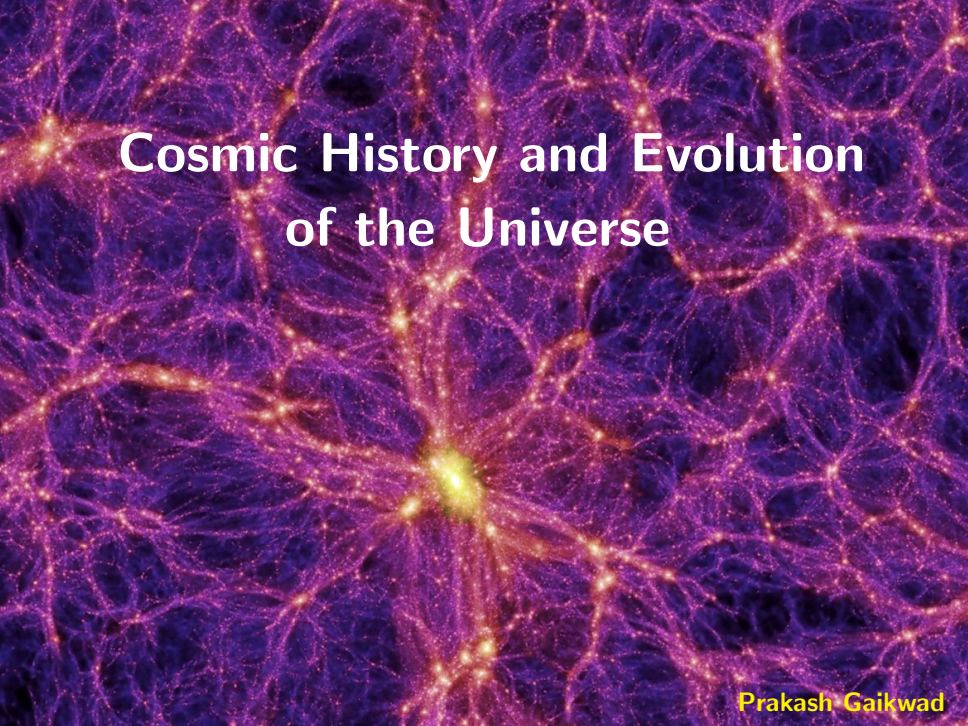


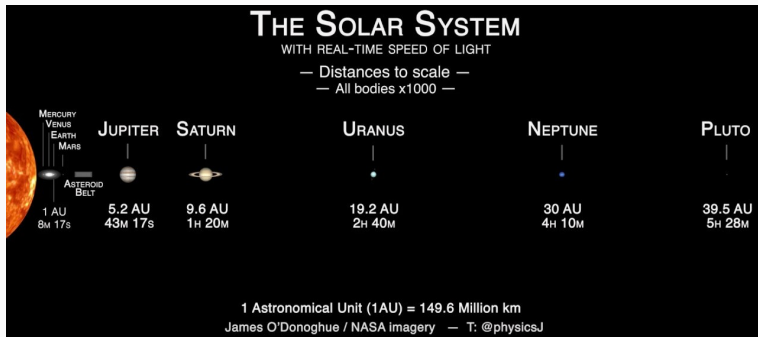
A visualization of the cosmic web, showing a dense network of purple filaments and nodes of yellow and orange light against a dark blue background. The central node is particularly bright and yellow.

Cosmic History and Evolution of the Universe

- Astrophysical scales
- Structures
- Large scale structures
- The formation of large scale structures
- Future Prospects

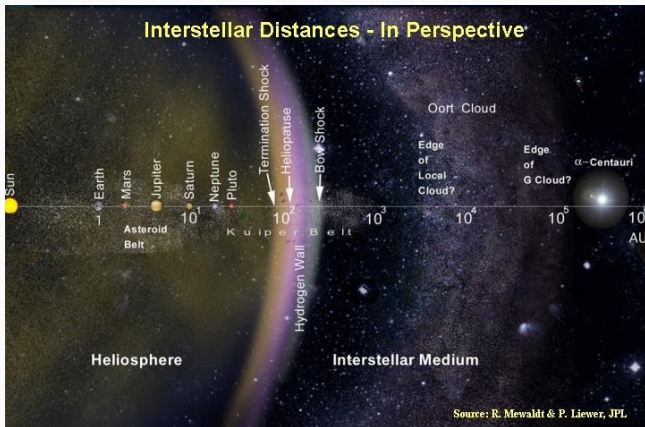
Astrophysical Scales

Scale: Solar System



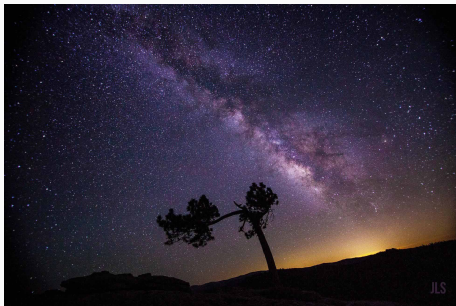
- Size of earth (radius) 6000 km
- Average distance between sun and earth is 150 million km.
- Large distances are expressed in light travel time (300000 km/s)
- Average distance between sun and earth is ~ 8.25 light minutes.
- Distance between Pluto and Sun is 5.5 light hours
- **Scale of Planetary systems is few light hours**

Scale: Interstellar Medium



- Extent of solar system : ~ 16 light hours
- Voyager 1 launched on September 5, 1977 is at 20 light hours from Sun
- Nearest star Proxima Centuari is at 4.25 light years
- **Interstellar distances are usually expressed in light years**

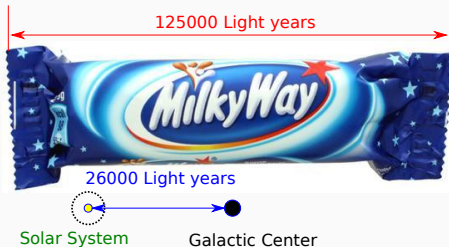
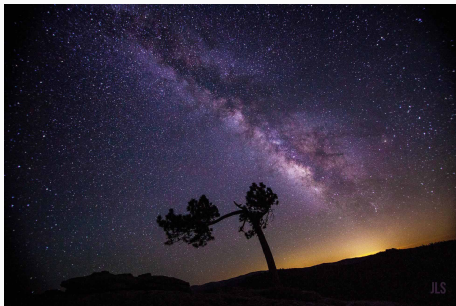
Scale: Milky Way



- Milky way: A hazy band of light seen in the night sky
- Stars cannot be individually distinguished by the naked eye.
- No man-made object has gone outside milky way to take pretty pictures.
- **Imagination is more than knowledge**

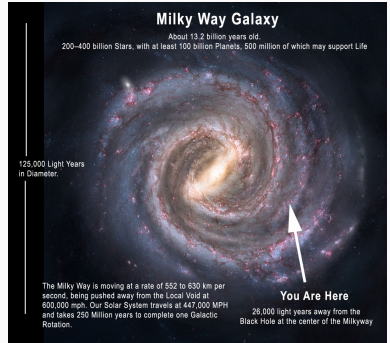
A. Einstien

Scale: Milky Way



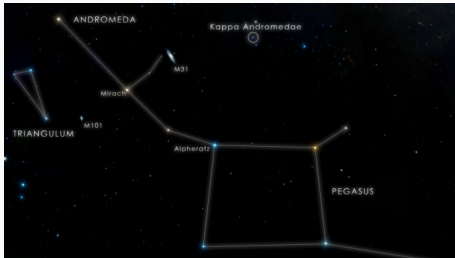
- Milky way: A hazy band of light seen in the night sky
- Stars cannot be individually distinguished by the naked eye.
- Diameter of Milky way is 125000 (0.125 million) light years
- Solar system is at 26000 light years from Galactic center.

