Cosmology - The Story of our Universe

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What is Cosmology?

- Study of our Universe today – galaxies, clusters, superclusters

- Understanding the past history and future evolution of our Universe

PAST ← PRESENT → FUTURE

Cosmology - The Story of our Universe

- How old is the Universe? Existed forever or does it have a beginning? Will it exist forever, or have an end?
- What governs the motion of the stars?

Cosmology - The Story of our Universe

Curiosity led to the development of science – astronomy and mathematics – in all societies

- Position and motion of stars and planets in the sky

  Calendar, navigation

- Telescope 17th c. Galileo, Kepler

Cosmology - The Story of our Universe

Curiosity led to the development of science – astronomy and mathematics – in all societies

Gravity

- Galileo – study falling bodies on Earth

  Kepler's laws of Planetary Motion

  Newton's law of Gravitation – universal 17th c.
- Einstein's theory of Gravity – General Relativity

  Application to the Universe early 20th c.

- Observational Astronomy and Theory of General Relativity has given us today an understanding of the Cosmos

Course Outline

I. Overview of what we know about our Universe

II. Laws governing the evolution of the Universe

III. Constituents of our Universe
(radiation, matter incl. dark matter, dark energy)

IV. Formation of Structure

V. Physics of the very early Universe ($t < 10^{-6}$ s)
Interface with Particle Physics

Course Outline

- Tuesdays 5:00 – 6:30 pm, Fridays 5:30 – 7:00 pm, till Tuesday, Sept. 7 (5:00 – 7:00 pm)

