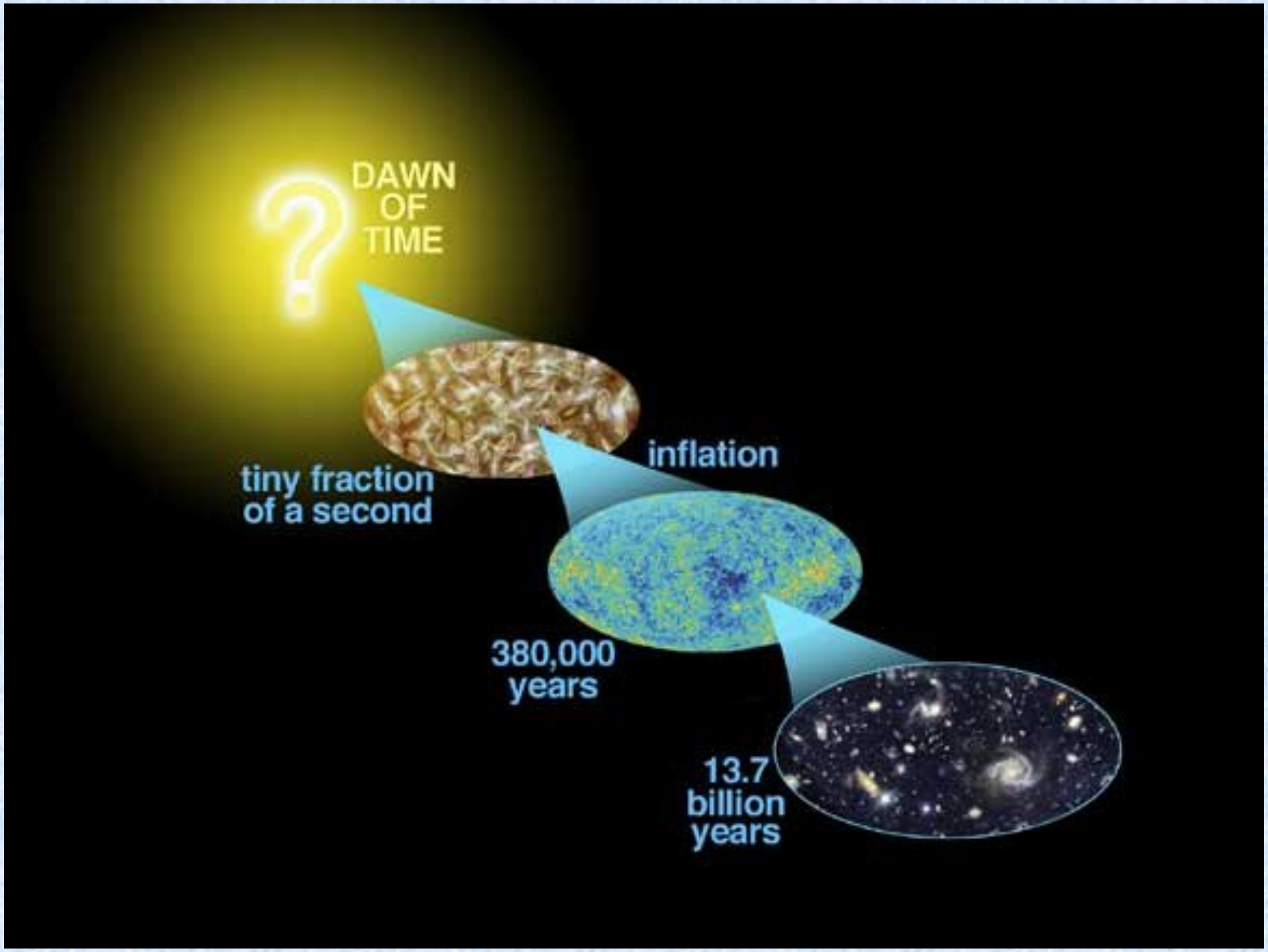
Physics 133: Extragalactic Astronomy ad Cosmology



Lecture 1; January 6 2014

Physics 133

- Instructor: Prof. Tommaso Treu
  - Lectures: MW 9:30-10:45 PHELP3519
  - Office hours: M 2:30 3:30 W 11:00-12:00 Broida 2015F
- TA: Mr. Jared Brooks
  - Office hours: TBD
- MIDTERM:
  - February 5 2014
- **FINAL EXAM: March 19 2014 8:00-11:00**

