Indian Institute of Technology, Kanpur
Department of Earth Sciences

ES0213A: Fundamentals of Earth Sciences

Lecture 03. Origin of the Universe

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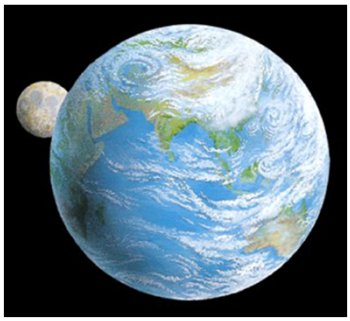
Aims of this lecture

Concept of Scale and Time

Origin and the Universe

The Earth



We pass our lives on our one planet Earth.

Earth may seem endless; it isn't.

Viewed from space, Earth is a small, shiny globe.

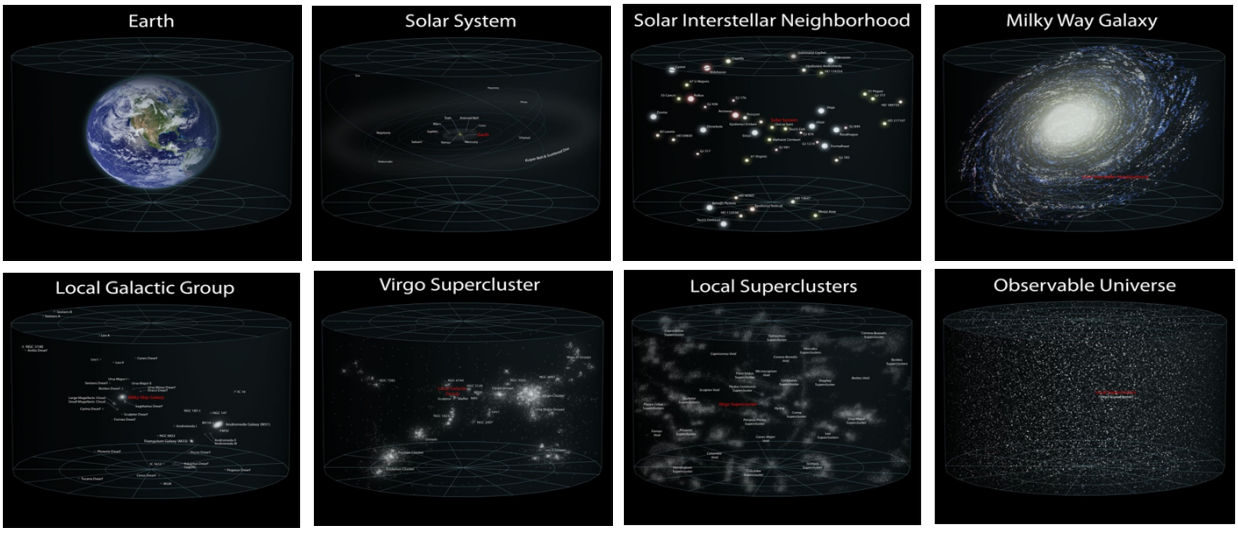
It is truly our island oasis in space.

The Earth is a very special and unique planet.

- Its temperature, composition and atmosphere favor life.
- It is dynamic and ever-changing.
- It has a long and complex history

Where is our place in the space, actually?

Concept of Scale



Courtesy: Andrew Z. Colvin, Arizona State University

Concept of Scale

https://htwins.net/scale2/

[View of the universe from the Planck Length to the Universe]

Concept of Time

- If we were to compress the time since the beginning of the universe into one year, and set the first time at January 1st -
  - MID MARCH: Milky way Galaxy formed
  - END AUGUST: Sun and Solar System formed
  - MID SEPTEMBER: Earth Formed
  - END SEPTEMBER: First Life
  - 26th DECEMBER: First Mammal
  - 31st DECEMBER (22:24): Early Human, Stone tools and weapons
  - 31st DECEMBER (23:54): *Homo sapiens* (Modern Human)

Concept of Time

13.7 billion years ago – origin of the universe
4.6 billion years ago – formation of solar system and Earth
3.5 billion years ago – formation of geodynamo; first known fossils (bacteria)
2.7 billion years ago – oxygen begins to build up in atmosphere
2.5 billion years ago – large continents in crust
2.0 to 1.0 billion years ago – more complex life, such as algae, evolved
600 million years ago – first animals
443 million years ago – first mass extinction of life
420 million years ago – first land mammals
359, 251, and 200 million years ago – mass extinctions of life
125 million years ago – first flowering plants
65 million years ago – last mass extinction (death of the dinosaurs and many other species)
5 million years ago – appearance of first hominids
200,000 years ago – appearance of *Homo sapiens*

Cosmology

Conscious thought distinguishes humans.