Scale: Galactic



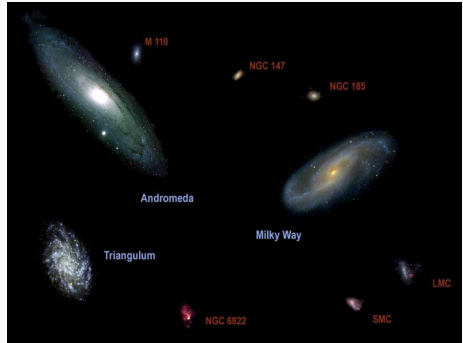
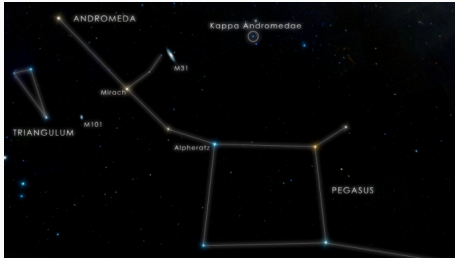
- Milky way: A hazy band of light seen in the night sky
- Stars cannot be individually distinguished by the naked eye.
- Diameter of Milky way is 125000 (0.125 million) light years
- Solar system is at 26000 light years from Galactic center.
- Milky way contains 200-400 billion stars and at least 100 million planets.
- **Galactic scales are expressed in units of few million light years.**

Scale: Intergalactic



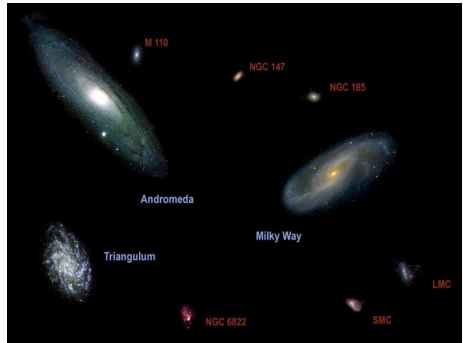
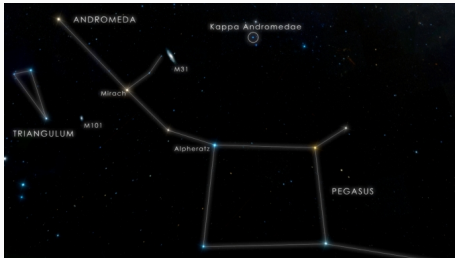
- Milky way is not the only Galaxy in the Universe.
- M31 Galaxy in Andromeda constellation is largest nearby spiral galaxy.
- Diameter of M31 (Andromeda Galaxy) 0.22 million light years.
- Diameter of Milky Way 0.125 million light years.

Scale: Intergalactic



- M31 (Andromeda Galaxy) : 0.22 million light years in diameter
- Milky Way : 0.125 million light years in diameter.
- M33 (Triangulum Galaxy) : 0.03 million light years in diameter
- Local group: Group of ~ 30 galaxies
- **Intergalactic scale: Distance between galaxies?**

Scale: Intergalactic



- Distance between Milky Way and Andromeda Galaxy : 2.5 million light years
- Distance between Milky Way and Triangulum Galaxy : 2.7 million light years
- **Intergalactic scale: > 3 million light years**

Scale: Overview

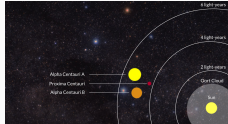
Planetary



~ 100 light hours

~ 4 light days

Interstellar



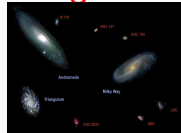
~ 100 light years

Galactic



~ 0.5 million
light years

Intergalactic

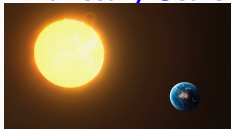


> 3 million
light years

Structures

Structures

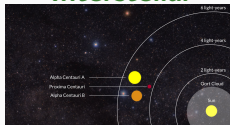
Planetary Scale



~ 100 light hours

~ 4 light days

Interstellar



~ 100 light years

Galactic



~ 0.5 million
light years

Intergalactic

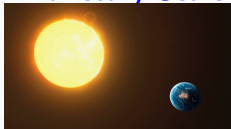


> 3 million
light years

Structures: Gravitationally bound systems

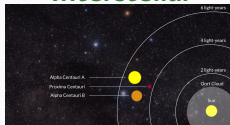
Structures

Planetary Scale



~ 100 light hours
~ 4 light days

Interstellar



~ 100 light years

Galactic



~ 0.5 million
light years

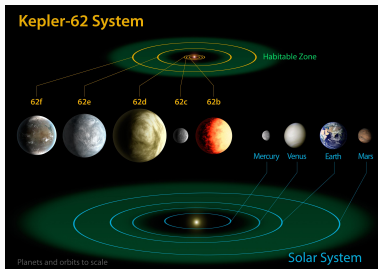
Intergalactic



> 3 million
light years

Planetary System

~ 100 light hours
~ 4 light days



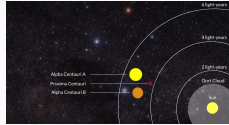
Structures

Planetary Scale



~ 100 light hours
~ 4 light days

Interstellar



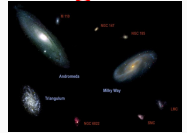
~ 100 light years

Galactic



~ 0.5 million
light years

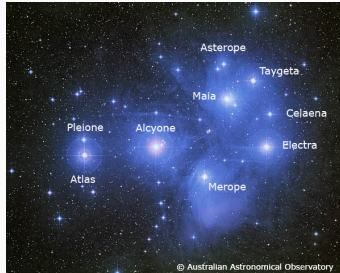
Intergalactic



> 3 million
light years

Star Clusters

~ 100 light years



@ Australian Astronomical Observatory

Structures

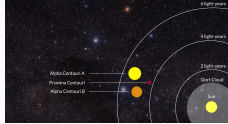
Planetary Scale



~ 100 light hours

~ 4 light days

Interstellar



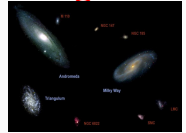
~ 100 light years

Galactic



~ 0.5 million
light years

Intergalactic



> 3 million
light years

Galaxies

~ 0.5 million
light years



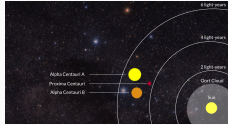
Structures

Planetary Scale



~ 100 light hours
~ 4 light days

Interstellar



~ 100 light years

Galactic



~ 0.5 million
light years

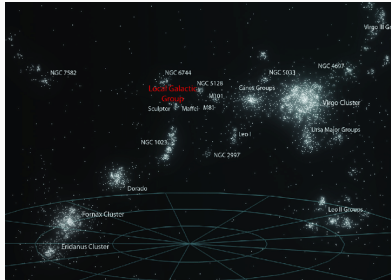
Intergalactic



> 3 million
light years

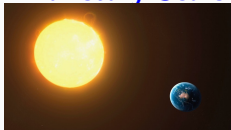
Galaxy Cluster

> 3 million
light years



Structure: Overview

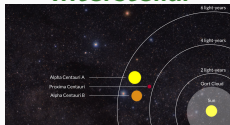
Planetary Scale



~ 100 light hours

~ 4 light days

Interstellar



~ 100 light years

Galactic



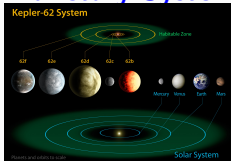
~ 0.5 million
light years

Intergalactic



> 3 million
light years

Planetary System



Star Clusters



Galaxies



Galaxy Cluster



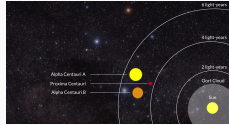
Structure: Overview

Planetary Scale



~ 100 light hours
~ 4 light days

Interstellar



~ 100 light years

Galactic



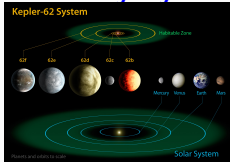
~ 0.5 million
light years

Intergalactic



> 3 million
light years

Planetary System



Star Clusters



Galaxies



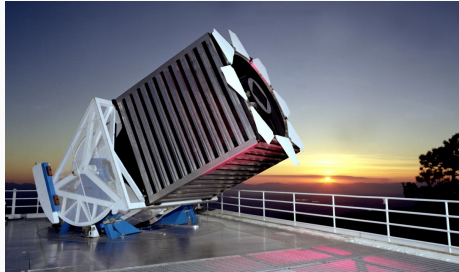
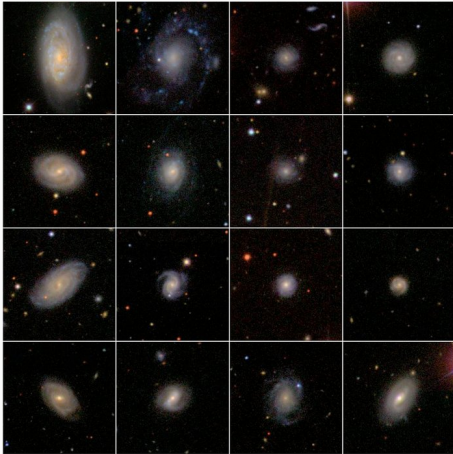
Galaxy Cluster



