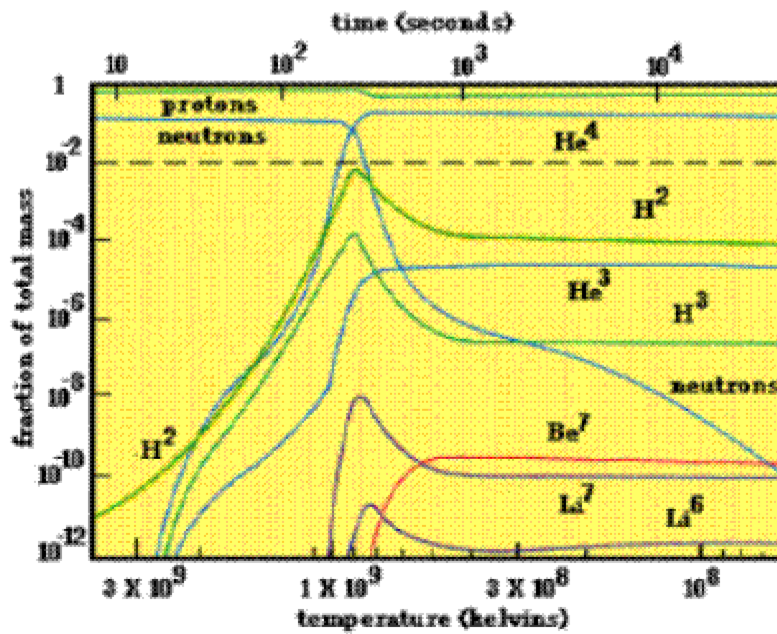

History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
BIG BANG
?
possible dark matter relicts
cosmic microwave radiation visible
t 10^-44 10^-37 s
T 10^32 10^28
E 10^19 10^15
10^-10 s
10^15
10^2
10^-5 s
10^12
10^-1
10^2 s
10^9
10^-4
3x10^5 y
3000
3x10^-10
10^9 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



Problems w/ Big Bang

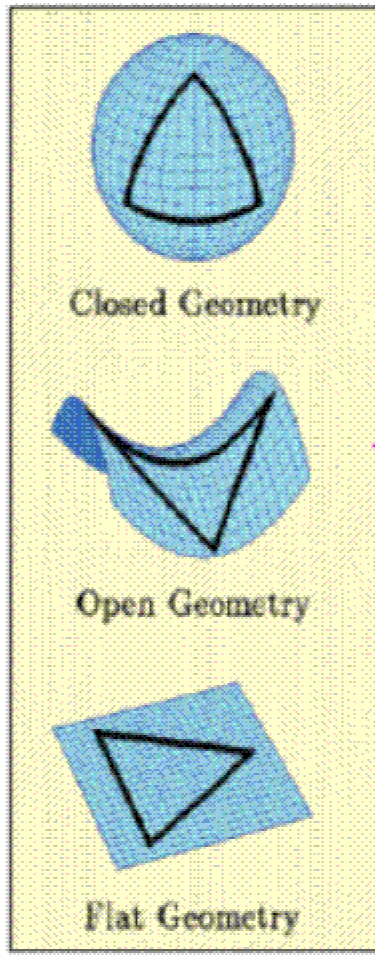
nonstatic universe expected from Relativity

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° ← universe expands... slows down + collapses

< 180° ← universe expands forever

= 180° ← 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?