- Developed across thousands of generations.
- Lends us curiosity, insight, and the ability to learn.

As a result, we seek to explain our surroundings.

- Where do we come from?
- Where do we fit in the Universe?
- Why are we here?

Cosmology

Study of the structure and evolution of the Universe.

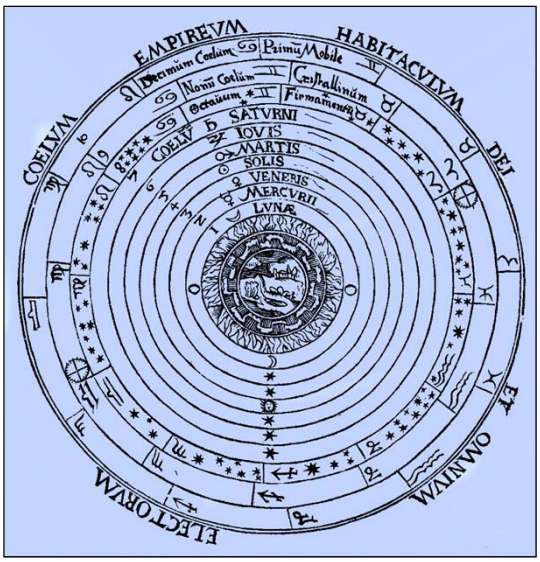
Cosmology is a complicated science.

- Requires thinking in unfamiliar scales of space and time.
  - Spatial scales.
    - Attometers (10^{-21} meters), to
    - 10s of billions of light years (9.46^{22} meters +).
  - Temporal scales.
    - Attoseconds (10^{-21} seconds), to
    - 10s of billions of years (3.15^{17} seconds +).

Ideas about the Universe have a rich history.

- These ideas are often culturally determined (and dominated).

The Earth Centered Universe



Universe as conceived of by **Aristotle** and **Ptolemy**.

The earth is in the center, does not revolve on its axis and composed of four elements: Earth, Water, Fire and Air. It is surrounded by ten concentric spheres made of a perfectly transparent substance known as "quintessence." These spheres revolve around the earth, carrying the other celestial bodies. As you can see, one is the sphere "of the Moon" ("Lunae"), two is Mercury ("Mercurii"), three is Venus ("Veneris"), four is the Sun ("Solis"), five is Mars ("Martis"), six is Jupiter ("Iovis"), seven is Saturn ("Saturni"), and spheres eight, nine and ten hold the "fixed stars". Beyond the tenth sphere is, as the words in the periphery say in Latin, "The Kingdom of Heaven, the Abode of God and of the Elect."

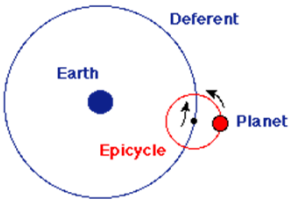
What is the problem of this model?