- Assessment – Attendance, Test

- Reading material

Send email to raghavan@prl.res.in

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Cosmology

- Make observations of our Universe today – galaxies, clusters, superclusters

- Understand the past history and future evolution of our Universe

PAST ← PRESENT → FUTURE

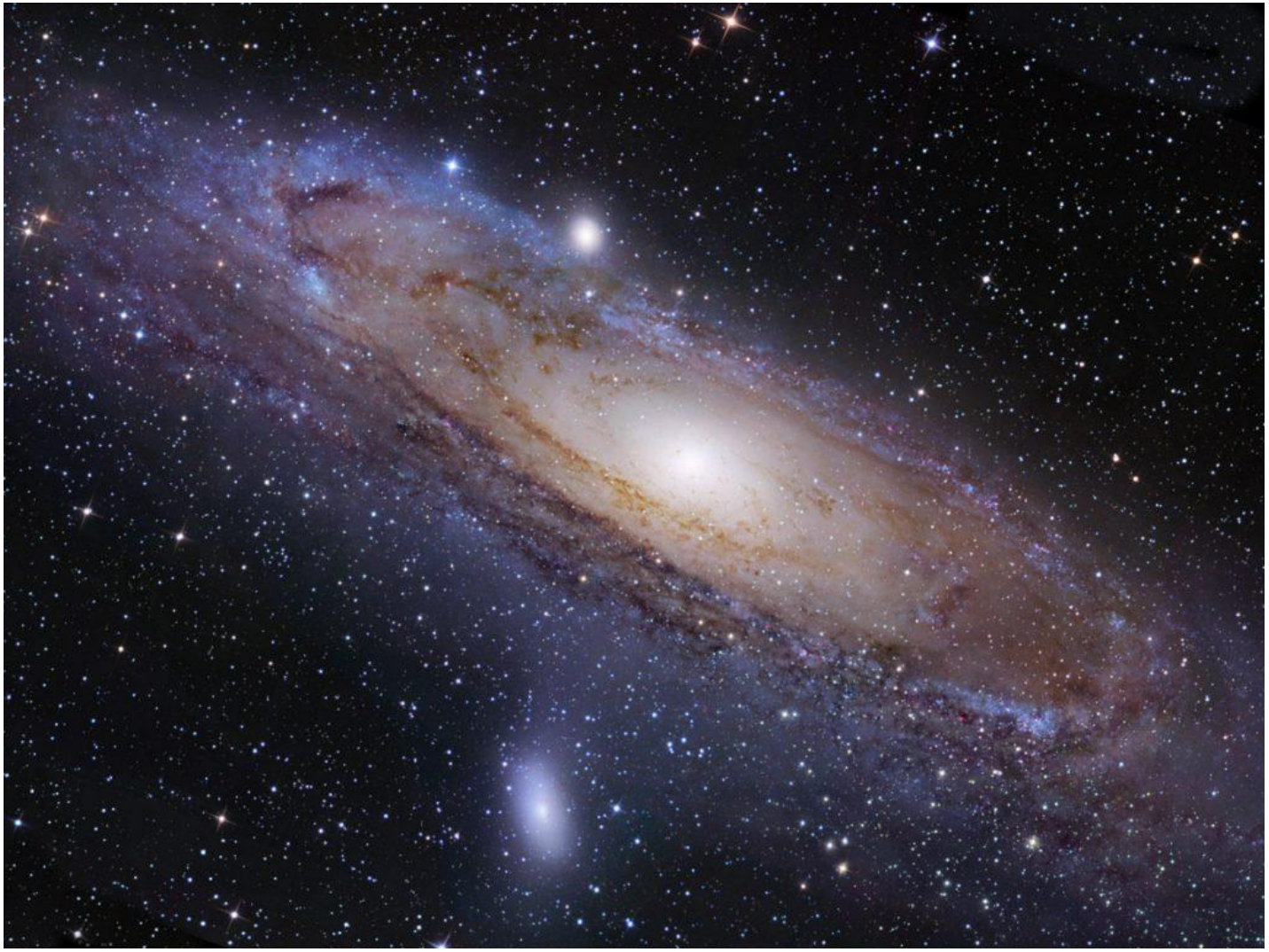
PRESENT

- Stars with planets
- Galaxies
- Clusters of Galaxies
- Superclusters
- Voids

Galaxies

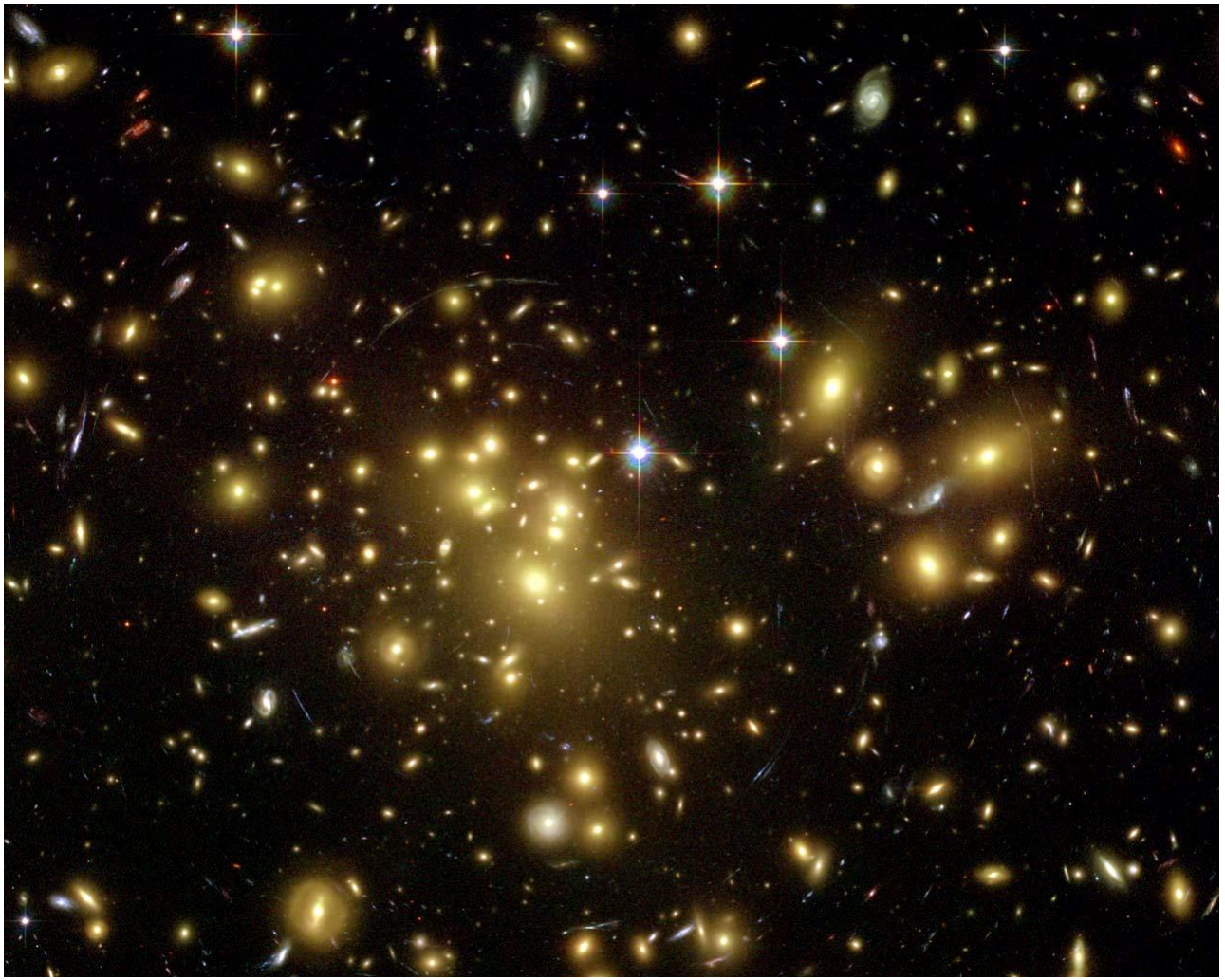
- Spherical, elliptical, spiral, irregular