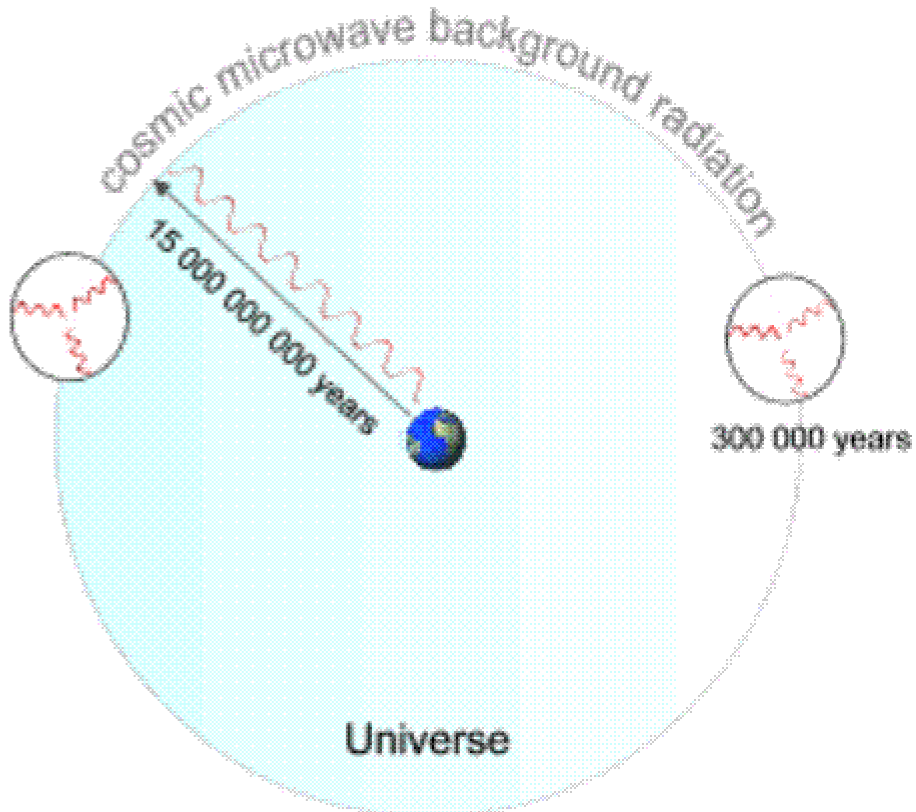
  Why CMB so smooth and isotropic

  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.