Large Scale Structure : Galaxy clusters and above 12

Large Scale Structure

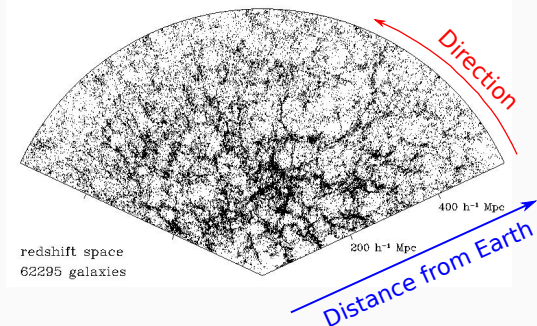
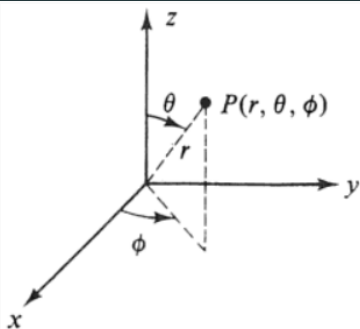
Galaxy Survey



Sloan Foundation 2.5m Telescope
at Apache Point Observatory

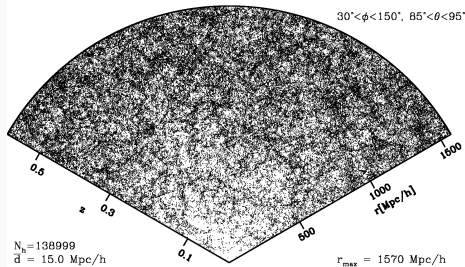
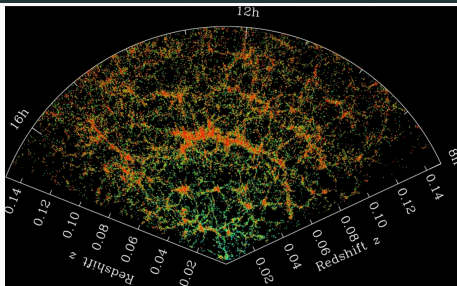
- Sloan Digital Sky Survey (SDSS), Sample of Galaxies detected in SDSS
- Number of Galaxies detected : 208,478,448
- One can not study each and every individual galaxy.
- Instead we ask, how are the galaxies distributed in the Universe?

Galaxy survey



- How are the galaxies distributed? Position of a galaxy?
- **3 Numbers: Longitude, latitude and radial distance**
- **Direction: Longitude and latitude are projected on plane.**
- **Radial distance: Distance to galaxy from earth**
- 1 Mpc = 3.26 million light years

Galaxy survey



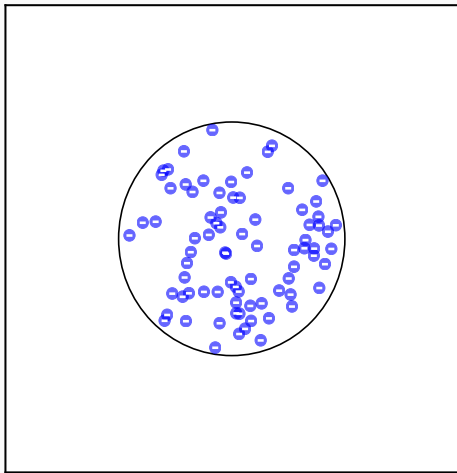
Observation: SDSS Galaxy survey

Simulation: Theoretical Prediction

- Each dot is a galaxy.
- Observations: Galaxies in some places are located very close to each other
- Theoretical prediction of galaxies distribution is more uniform.
- Theoretical prediction of galaxies is different than observations.
- Why do observed galaxies show clustering? $\Rightarrow$ How do galaxies form?

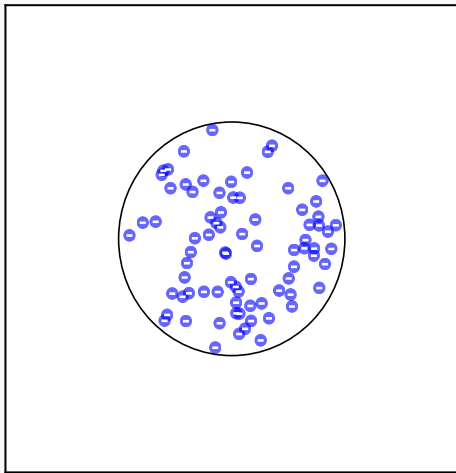
Large Scale Structure Formation

At the beginning ...



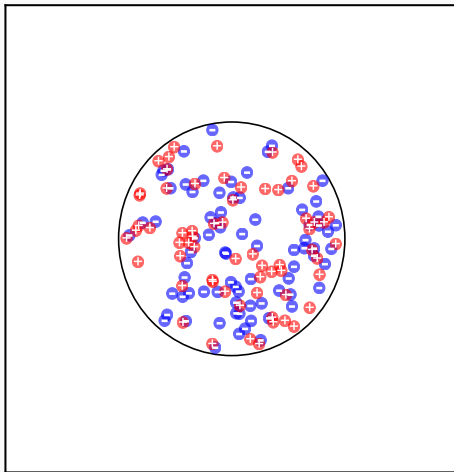
Big Bang: Elementary particles and high energy radiation were produced

Structure Formation



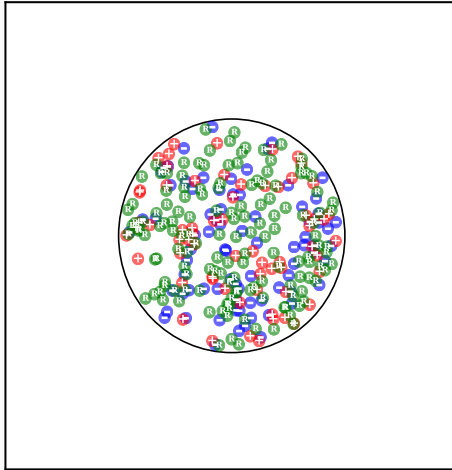
- Big Bang: Elementary particles and high energy radiation were produced
- **Electrons**

Structure Formation



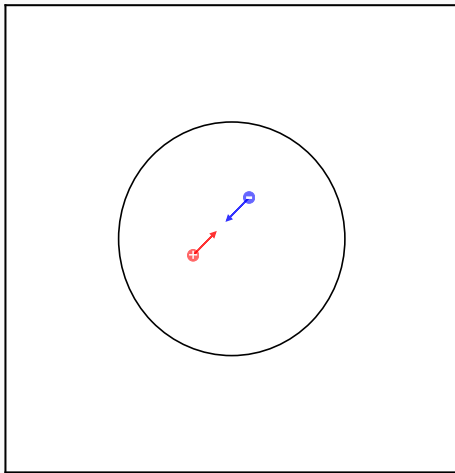
- Big Bang: Elementary particles and high energy radiation were produced
- **Electrons**, **Protons**