Physics 133

- Textbooks:
  - **Introduction to Cosmology**, Barbara S. Ryden
- Prerequisites: completion of the lower division physics series.
- Website: www.physics.ucsb.edu/~tt/PHYS133
- Power point files, homework, and reading assignments will be found on the website

Physics 133

- **Grading:**
  - 20% Homework
  - 20% Class participation
  - 20% midterm (Februrary 5 2014)
  - 40% final exam (March 19 2014 – 8-11AM)

Physics 133

- **Homework assigned on wednesday is due the next on Wednesday at 4:00PM (details from the TA)**
- **Class participation is essential. Ask questions! There are no stupid questions!!!**
- **Grades as in Table. There will be some renormalization to ensure grades are sensible**

A+	95%	C+	60%
A	90%	C	55%
A-	85%	C-	50%
B+	80%	D	40%
B	75%	F	<40%
B-	70%		

Physics 133


COSMOLOGY MARCHES ON
Where did it all come from?
Where did it all come from?
s. harris

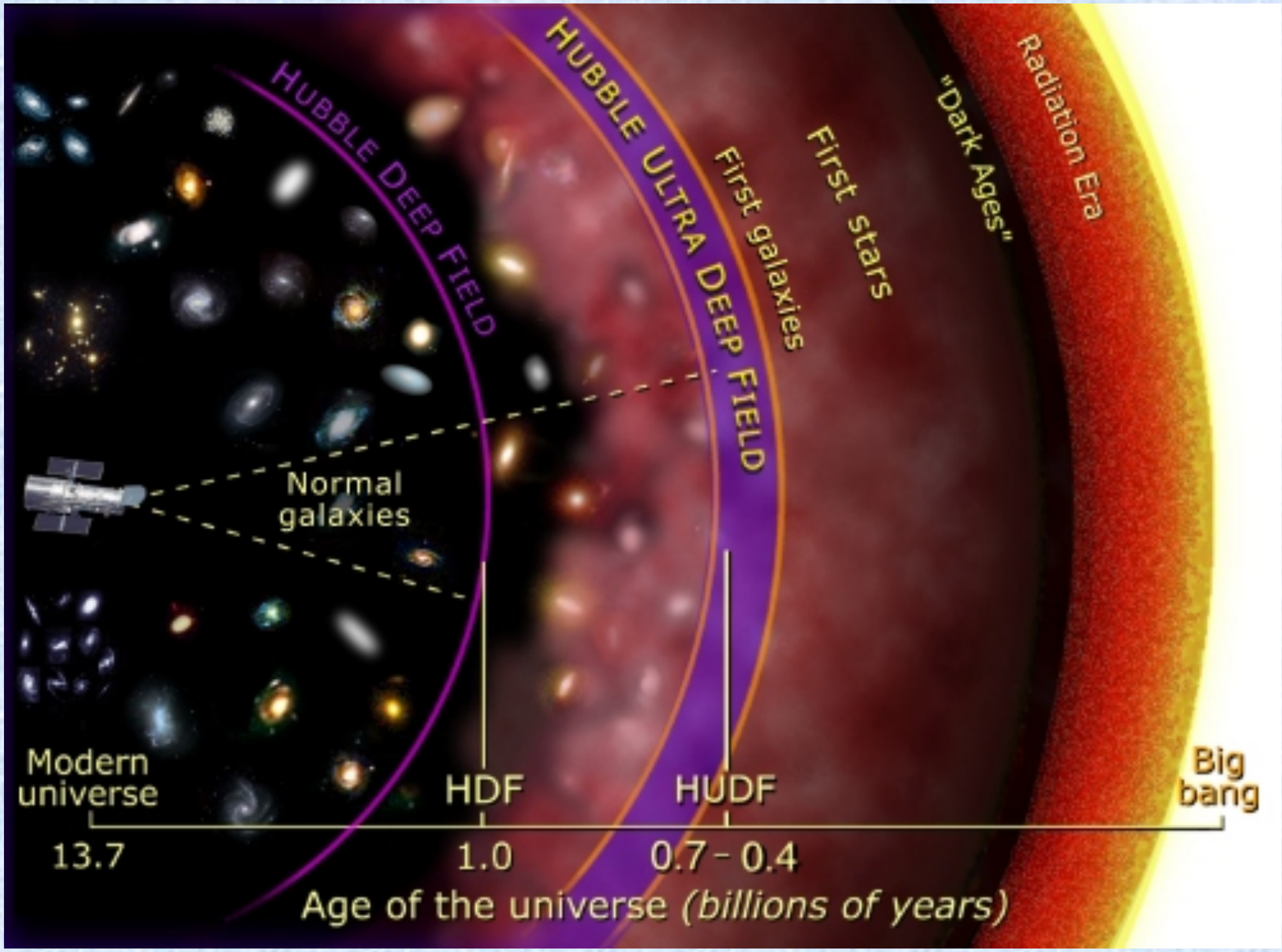
Physics 133: More big questions

- Is the Universe evolving?
- If so, how and when did it form?
  - How and when did galaxies and black holes form?
- How big/old is the universe?
  - What's the geometry of the Universe? Dynamics?
- Can we put together a physical model of the universe and its contents, capable of reproducing the observations and predicting falsifiable observations? The best we could come up so far is the so-called Standard Cosmological Model (by analogy with particle physics' Standard Model)