NGC 7331

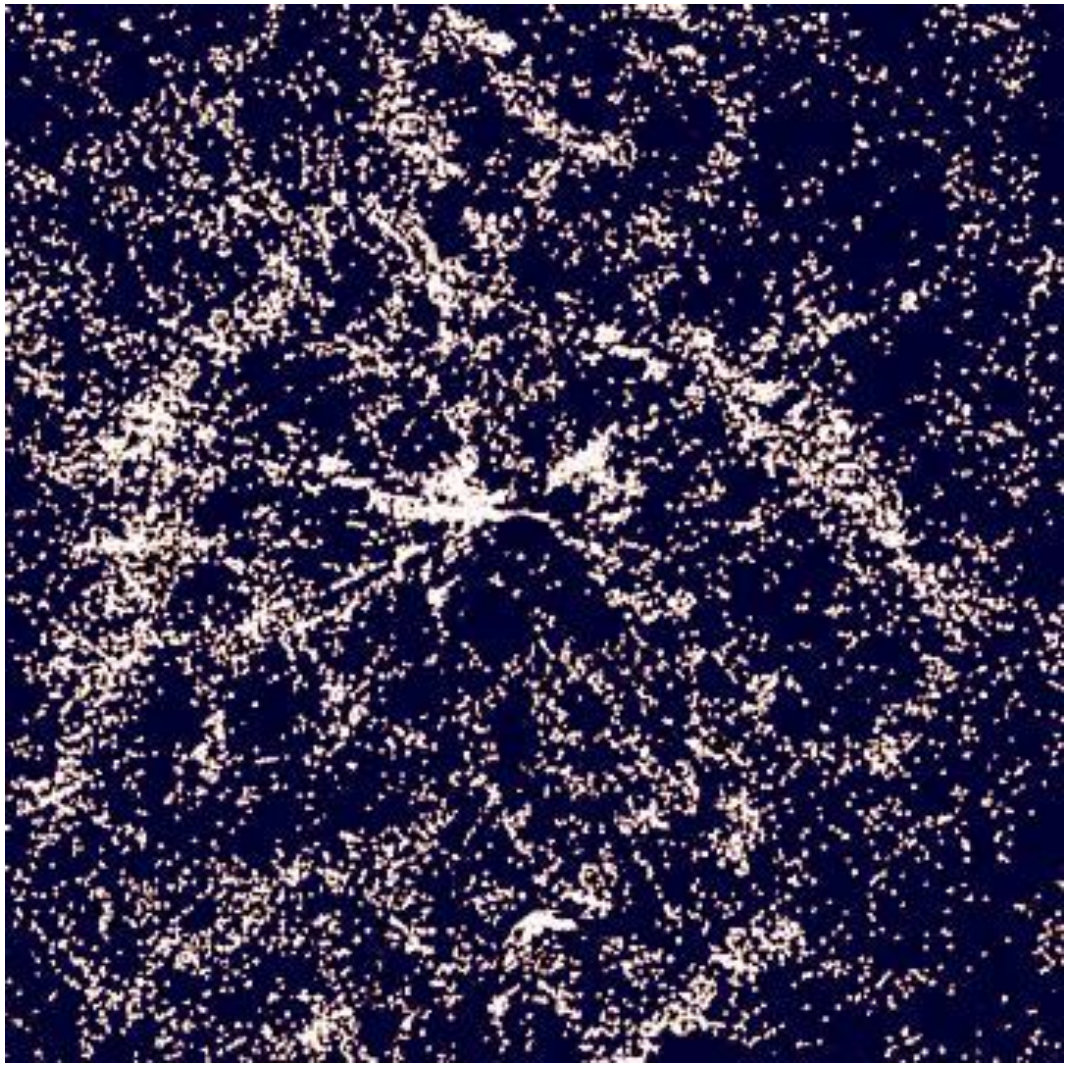


Andromeda Galaxy

Galaxy Cluster



Superclusters and Voids



Present

- Structure: Galaxies, Clusters, Superclusters
- What is the Universe made up of ?

Background radiation

- Ignore radiation from stars and galaxies
- Background of photons in the microwave – Cosmic Microwave Background (2.725 K)
- Cosmic Neutrino Background (undetected)

  (light m < one-millionth electron mass, neutral, also from sun)

Luminous matter

Protons, neutrons, electrons (interactions produce light)

Dark matter

Dark matter ~ 10 Luminous matter

Dark Energy

- All distant galaxies are moving away from each other (spectra redshifted) Hubble 1929

- Not because of intrinsic velocities but because space is expanding (Gen. Rel.)

Universe is expanding

Dark Energy

- Observations indicate that the expansion rate of the Universe was decreasing for the first 9 billion years after the Big Bang and has been increasing for the last 5 billion years
- The earlier period of deceleration is understood. But we do not know what is causing this acceleration

Dark Energy

- Can be explained by modifying Einstein's equations in General Relativity by including

  1. a constant term (Cosmological Constant), or
  2. some new matter with a different equation of state than regular matter (Quintessence)

  in the energy density of the Universe
- Referred to as Dark Energy

Composition of our Universe

- Photons and neutrinos
- Protons, neutrons and electrons
- Dark Matter
- Dark Energy

- Quantify: Averaged over the Universe, how much contribute to the energy density (remember, mass is a form of energy)