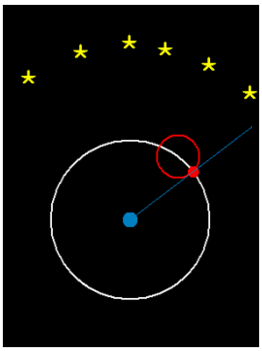
The problems of Earth Centered Universe

- Does not explain retrograde motion of planets

Retrograde motion of Mars in summer of 2003.
Image source: NASA

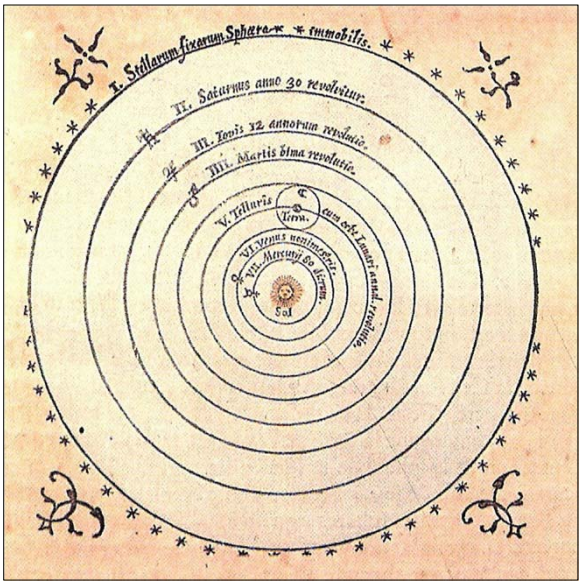
SOLUTION: Claudius Ptolemy





- Does not explain the changing brightness and phases of the planets

Sun Centered Universe

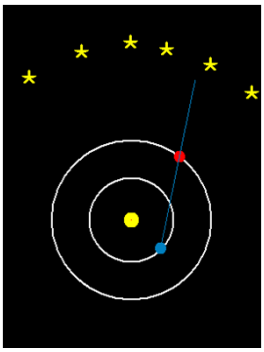


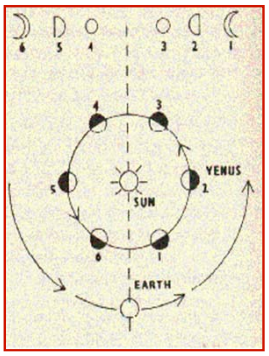
Through careful observation, **Nicolas Copernicus** noted a major problem with Ptolemy's model. The mathematical issue he noticed was that occasionally the planets would travel backwards through the sky. This is known as retrograde motion.

In 1514 after moving back to Poland, Copernicus distributed the first handwritten copies of his book to his friends. In his book he purposed that the Earth was not in ne center of the universe but instead the sun was. The principles of his sun-centered astronomy became known as ***heliocentric astronomy***. His book also stated that the rotation of the Earth around the sun accounted for the rising and setting of the sun, movement of the stars, and the changing season. Finally his book also explained that the Earth's motion through space caused the retrograded motion of the planets.

Sun Centered Universe

- Retrograde motion of planets (Nicolai Copernicus)
- Phase changes of planets (Galileo Galilei)
- Varying brightness of planets



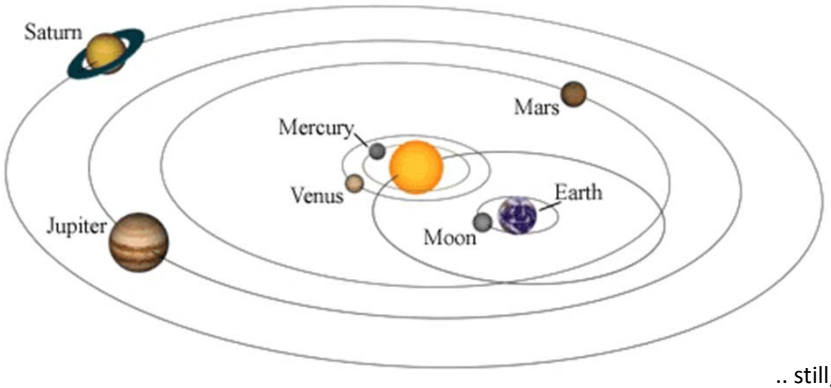


.. automatically solves as the distance between the planets and the Earth varies with time.

- Note, the orbits of the planes are still CIRCULAR and the planets have uniform motion.
- Problems in predicting the future positions of planets.

Sun Centered Universe

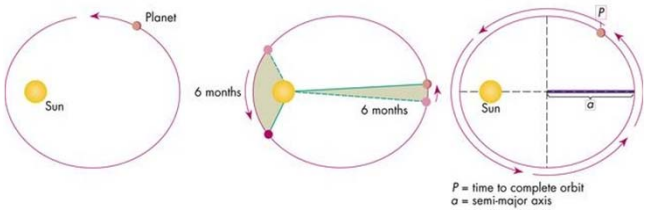
- **Tycho Brahe** proposed a model of the solar system to explain Galileo's observation that Venus has phases without making it necessary for Earth to be moving. His model had all the planets (except Earth) orbiting around the Sun, but then the Sun orbited around the Earth. This model satisfies ALL the observations because it corresponds to reality except that is viewed from the point of view of someone on Earth.