Physics 133

- Cosmology uses all the knowledge of physics that we learn from laboratory experiments
- Some of the most extraordinary discoveries in physics come from cosmology: dark matter and dark energy, just to name two
- The subject of the discipline is unique: we only have one Universe, we cannot replicate/alter/reproduce our "sample"
- We can only do experiments and measurements from one specific point in time and space

Physics 133: Tools of the trade – Telescopes as time machines



Physics 133: a golden era for cosmology

Physics 133: the role of observations

- **Experiments and Observations force us to modify/ change our view of the Universe. Examples:**
  - Galileo's observations of sun spots proved that the heavens are not time-invariant
  - Hubble's measurement of galaxy redshifts showed that the Universe is not static
  - High speed motions of stars in galaxies show that either we do not understand gravity or that there is a large amount of "dark matter", i.e. different stuff that the ones that makes you and me (and Earth)

Physics 133: a fundamental dilemma…

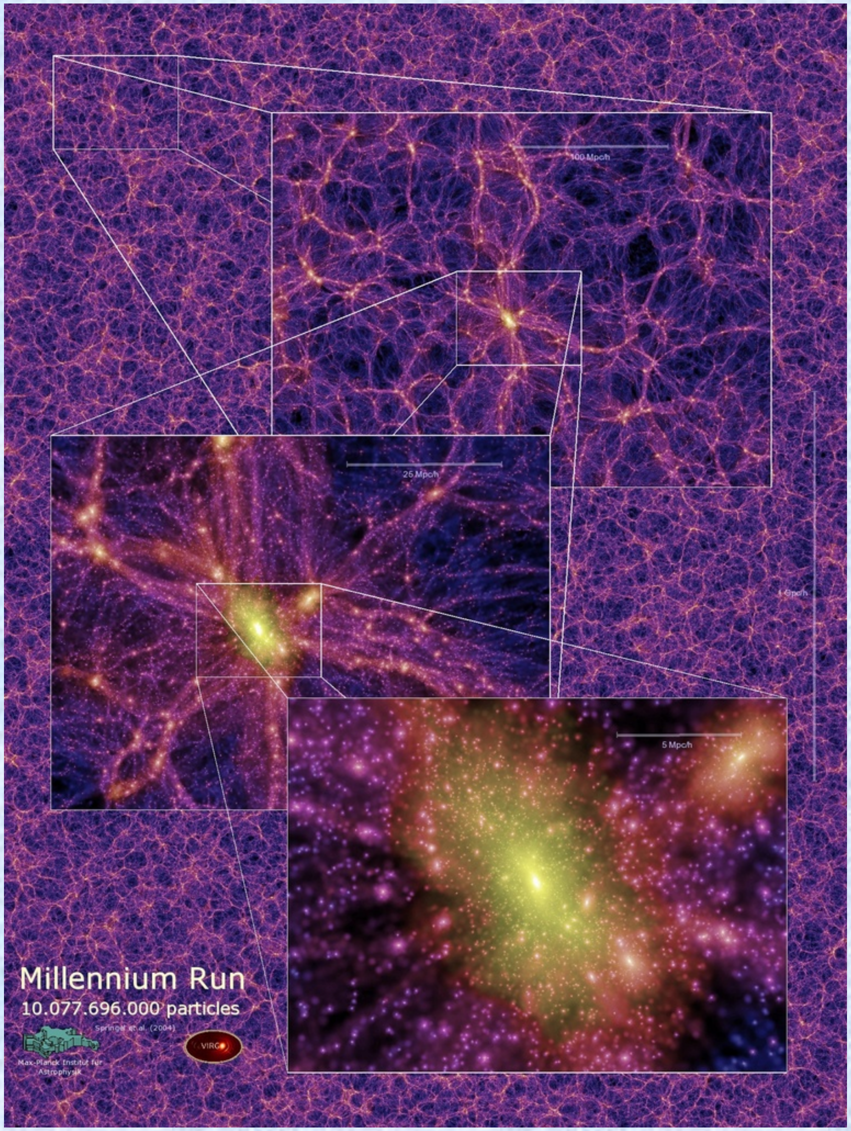
- Experiments and Observations can only be made from a very special point in space and time: Earth now.
- Yet we would like to construct a scientific theory that describes the universe everywhere and at all times.