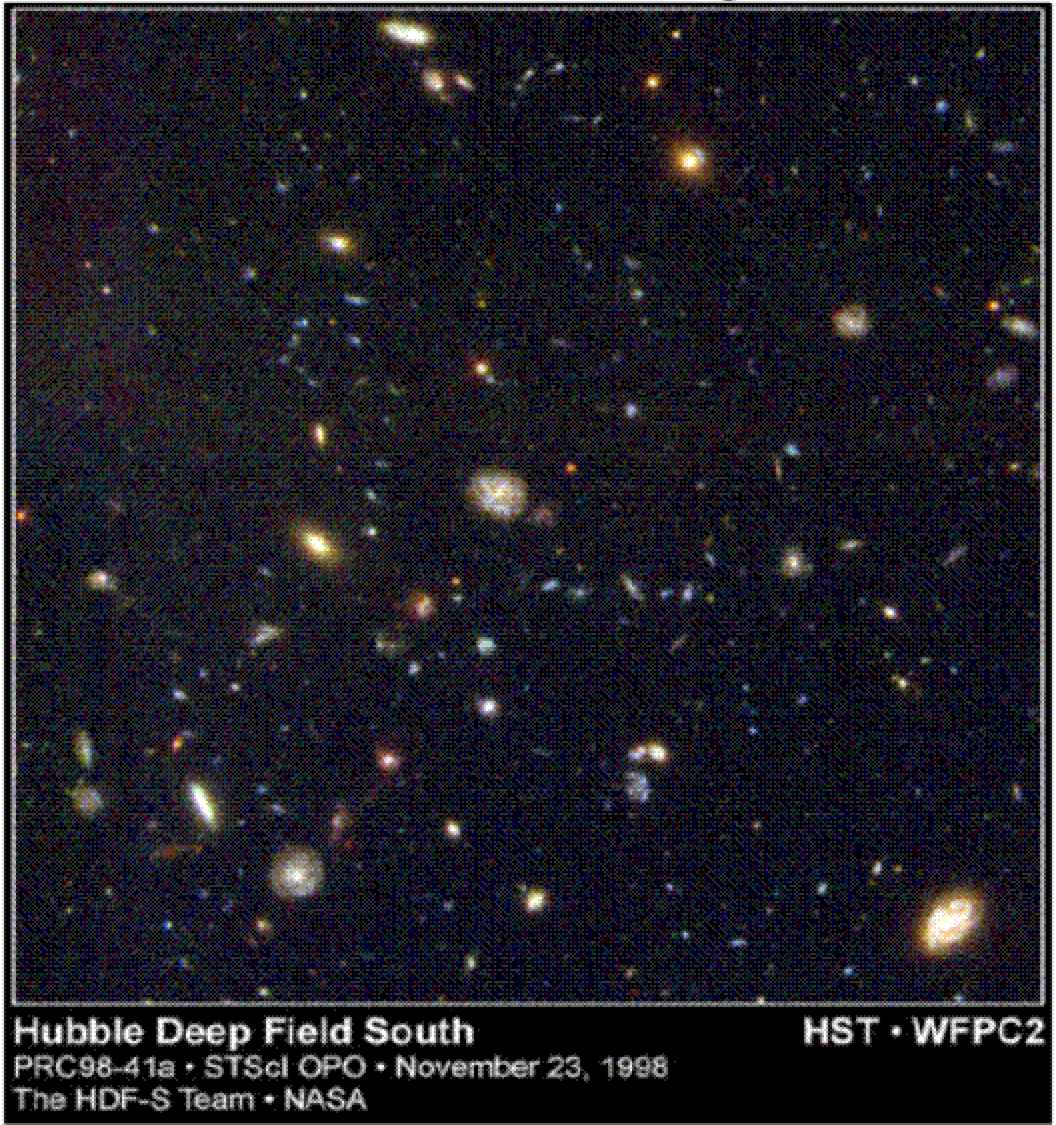
  Requires fine tuning of basic Model

Horizon Problem



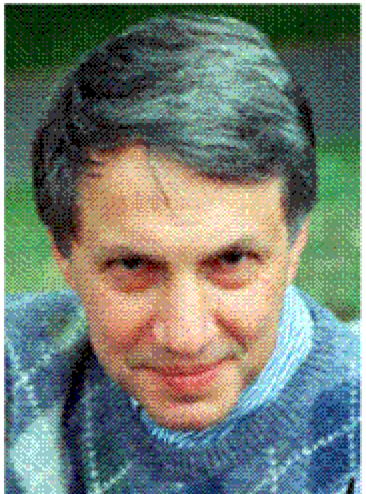
– drawing by Theresa Knott
Taken from Wikipedia