.. still, circular orbits

Sun Centered Universe

- Laws of planetary motion (1602) – Johannes Kepler [1571-1630]
  - FIRST LAW: The path of the planets about the sun is elliptical in shape, with the center of the sun being located at one focus. [The Law of ELLIPSE]
  - SECOND LAW: The orbital speed of a planet varies so that a line joining the Sun and the planet will sweep over equal areas in equal time intervals. [The Law of EQUAL AREAS]
  - THIRD LAW: The ratio of the squares of the periods of any two planets is proportional to the ratio of the cubes of their average distances from the sun. [The Law of HARMONICS]

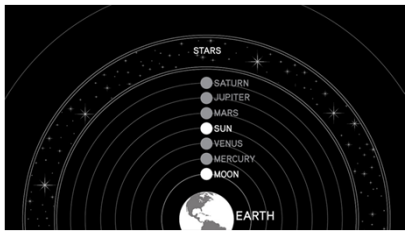


$$P^2 \text{ (years)} \propto \alpha^3 \text{(AU)} = \frac{4\pi^2}{G(M_1+M_2)}\alpha^3$$

- Observations support these laws, but WHY the laws should work was unknown.

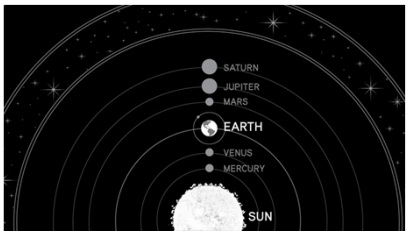
The evolution of understanding

Ptolemy's Universe



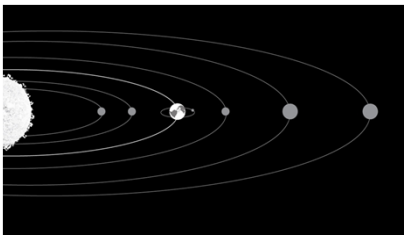
The Ptolemaic view of the Universe was an Earth-centered, or geocentric, model. The Sun and all of the planets orbited the Earth and the other stars formed a backdrop that also orbited Earth.

The Copernican Model



Sun-centered, or heliocentric, view of the Universe had been suggested by ancient Greek astronomers like Aristarchos and was later published by Polish astronomer Nicolaus Copernicus in 1543. To some extent, this model (not at actual scale in this illustration) ushered in a new age of astronomy.

The Copernican Model



The German astronomer and mathematician Johannes Kepler demonstrated that the orbits of Earth and the other planets (not drawn to scale in this illustration) were not perfectly circular but were actually elliptical, or egg-shaped.

Sun Centered Universe

- **Galileo Galilei** started observing the "heavens" with his telescope. His observations also supported the sun-centered universe model.
  - "Sun has dark patches and it rotates on an axis"
  - 4 Galiliean Moons of Jupiter
  - Phases of Venus
  - "Great cloud" – the Milky Way
  - "Saturn has ears" – the Ring of Saturn
  - The surface of moon is rough, not smooth
- His greatest contribution towards understanding our Universe is the concept of inertia.
- **Isaac Newton** first explained **WHY** Kepler's laws of planetary motion should work – the three Laws of Motion and Gravity

Sun Centered Universe - issues and problems

- The Parallax phenomena was an expected observation as the Earth orbits around the sun. However, there was no OBSERVED shift of distant stars. [well, we had to wait for Friedrich Bessel, who first precisely measured the distance of another star (*61 Cygni*) from Sun using parallax].
- With the invention of better technology (telescope) the details of Galaxy was known but even at late 20th century, SUN was still at the center of Galaxy and therefore center of the universe.
- In 1918, Harlow Shapley and Henrieta Leavitt moved the Sun from the center of the Galaxy and which was later (1923) confirmed by the observation from Hubble Telescope. In fact, it showed there are many Galaxies in the universe moving away (the Redshift).
- NOTE: Albert Einstein was already in the picture then with his special (1905) and general (1915) theory of relativity. The first one proposed that the Laws of Motion does not hold when velocities approach to that of light. The second one suggests that Newton's Law of Gravitation is only approximately correct; breaks down in at very strong gravitational fields.

