Physics 102 - Apr 16, 2011

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

Unable to find a good single time for the makeup

Will probably do makeup evening of Apr 14
Observe light from
Time universe became Transparent
\( T \sim 400,000 \) years

Perfect blackbody
all directions in sky

Amount of light nuclei in interstellar/intergalactic space agrees with expectation from Big Bang nucleosynthesis
\( T \sim 3 \) 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 homogeneous universe?
Cosmic Inflation

\[ \sim 1979 \]

Andrei Linde (Stanford)

Idea used by many cosmological theories to solve basic problems in Big Bang model

Inflationary Big Bang Models

Paul Steinhardt (Princeton)

Andy Albrecht (UC Davis)

Alan Guth (MIT)
Inflation

Singularity

- Inflation concept
- Solves major problems of Big Bang Cosmology

Structure

Quantum fluctuation possibly in endless fractal-like stream of universes

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
Energy Stored in field

Value of field

Diagram showing a potential energy curve with a minimum point, indicating stored energy.
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 sets of scientists: Supernova Cosmology Project, Perlmutter at UC Berkeley; High-Z Team
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.
Observable universe

Event Horizon

particle Horizon

Observable universe

x

you are here
The bubble multiverse

inflation - once started cannot be stopped everywhere at once

Within each Bubble universe is a beyond the horizon Multiverse Potentially

Domains where Quantum fluctuations cause inflation to and universes

Event Horizons

Eternal inflation

Bubble universes Could have different physical laws
Beyond the horizon multiverse

You are here

Event horizon

Observable universe

Inflation \rightarrow \text{countless \# of such regions}

? Elvis lives

Similar physical laws
Different initial conditions
Identical you?

Causally disconnected parts of reality
A multitude of multiverses...

Within each bubble universe, there are domains where quantum fluctuations cause inflation to universes. Beyond the horizon, the multiverse potentially contains similar physical laws. Bubble universes could have different physical laws.

Eternal inflation
Much of the puzzle is in place
Still some missing pieces...
DARK MATTER

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

Fritz Zwicky (1898-1974)
CalTech astrophysicist
Coma Cluster of galaxies

Nasa/JPL/Slan Dig. Sky Survey
Zwicky compared mass of galactic cluster using two methods:

1. Number + brightness of galaxies in cluster

2. Motion of galaxies at edge of cluster

Mass \[ \Rightarrow \text{method 2} \] \text{Mass} \[ \text{method 1} \] \quad \text{DARK Matter}
1975
Vera Rubin
Kent Ford
Carnegie Institution of Washington

measured velocities of stars in spiral galaxies

velocity

Distance from galactic center

Scanned at the American Institute of Physics
Dark Matter

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.

Andromeda Galaxy (M31)

Satellite Galaxies

Outer stars rotate too quickly for observed mass

- P. Cashman
galaxies + dark matter

zip past

bullet cluster

colliding galactic clusters

intergalactic gas slowed down
The universe at $t = 400,000$ years

Cosmic Microwave Background from WMAP
"Power spectrum" (size) of temperature fluctuations sensitive to different matter/energy components of the universe
The Cosmic Pie

Composition of the Cosmos

- Neutrinos: 0.6%
- Baryons (atoms): comprising stars, heavy elements, and helium and free hydrogen: 4.4%
- Dark matter: 22%
- Dark energy: 73%

95% of the universe is unknown!

Figure from E. Lindo, LBL

STScI