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



Cosmic Inflation

~1979



Andrei Linde (Stanford)

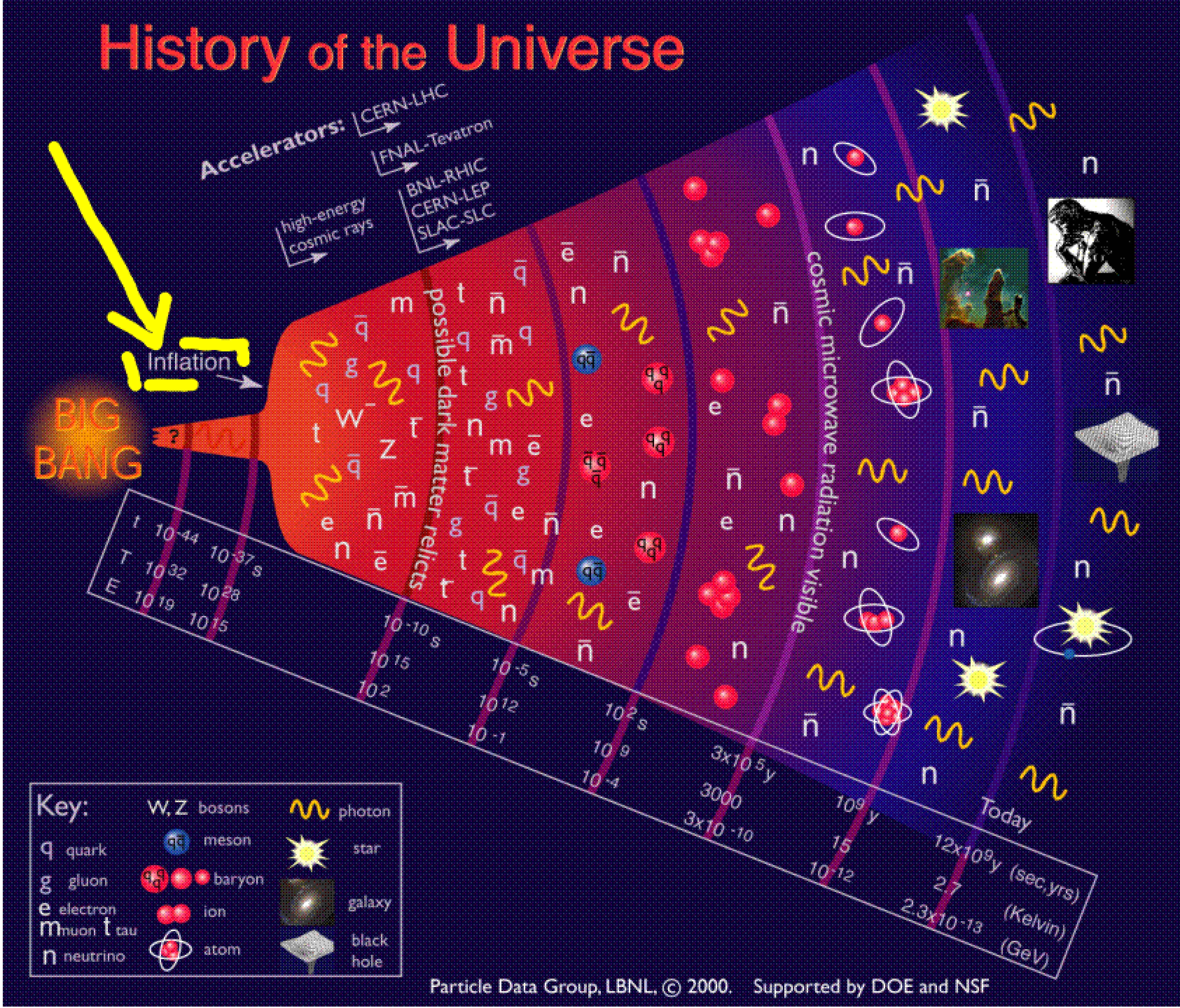
Paul Steinhardt (Princeton)