… all of these and many others set the foundation of BIG BANG THEORY.

Where did we start?

The best-supported theory of our universe's origin centers on an event known as the big bang. This theory was born of the observation that other galaxies are moving away from our own at great speed in all directions, as if they had all been propelled by an ancient explosive force.

- 1927: Georges Lemaitre independently derived formulations for expanding universe.
- 1929: Edwin Hubble's observation of receding galaxies and stars supported Lemaitre's theory.
- 1931: Georges Lemaitre finally proposed the hypothesis of the primeval atom, which idealize the fact that the universe took its birth by an **explosion of primitive atom**.

Where did we start?

It happened about 13.7 billion year ego when the whole universe was concentrated in an incredibly hot and super dense point.

TIME	10^{-43} sec.	10^{-32} sec.	10^{-6} sec.	3 min.	300,000 yrs.	1 billion yrs.	9.0-9.1 billion y
TEMP	10^{32} °C	10^{27} °C	10^{13} °C	10^{8} °C	10,000 °C	-200 °C	-258 °C
	From nothing, something infinitely small dense and hot appeared. Everything that exists today was compressed into a volume smaller than the nucleus of an atom!	Post-inflation, the universe is a seething hot soup of electrons, quarks and other particles. The size is more than trillion trillion times.	Rapidly cooling universe. Gravity, electromagnetic force and the string and week nuclear interactions appear.	The nuclei of the lightest elements, H and He form.	First appearance of atom. Electrons orbit the nuclei, attracted by the protons. The universe become transparent as photons travel through space.	Galaxies acquire their definitive shape – islands of millions of star. Star explodes as supernovas and disperse heavier elements, like C.	Emergence of Solar system; "Soon after" the our Earth (the only planet known to have life).

Where did we start?

This course is certainly not meant for going in to the details of the Big Bang Theory. However, if you are interested, can click the following link and check the videos. There are also many online resources…

https://www.space.com/13352-universe-history-future-cosmos-special-report.html

Solar System Simulator

https://space.jpl.nasa.gov/

Assignment 02

- What are the evidences of the Big Bang Theory?
- Why is the Big Bang Theory unique?
- Calculate the semi-major axis of Venus using the Laws of Kepler [P=225 yrs.]
- Is the universe Expanding or Contracting? Justify.

Assignment 03

- If you are in Mars, which of the following planet(s) will show phases:

  (a) Mercury, Earth and Venus

  (b) Mercury and Venus

  (c) Venus

  (d) Saturn, Uranus and Neptune

- Illustrate a drawing to show the Sun at the centre and the orbits of Venus, Earth, and Mars. Is the figure, mark the location in Venus' orbit where a new phase of Venus can be seen from Earth. Also mark a sport with a different symbol to show where Venus will show a full phase. (use simple pencil on paper or any illustrating software (Illustrator, Corel, CAD etc.) [*clue: think the way of Galileo!]*

Summary of this lecture

- The ancients thought the Universe was geocentric

- The Renaissance: (1) Copernicus – Published evidence for heliocentricity. (2) Kepler – His elliptical planetary orbits refuted Ptolemy. (3) Galileo – Observed moons orbiting Jupiter. (4) Earth didn't center the Universe. (5) Planetary orbits weren't circular. (6) Not all bodies orbited Earth.

- The Enlightenment: (1) The Law of Universal Gravitation. (2) The Three Laws of Motion. (3) The mathematics of change (calculus).

Summary of this lecture

- The Earth is not in the center of the universe, nor the Sun.
- Earth is one of nine planets in the solar system.
- The solar system is on an arm of the Milky Way galaxy.
- Our Sun is one of 300 billion stars in this galaxy.
- The Universe contains more than a billion galaxies.

Next lecture

Origin of the Solar System