Structure Formation



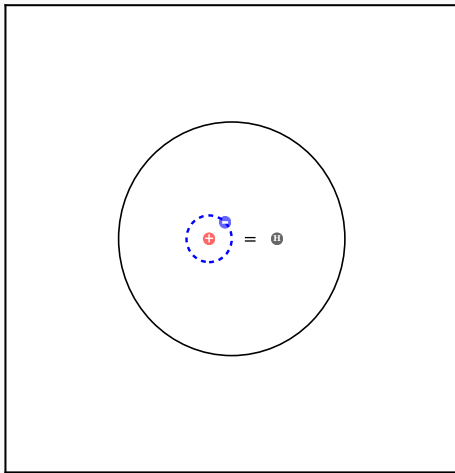
- Big Bang: Elementary particles and high energy radiation were produced
- **Electrons**, **Protons**, **High Energy Radiation**

Structure Formation



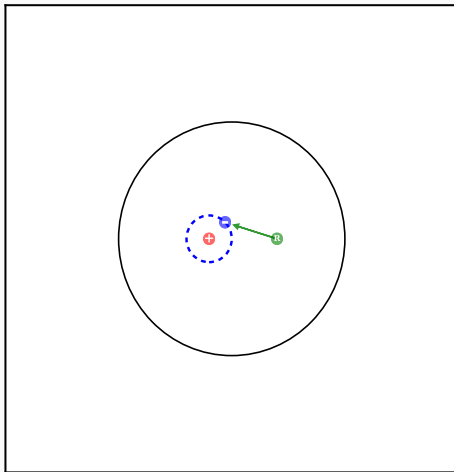
- Negatively charge electrons are attracted towards positively charged protons.

Structure Formation



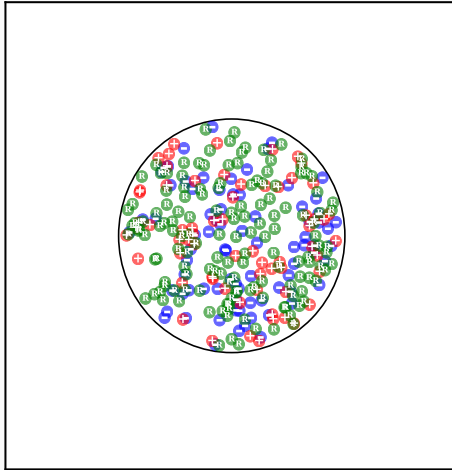
- Negatively charge electrons are attracted towards positively charged protons.
- If proton captures electron, it creates hydrogen atom.

Structure Formation



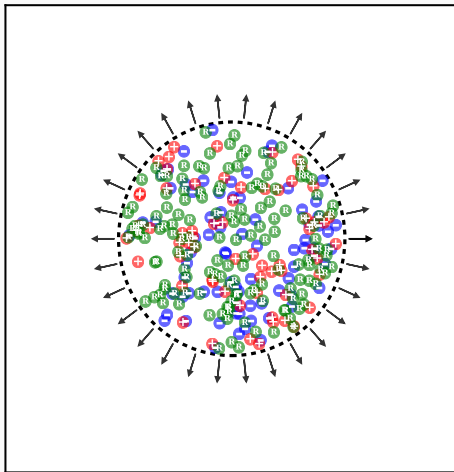
- If proton captures electron, it creates hydrogen atom.
- However, high energy radiation/photons collide with electron and separate electrons and protons

Structure Formation



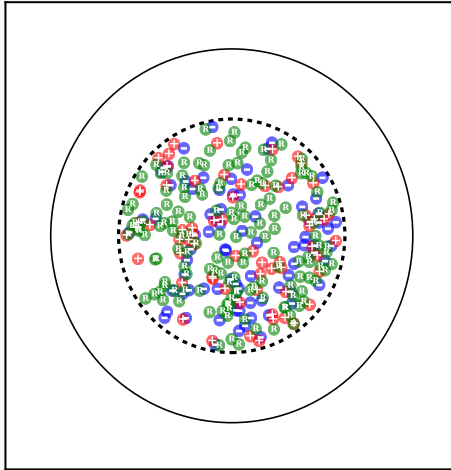
- In early universe, protons and electrons were separated due to high energy photons.

Structure Formation



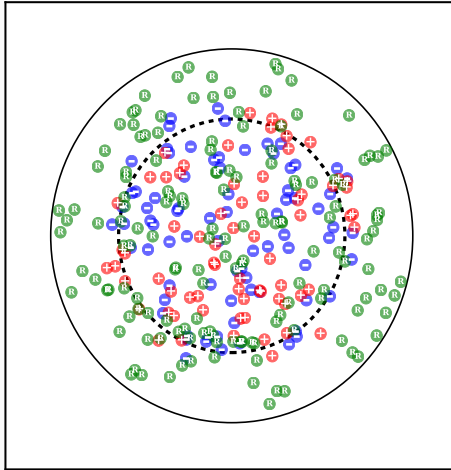
- In early universe, protons and electrons were separated due to frequent collisions with high energy photons.
- But universe continues to expand with time..

Structure Formation



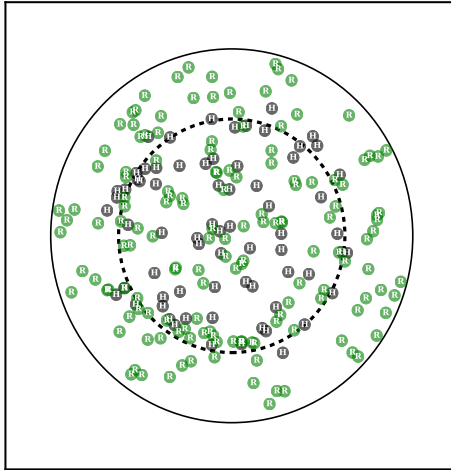
- With the expansion of the Universe, more space is available for electrons, protons and high energy photons to occupy.

Structure Formation



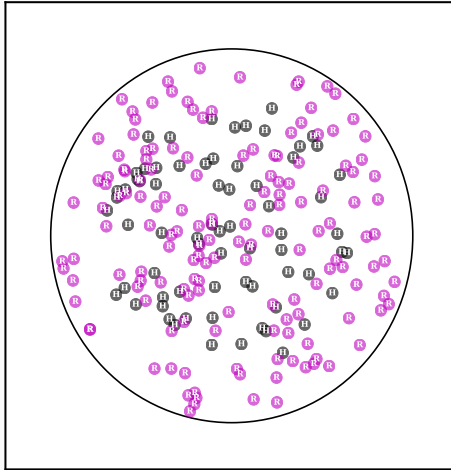
- Photons occupy extra space quickly as compared to electrons and protons.
- Because photons move at speed of light while electrons and protons move slightly slowly.

Structure Formation



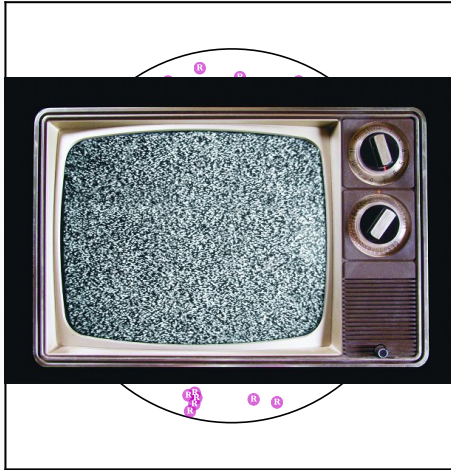
- Since density of photons drops quickly compared to electrons and proton, there is less frequent collisions between photons and electrons.
- As a result hydrogen atoms can be formed.

Structure Formation



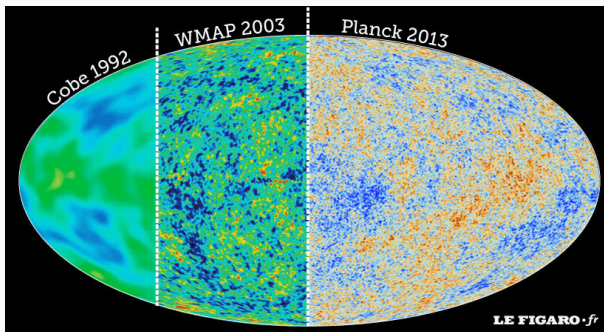
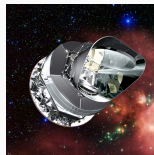
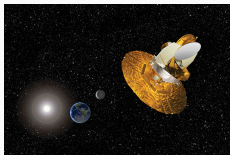
- Thus photons are decoupled from protons and electrons (hydrogen atom).
- These photons travel through space without interacting with matter and we all have seen them.