Andy Albrecht (UC Davis)

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

Alan Guth (MIT)

Inflationary Big Bang Models


History of the Universe
Acceleartors:
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 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 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

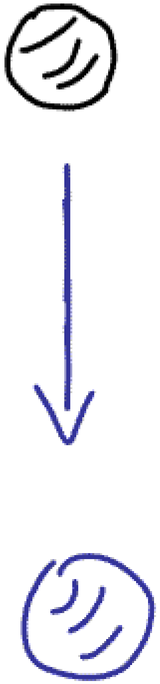
Inflation

- 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" or 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?



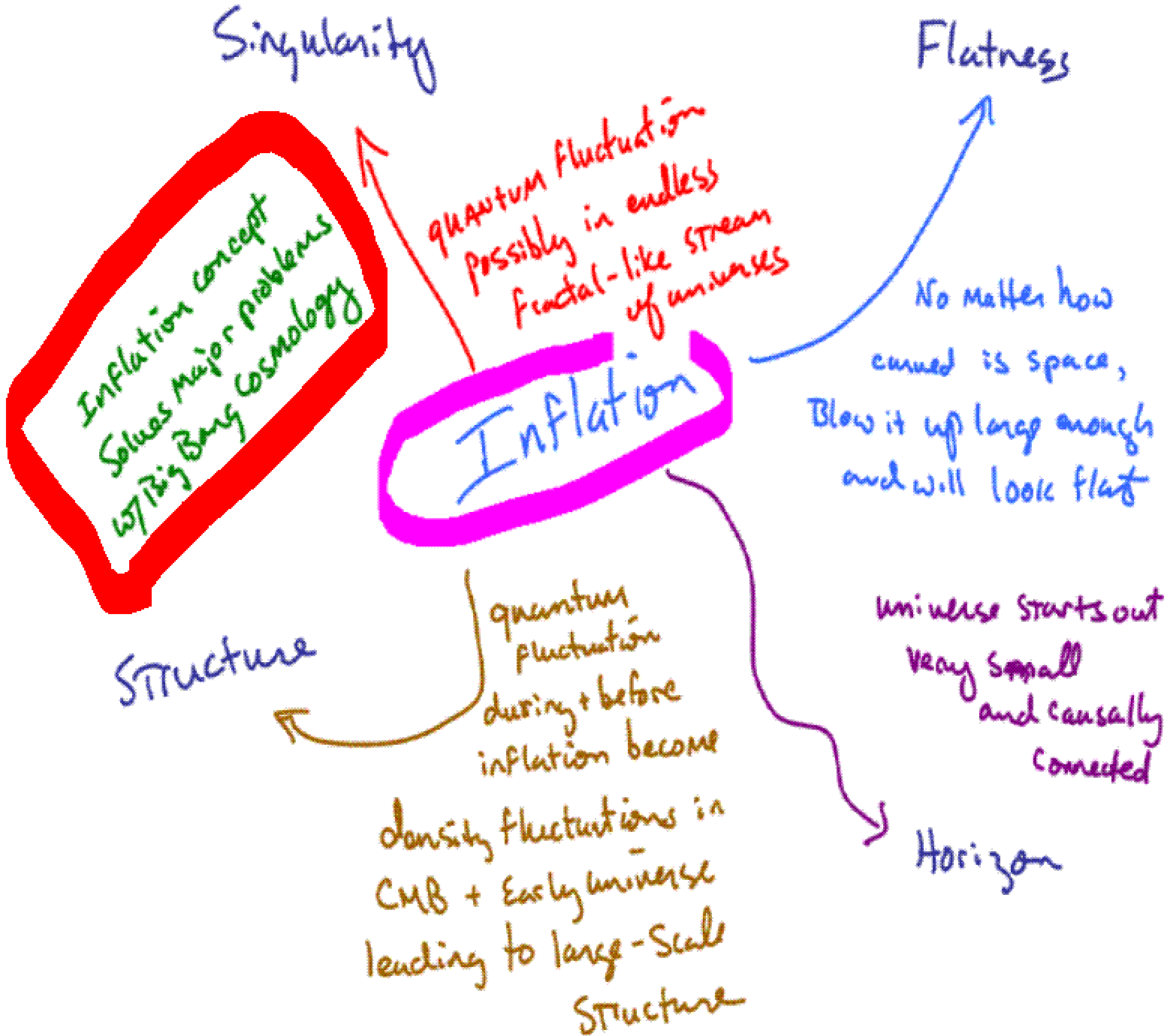
$V=0$ Total energy $=0$

$V \neq 0$

$\overset{+}{\Delta \text{ Kinetic energy}} + \overset{-}{\Delta \text{ grav. Potential energy}} = 0$

As inflation happens energy stored in increasing gravitational Potential energy

"The universe is the ultimate Free lunch" — Guth


Singularity
Flatness
Inflation
Inflation concept
Solves major problems
w/ Big Bang cosmology
quantum fluctuation
possibly in endless
fractal-like stream
of universes
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

- Fluctuations in the Temperature /color of the CMB (1 part in 10^5)
- universe is "flat"