Physics 133: … and its solution

- Physicists postulate a universal principle: our local sample of the universe is no different from more remote and inaccessible places
- This postulate is deeply rooted in two fundamental principles of physics:
  - The laws of physics (whatever they are!) do not depend on space and time
  - Physical explanations of natural phenomena should be as simple as possible (Ockham's razor)

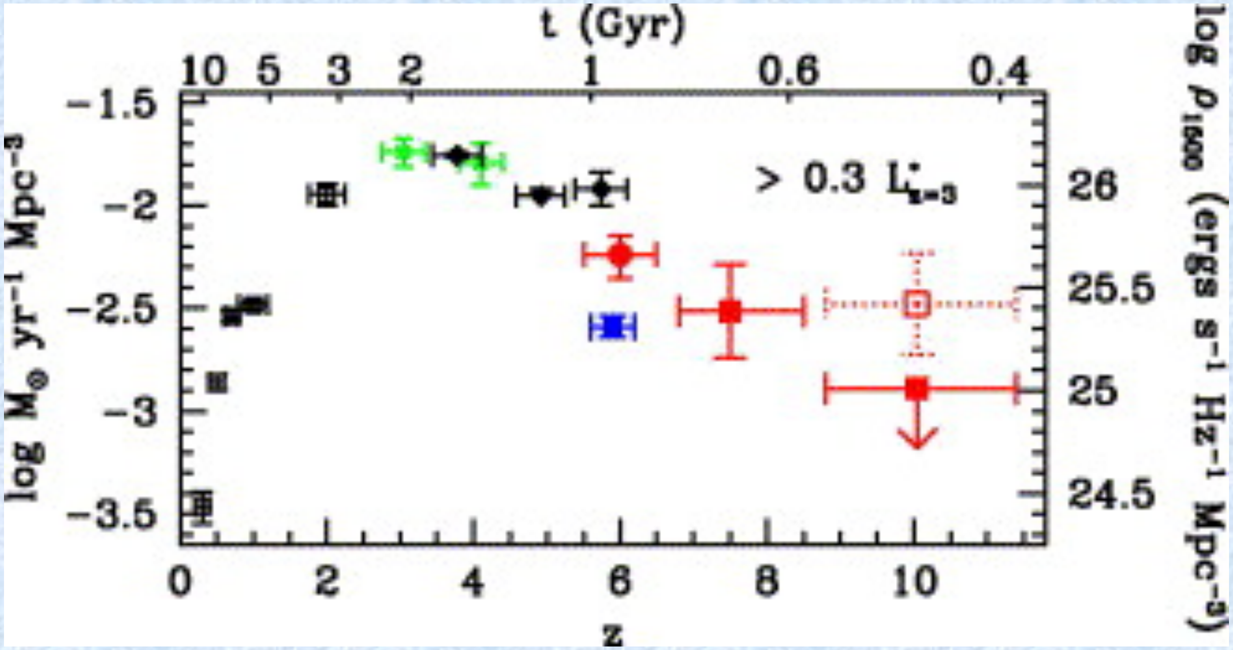
Physics 133: cosmological principles

- 1) Cosmological (Copernican) principle: the universe is homogeneous and isotropic