Structure Formation



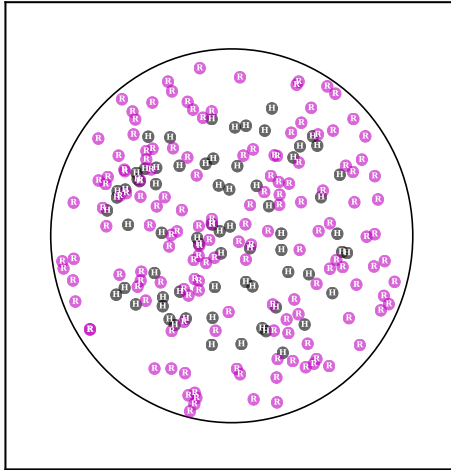
- 1 % of Television static noise is contributed by Cosmic Microwave Background Photon.

Cosmic Microwave Background



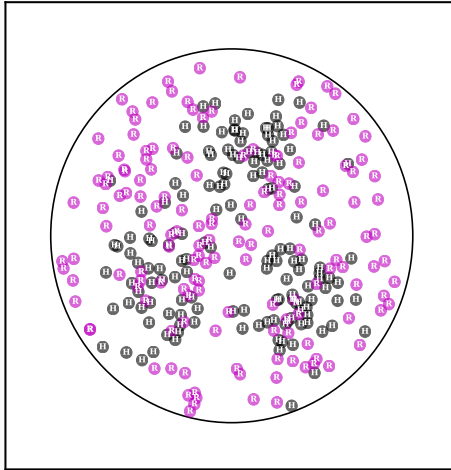
- Observations using space satellite.
- Nobel Prizes: 1978 (Discovery of CMB), 2006 (Measuring properties of CMB)

Structure Formation



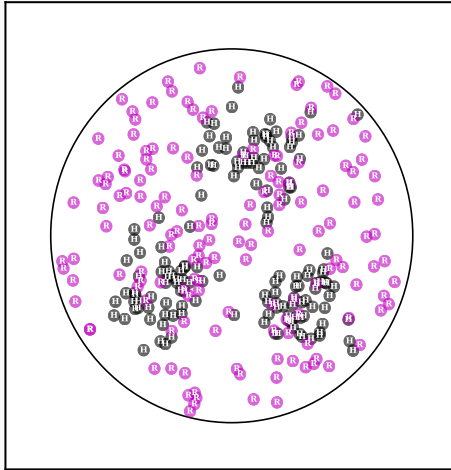
- Thus photons are decoupled from protons and electrons (hydrogen atom).
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Structure Formation



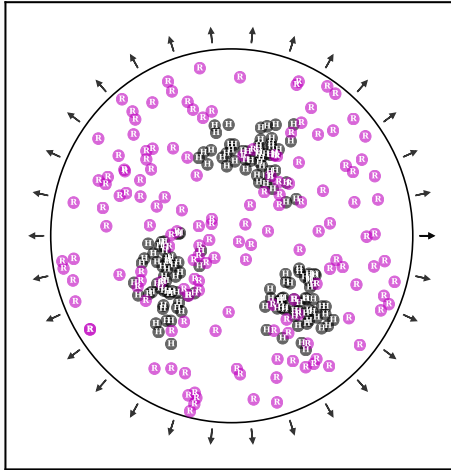
- Hydrogen atom starts to come together due to force of gravity.

Structure Formation



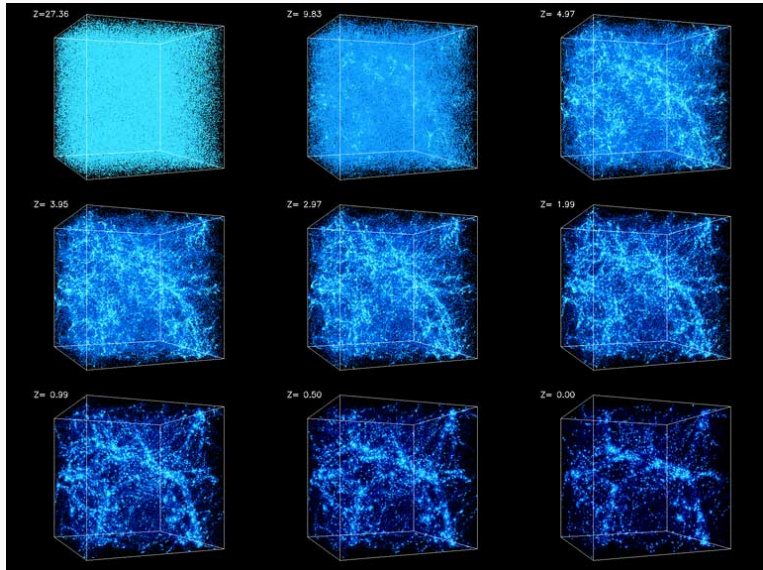
- Formation of Structures due to gravitational collapse.
- Large clouds of Hydrogen atom forms stars

Structure Formation



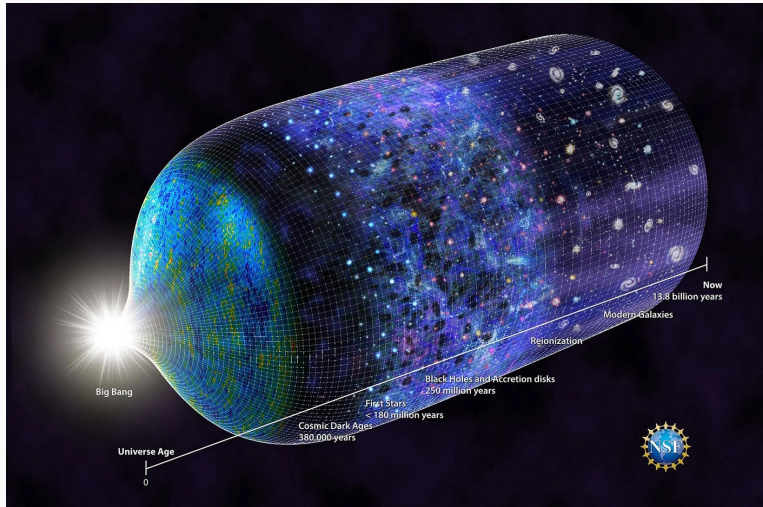
- Hierarchical Structure Formation: Stars, Galaxies and Galaxy clusters
- During all this time Universe continue to expand

Structure Formation



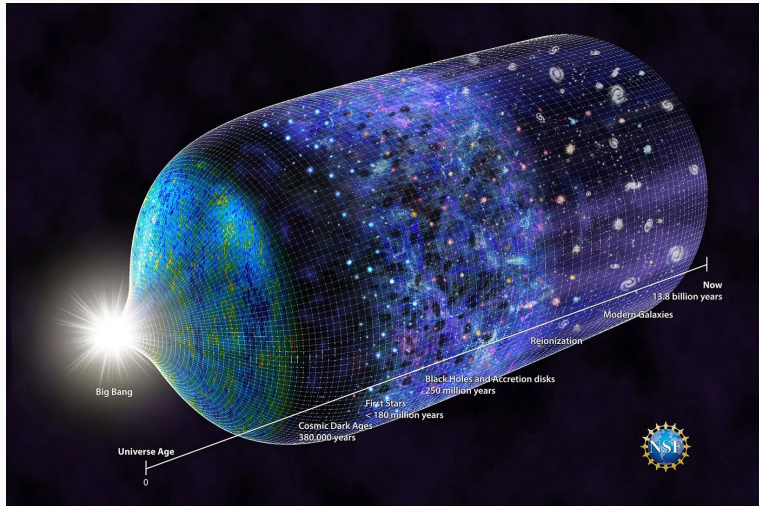
- Cosmological Simulations performed on supercomputers

