Physics 102 - November 18, 2009

- Exam Monday
- No Recitations Next week at all
- Projects
- A bit off syllabus
History of the Universe

Accelerators:
- CERN-LHC
- FNAL-Tevatron
- BNL-RHIC
- CERN-LEP
- SLAC-SLC

Key:
- W, Z bosons
- photon
- quark
- gluon
- electron
- muon
- tau
- neutrino

Possible dark matter relics

Possible cosmic microwave radiation visible

Today

Particle Data Group, LBNL, © 2000. Supported by DOE and NSF
Observe light from
Time universe became
  Transparent
  \( T \approx 400,000 \) years

Perfect blackbody
  all directions in sky

Amount of light
  nuclei in
  interstellar/intergalactic
  space agrees w/ expectation from Big Bang Nucleosynthesis
  \( T \approx 3 \) minutes
Problems of the Big Bang

Non-static universes expected from Relativity

Relativity allows space to have different geometries? Curved geometries? Which is our universe? Flat space is a very special case!

Closed Geometry

Open Geometry

Flat Geometry

Sum of angles in triangle

> 180°

Universe expands... slows down and 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 homogeneous universe?
Cosmic Inflation ~1979

Andrei Linde (Stanford)

Idea used by many cosmological theories to solve basic problems with Big Bang Model

Andy Albrecht (UC Davis)

Inflationary Big Bang Models

Paul Steinhardt (Princeton)

Alan Guth (MIT)
Inflation

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

3. Properties of such a fluctuation can be constructed so as to create an unstable repulsion filling the space of the fluctuation — some "field" of particles is created in a quasi-stable excited state $\rightarrow$ inflaton. What was it exactly?

4. 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?

\[ V = 0 \quad \text{Total Energy} = 0 \]

\[ V \neq 0 \quad \Delta \text{Kinetic Energy} + \Delta \text{Gravitational Potential Energy} = 0 \]

As inflation happens energy stored in increasing gravitational Potential energy.

"The universe is the ultimate Free lunch." - Guth
Singularity

Inflation concept solves major problems of Big Bang cosmology

Quantum fluctuation possibly in endless fractal-like stream of universes

Inflation

Structure

Quantum fluctuation during and before inflation become density fluctuations in CMB & early universe leading to large-scale structure

Flatness

No matter how curved is space, blow it up large enough and will look flat

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"
- Expansion of the universe is accelerating

Observations of supernovae in distant galaxies

Two gaps 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!!??


Brightness (distance)

Scale of the Universe Relative to Today's Scale

After inflation, the expansion either... first decelerated, then accelerated or always decelerated

Recession Velocity

Billions Years from Today

0.0
-20
-10
0
10

0.0
1.0
1.5

0
0.0001
0.01
0.1
1
10
100
1000

0
0.5
1
1.5
2
3
4

Expands forever
collapses

past → today → future
CMB "color" or temperature seen to vary by 1 part in 100,000
1992 COBE Satellite observation of CMB overall sky
Cosmic Background Explorer
Measure $\Theta_f$ if space is flat
$\Theta_0$ if space is "open"
$\Theta_c$ if space "closed"

$\delta$ Observer

Fluctuations in CMB
- light comes to us from Distance of
  \( \text{(Age of universe - 100,000)} \) 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.
Beyond the horizon multiverse

- Event horizon
- Observable universe
- You are here
- Inflation $\rightarrow$ countless # of such regions

Similar physical laws
Different initial conditions

Causally disconnected parts of reality
Cyclic big bang multiverse (non-brane version)

No beginning or end

Out of favor

- What exactly happens at crunch
- Entropy issue
-Actually the expansion rate in our universe is increasing