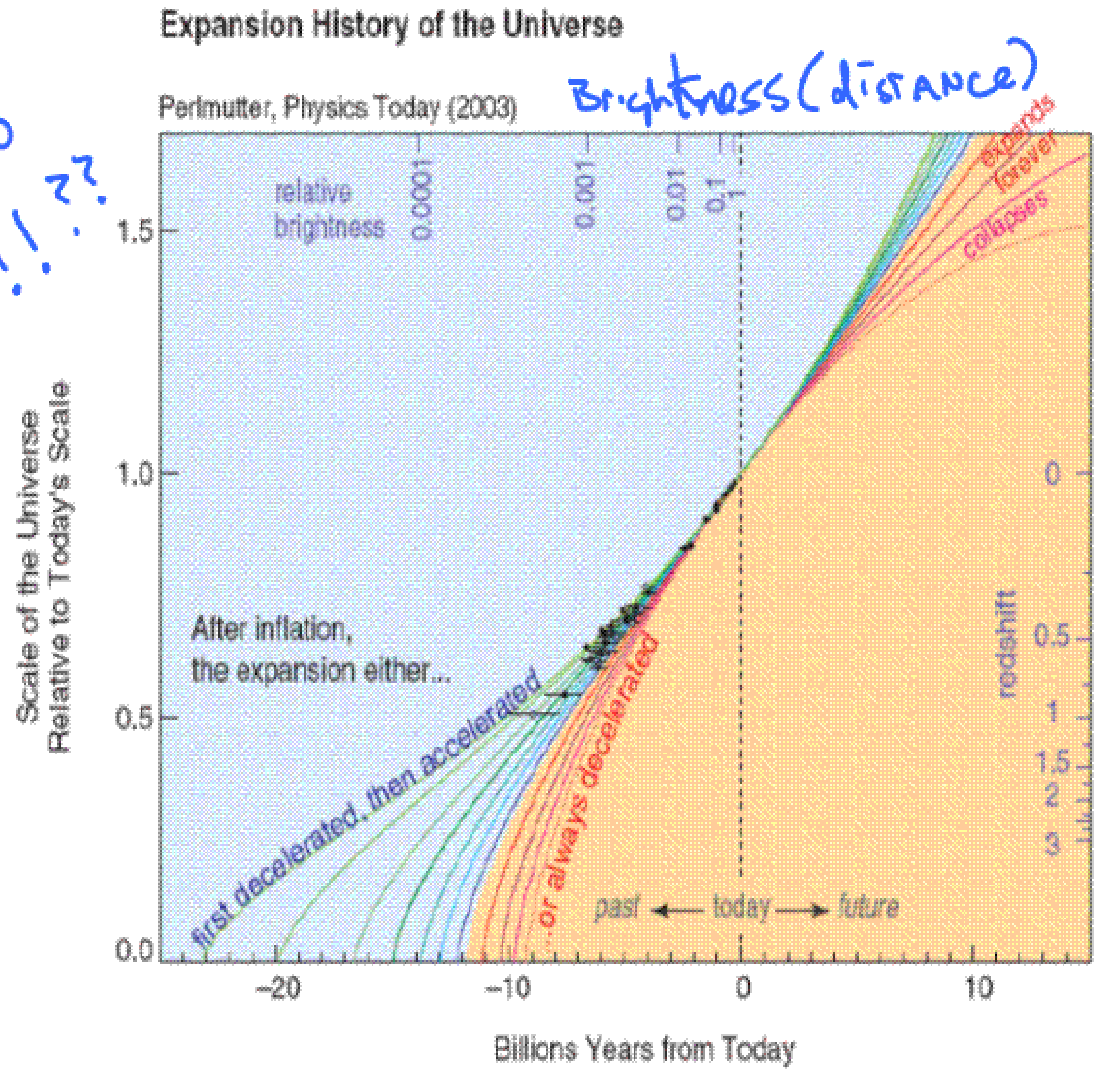
Cobe, WMAP — satellites

- Expansion of the universe is Accelerating

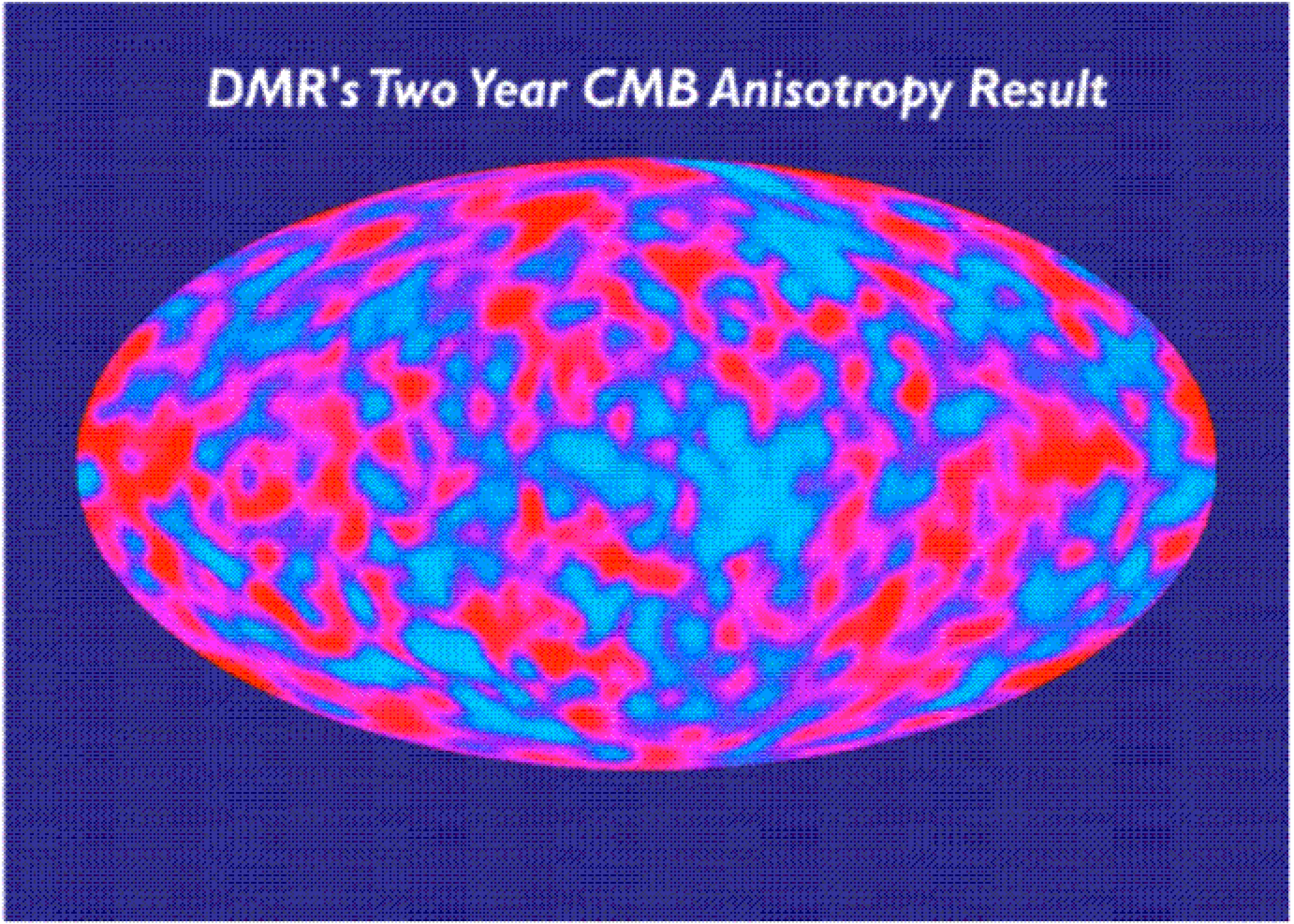
observations of supernovae in distant galaxies

Two grps of scientists:
- Supernova Cosmology Project — Perlmutter at UC Berkeley
- High - Z Team

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



Expansion rate of universe is increasing !! ??