Evolution of Universe



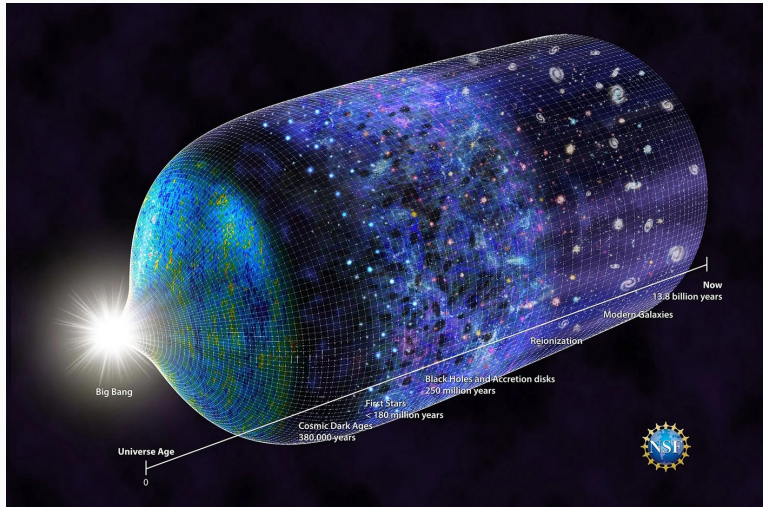
- Universe started with Big-Bang (~ 13.8 billion years ago)
- Big-Bang $\Rightarrow$ Event of creation of Space-Time

Evolution of Universe



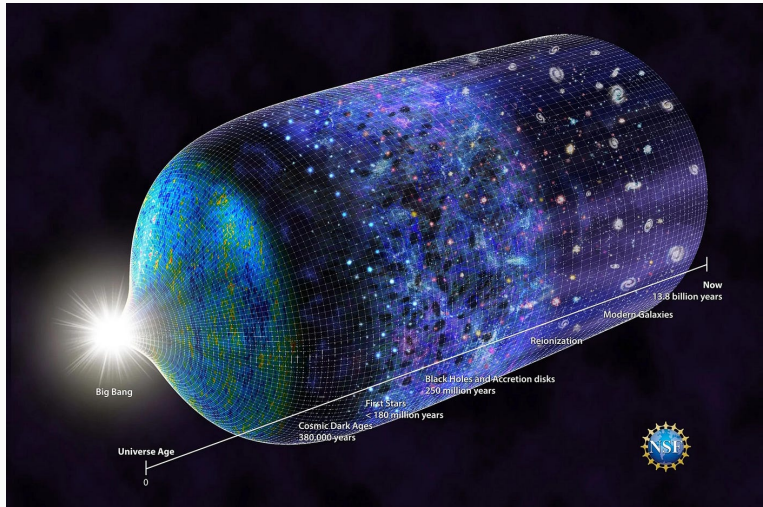
- Expansion of the Universe $\Rightarrow$ Decoupling of Photons
- Cosmic Microwave Background ($t_{\text{age}} \sim 0.4$ million years)

Evolution of Universe



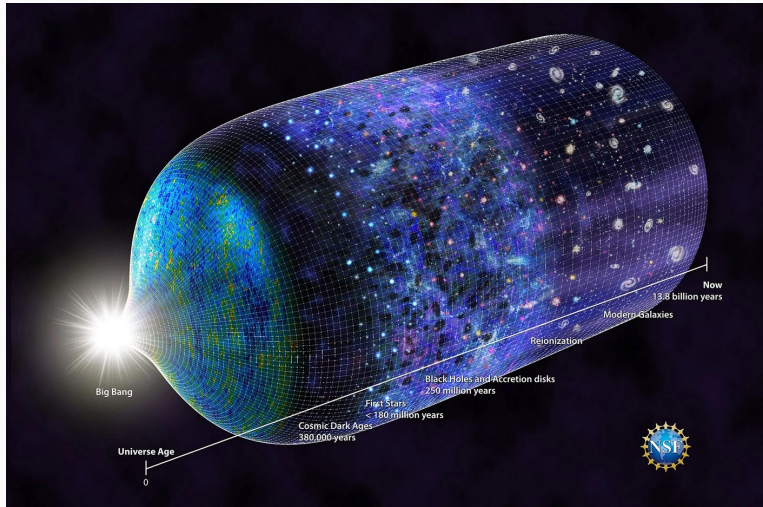
- Takes some time to form stars (Gravity is weak force)
- Dark Ages $\Rightarrow$ No visible light in Universe ($t_{\text{age}} \sim 0.4 - 180$ million years)

Evolution of Universe



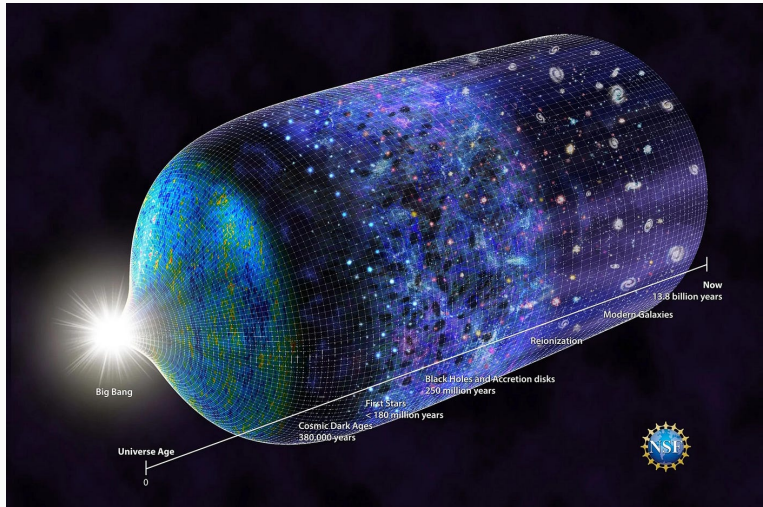
- Formation of first stars in the Universe ($t_{\text{age}} \sim 180$ million years)
- Age of the Sun $\Rightarrow$ ($t_{\text{sun}} \sim 4$ billion years)

Evolution of Universe



- First Blackholes formed around ($t_{\text{age}} \sim 250$ million years)
- Ionization of the Universe due to stars

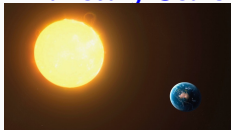
Evolution of Universe



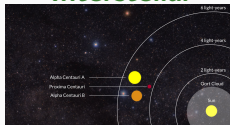
- Milkyway like Galaxies formed ($t_{\text{age}} \sim 1$ billion yrs)
- Today Universe is $t_{\text{age}} \sim 13.8$ billion yrs old