Composition of our Universe

- Photons and neutrinos – negligible

Composition of our Universe

- Photons and neutrinos – negligible
- Protons, neutrons and electrons – 5%

Composition of our Universe

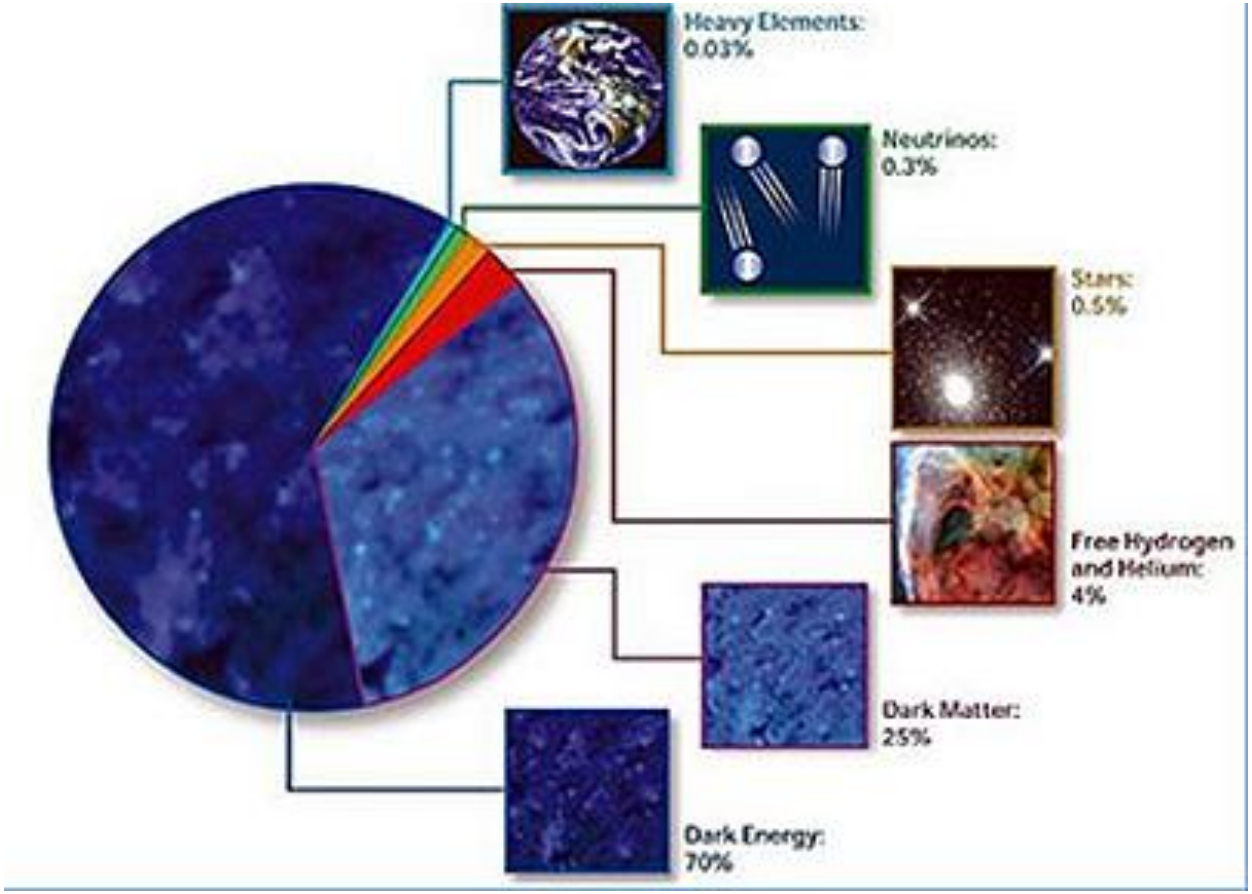
- Photons and neutrinos – negligible
- Protons, neutrons and electrons – 5%
- Dark Matter – 25%

(DM/LM in galaxies ~ 10, overall ~ 5)