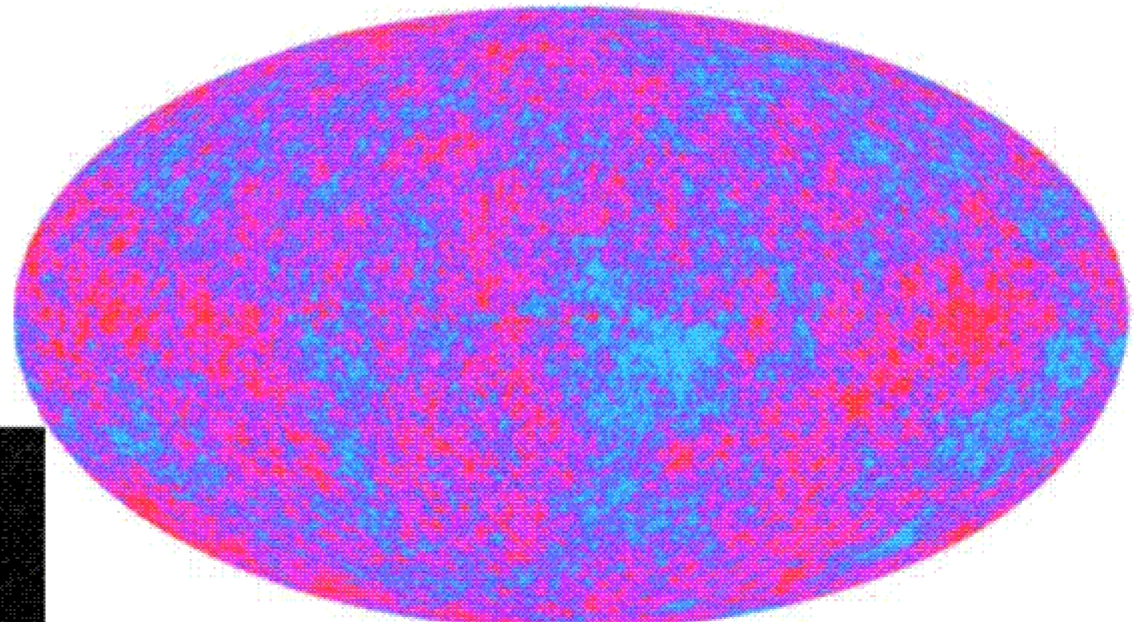


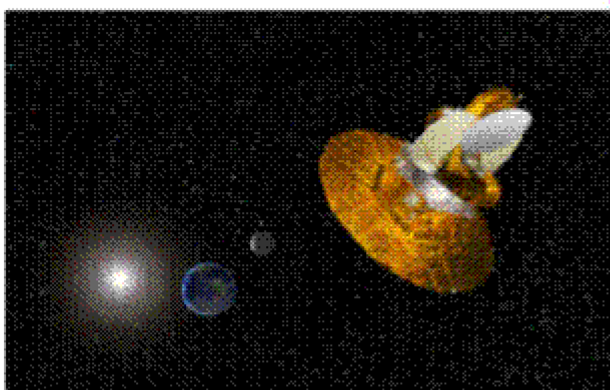
CMB "color" or Temperature seen to vary by 1 part in 100,000

1992 COBE Satellite observation of CMB over all Sky

Cosmic Background Explorer

WMAP – Wilkinson Microwave Anisotropy Probe
(2003) High Resolution Study of CMB

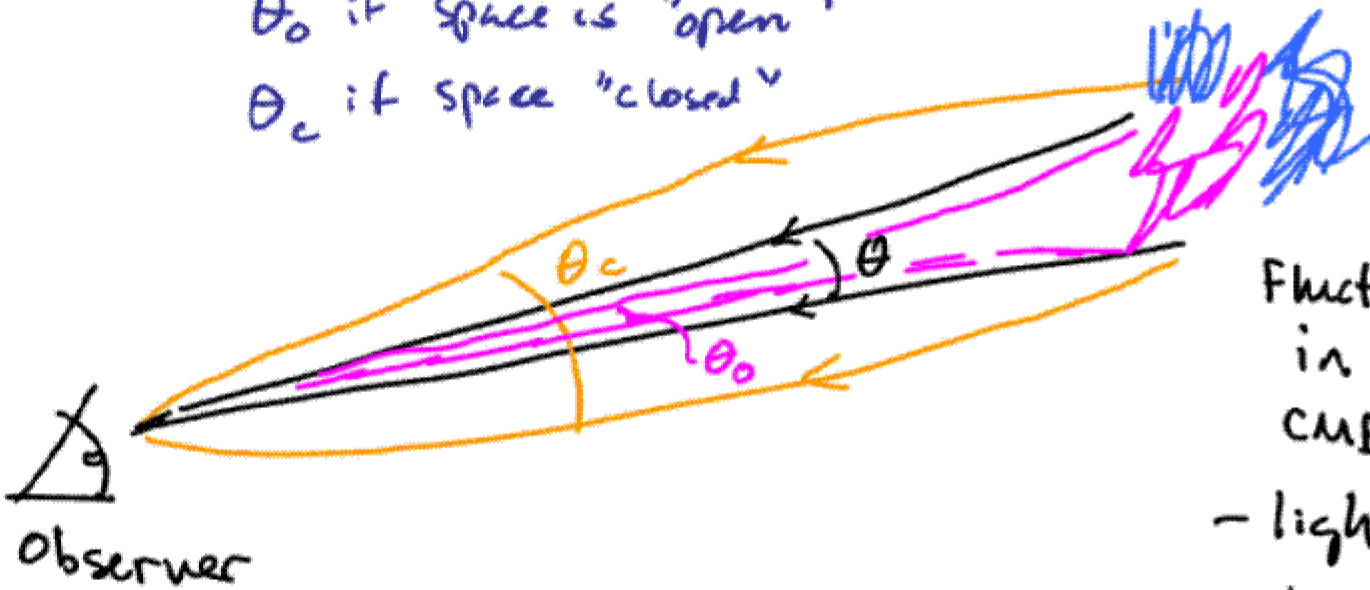




Measure θ_f if space is flat

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