Large Scale Structure: Summary

Planetary Scale



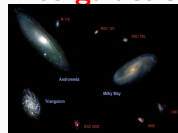
Interstellar



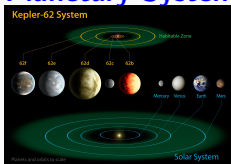
Galactic



Intergalactic



Planetary System



Star Clusters



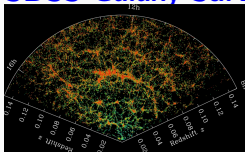
Galaxies



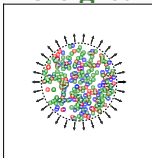
Galaxy Cluster



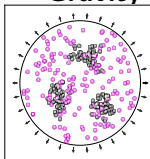
SDSS Galaxy Survey



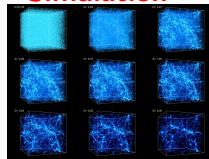
The big bang



Gravity

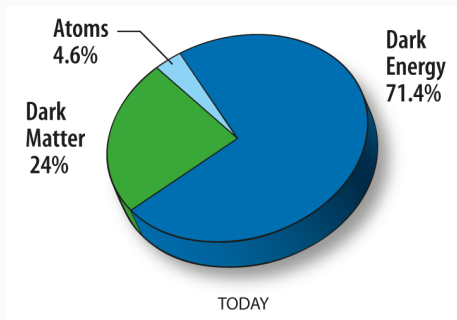


Simulation



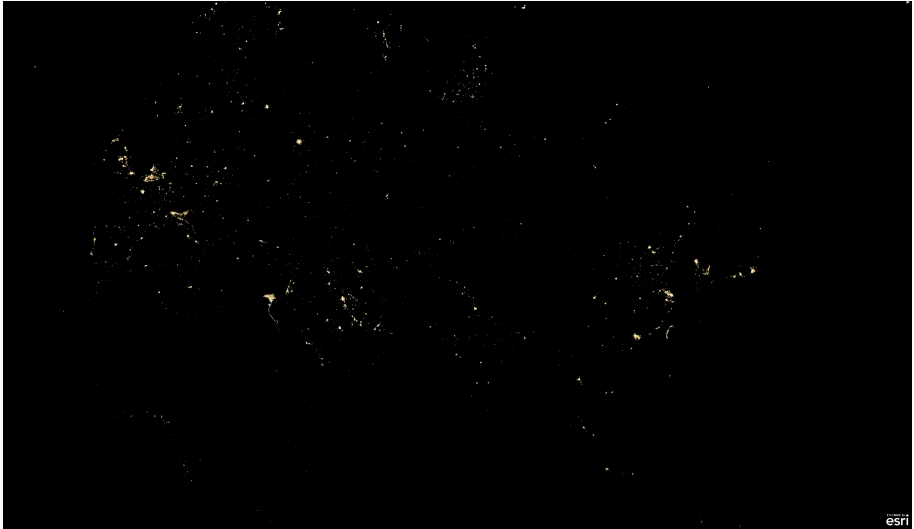
Future Prospect

Composition of the Universe



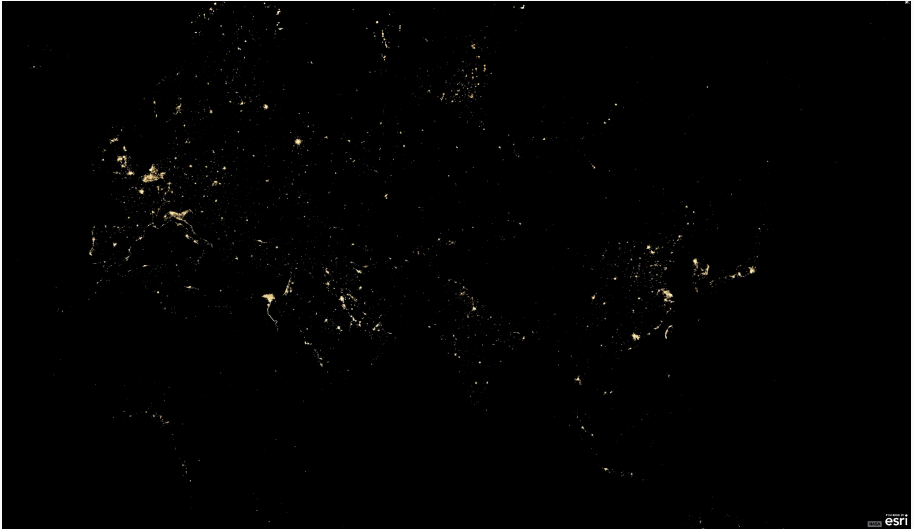
- Expansion of the Universe $\Rightarrow$ Dark Energy
- Gravitational Potential $\Rightarrow$ Dark Matter
- Dark Matter interacts with ordinary (baryonic) matter only through gravity.
- We see the light coming from 4.6% of baryonic component.
- How to use large scale structure and get information about dark matter?

Composition of the Universe



- Given a light distribution, what does it correspond to? Star Cluster or Galaxy Cluster?

Composition of the Universe



- To gain more information, we need to see fainter and fainter objects

Composition of the Universe



- We can do this by increasing observation time or making telescope bigger.

Composition of the Universe



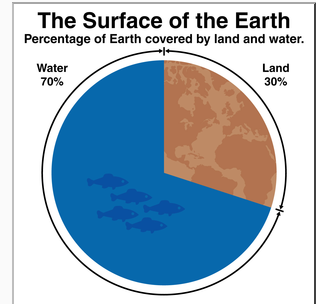
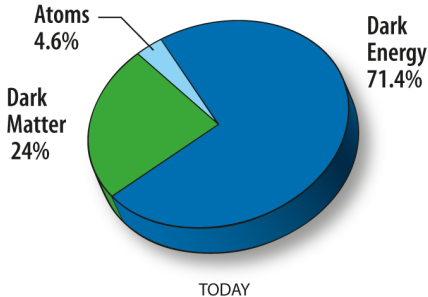
- When we see fainter and fainter object, we see light distribution corresponds the major cities in Europe and Asia.

Composition of the Universe



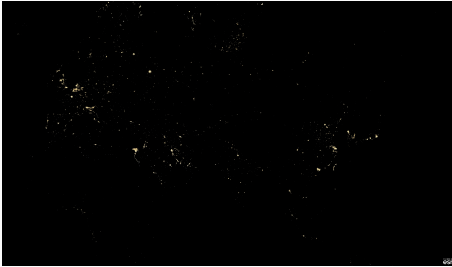
- This situation is very similar to the Universe.

Composition of the Universe

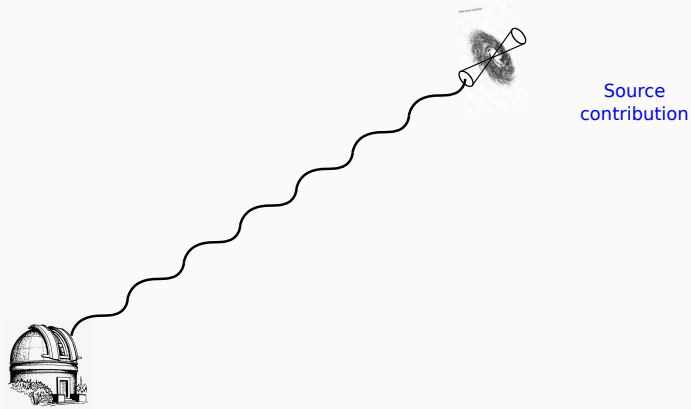


- Water on earth $\Leftrightarrow$ Dark Energy (70 %, do not emit light)
- Land on earth $\Leftrightarrow$ Total matter
- Major cities on earth $\Leftrightarrow$ Galaxies (4% that emit light)
- Major cities on earth $\Leftrightarrow$ Large population density
- Galaxies $\Leftrightarrow$ Large matter density

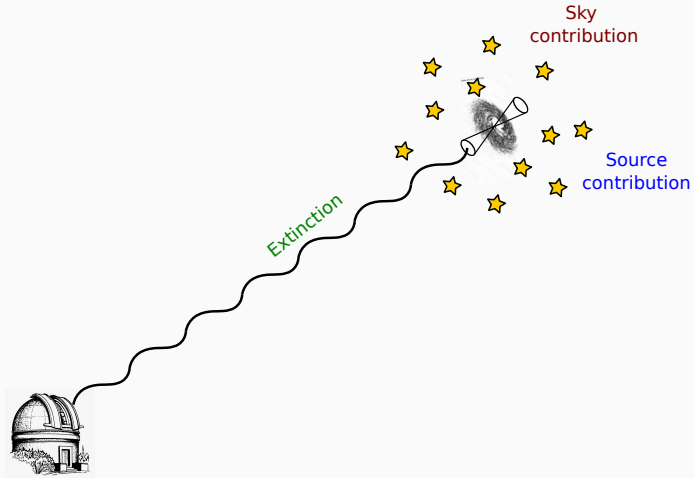
Composition of the Universe



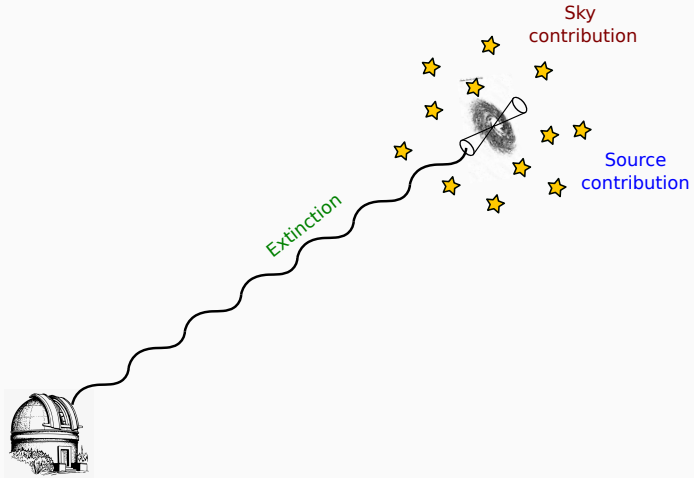
- Only when we see fainter light from small cities, we realize that the light distribution corresponds to Europe and Asia.
- Similarly, when we see fainter galaxies, we can trace the dark matter distribution in the Universe.
- Need Space Engineering Systems (Current area of research)