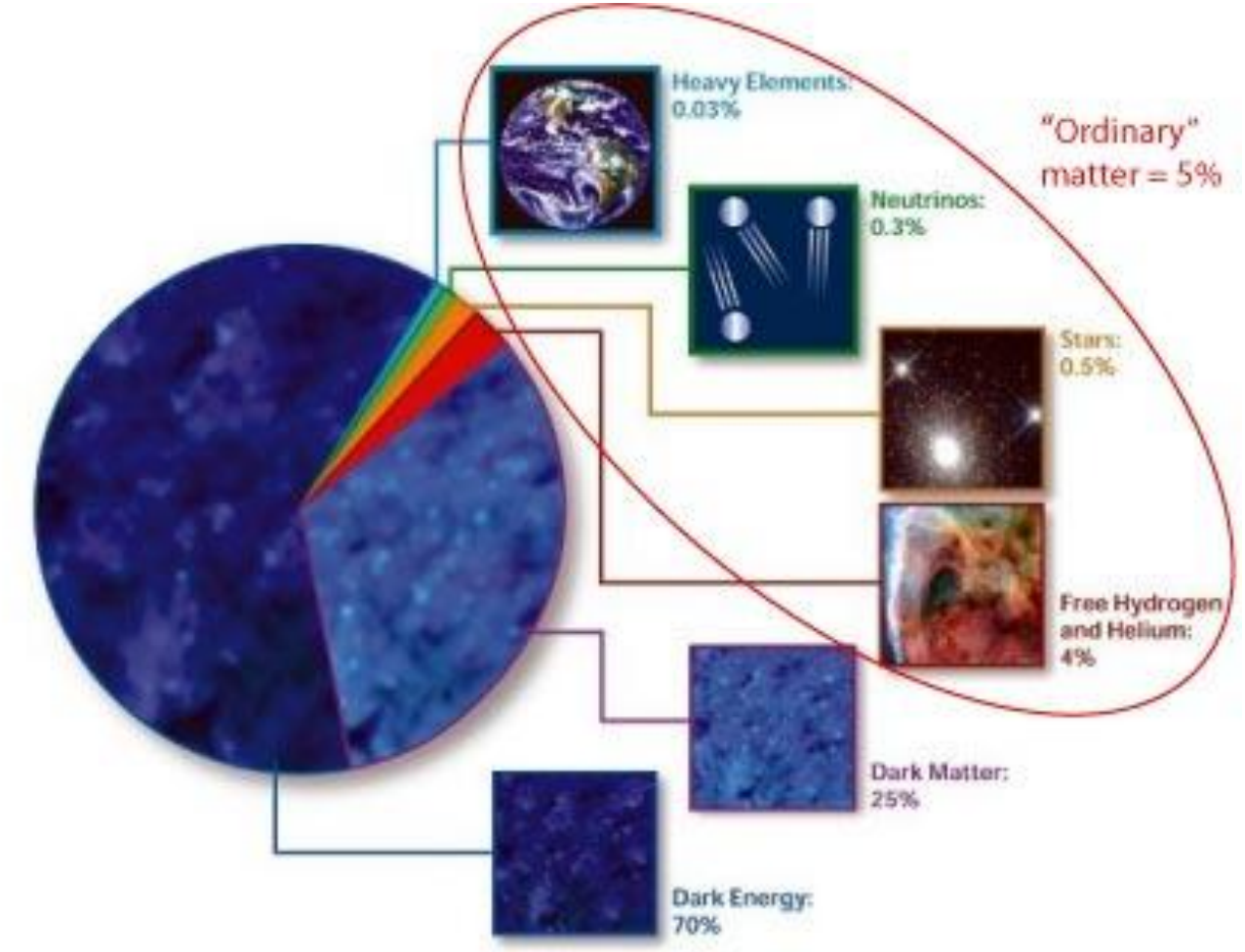
Composition of our Universe

- Photons and neutrinos – negligible
- Protons, neutrons and electrons – 5%
- Dark Matter – 25%
- Dark Energy – 70%

Composition of our Universe



Composition of our Universe



Composition of the Universe

Cosmology

- PRESENT (Structure and Composition)

  Astronomical Observations

- PAST ?

- FUTURE ?

Questions ?

- Was the Universe always like the present?

- Will the Universe continue to be like the present?

  All distant galaxies are moving away from each other (spectra redshifted) –

  Universe is expanding

The Past

- Go back in time, all material that is in all galaxies around us was in a smaller and smaller region

INITIAL STATE (14 b years ago)

- At the earliest instant, density very high
- All matter breaks down to elementary particles at high energies

  All matter moving out very fast

The Past

- Go back in time, all material that is in all galaxies around us was in a smaller and smaller region

INITIAL STATE

- At the earliest instant, density/energy very high
- Expansion rate very high

THE BIG BANG

THE BIG BANG

- Not an explosion of concentrated matter in space

- An initial state of rapid expansion of space (filled with matter) everywhere

Coined by an opponent of the model

After the Big Bang

- First second – hot primordial soup of electrons, protons, neutrons, dark matter
- 1 s – 3 min – light nuclei (helium, lithium, ..)
- 400,000 years – Atoms form
- 300 million years – First stars form
- 1 billion years – First galaxies form
- 9 billion years – Universe is accelerating
- Solar system formed
- 14 billion years – Today

The Future

- Universe keep expanding

- May continue to accelerate or may not

  Different expanding scenarios
  (also cyclic Universe models)

The Future

- Universe keep expanding
- All distant galaxies move away but galaxies retain their structure for a long time (100 trillion years)
- Galaxies move apart, Stars move apart, Stars break up Universe filled with dilute gas, dark and cold (50 b y)

[Solar system destroyed long before that (6b y)]

Summary

- We live in an expanding Universe
- Initial condition was a very dense, energetic, fast expanding state – The Big Bang
- Today Universe of stars and galaxies, clusters and voids - structure
- Accelerated expansion today. Unsure about future

Outstanding Issues

- Why the Big Bang ? Quantum Gravity
- What is the Dark Matter ? LHC
- Can not make a definitive prediction of the future as some parameters are not measured yet. Observations may tell us more about the nature of Dark Energy