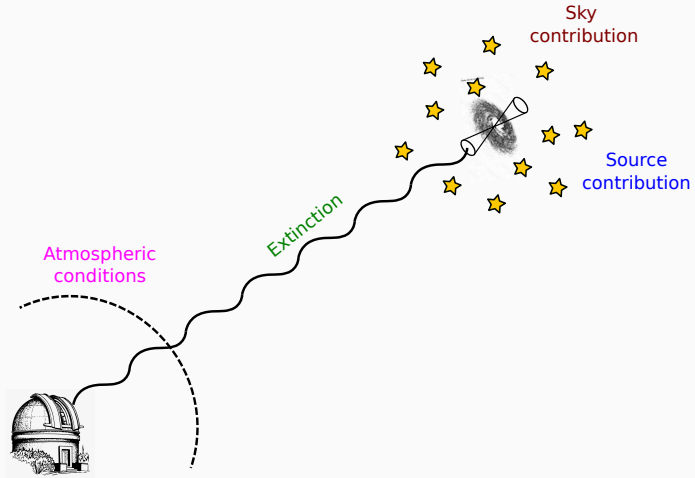
Our aim is to collect light from faint objects like Galaxies



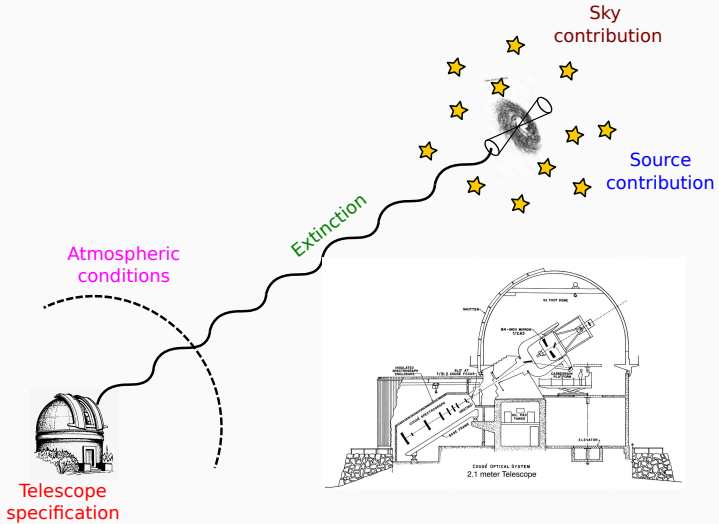
But we not only see Galaxies other objects in Field of View



Part of the light is absorbed by the Galaxy (Extinction)

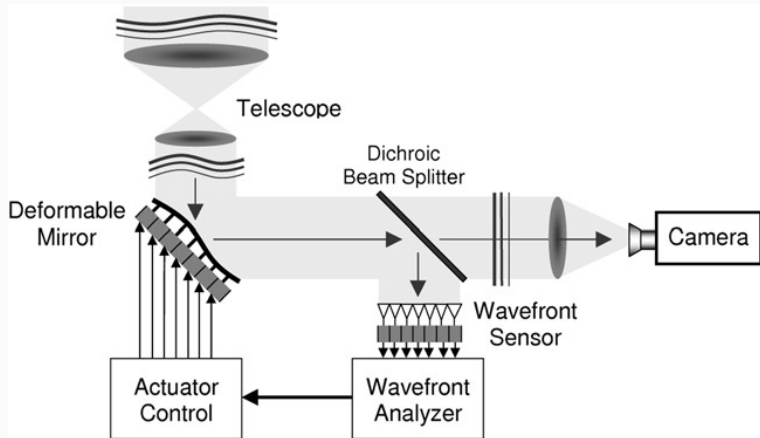


Light enters Earth's turbulent atmosphere



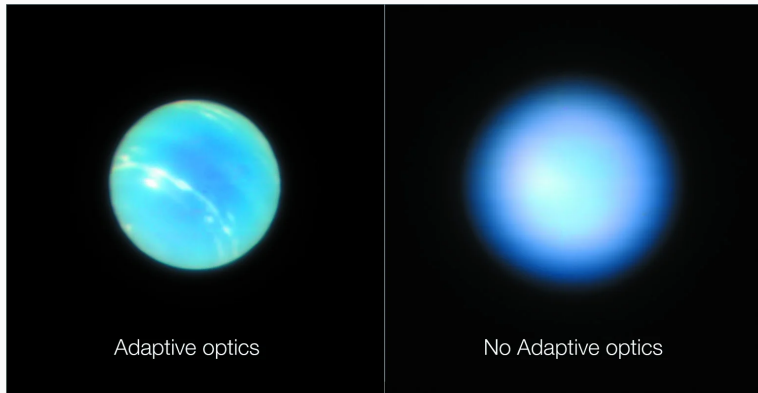
Sophisticated Engineering design of Telescope

Adaptive Optics



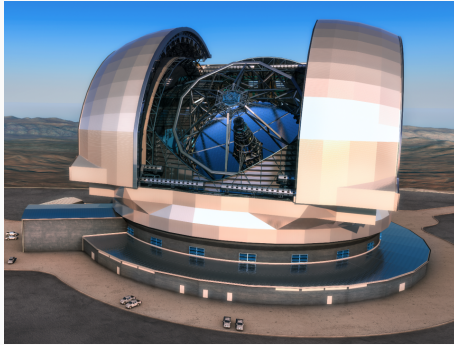
- Plane wavefronts are distorted due to Earth's turbulent atmosphere
- Need to correct through real time Control System
- Deform the shape of the mirror in microns for correction (10^{-6} m)

Adaptive Optics



- The images are much clear and sharper with Adaptive optics?
- AASE offers many elementary and advance courses on Controls
- AA216 : Flight Mechanics and Classical Control (Semester-IV)
- AA404 : Spacecraft Attitude Control and Dynamics (Semester VIII)

Next Generation Telescope



- Largest telescope today are 8m (diameter) class telescopes
- Next generation telescopes are 30 – 40 m class telescopes
- Indian Scientific community involved in TMT, SKA, SALT, uGMRT
- Very high precision Engineering is required!

Space Telescope



- James Webb Space Telescope, Hubble, Chandra, Euclid
- Indian : Astrosat, Aditya, Chandrayaan (series), Shukrayaan
- Need expert engineers to design and handle complex systems !

Elective Courses Offered by Space Engineering Department

- AA201 : An Introduction to Astronomy (Semester-III)
- AA203 : Introduction to Atmospheric and Earth Sciences (Semester-III)
- AA214 : Stellar and Planetary Science (Semester-IV)
- AA317 : Galaxies and Cosmology (Semester V)
- AA472 : Galactic and Extragalactic Astronomy (Semester VIII)

- AA216 : Flight Mechanics and Classical Control (Semester-IV)
- AA319 : Launch Vehicle and Propulsion Systems (Semester V)
- AA310 : Satellite Imaging (Semester VI)
- AA374 : Computational Fluids and Structures (Semester VI)
- AA404 : Spacecraft Attitude Control and Dynamics (Semester VIII)

- Many more courses are offered (Not an extensive list)