Physics 133: cosmological principles

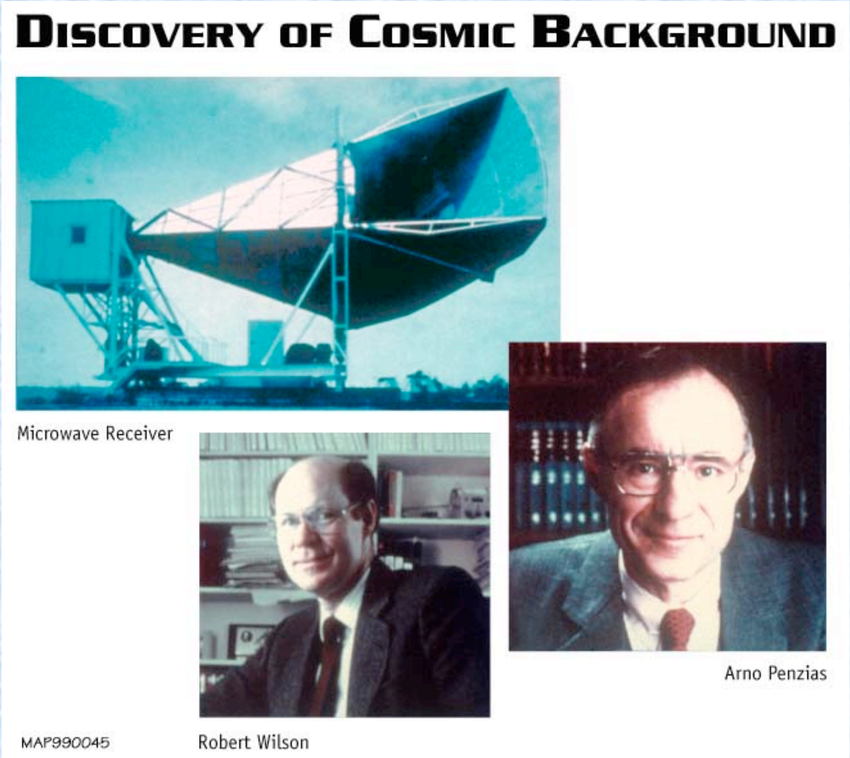
- 2) Perfect cosmological principle: The universe is homogenous, isotropic, and time-invariant



Inconsistent with observations!

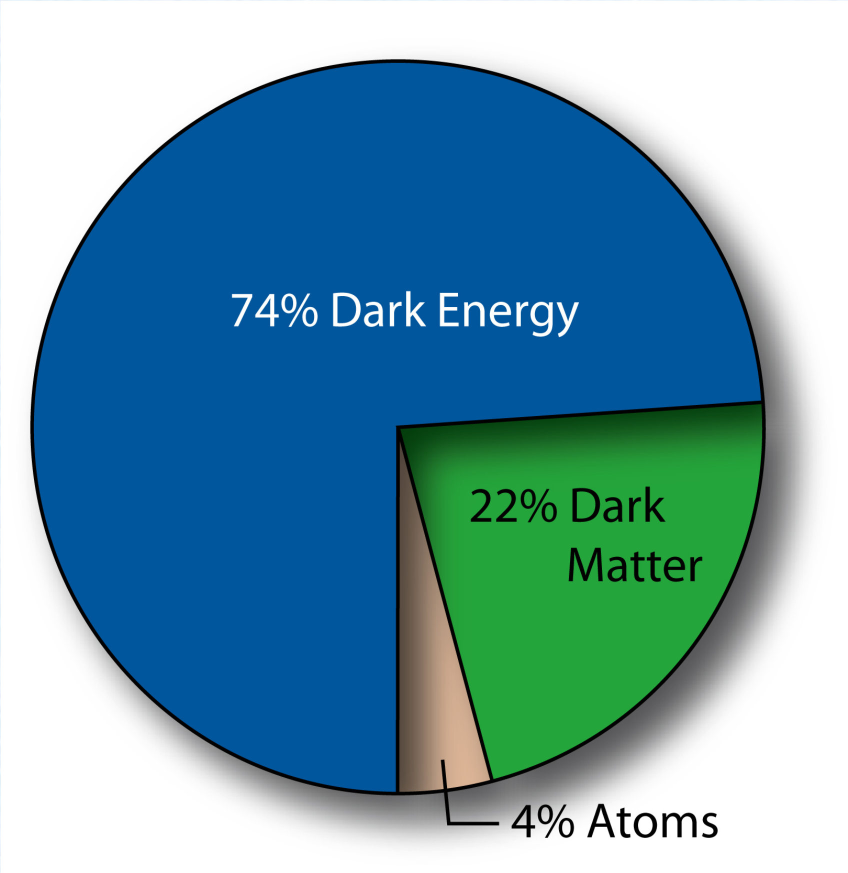
Physics 133: outline. Part 1

- Observational foundations of the Big Bang theory
  - Olbers' paradox
  - Homogeneity and isotropy
  - Hubble's Law
  - Composition of the Universe
  - Cosmic Microwave Background
- Geometry and gravity:
  - A brief introduction to general relativity



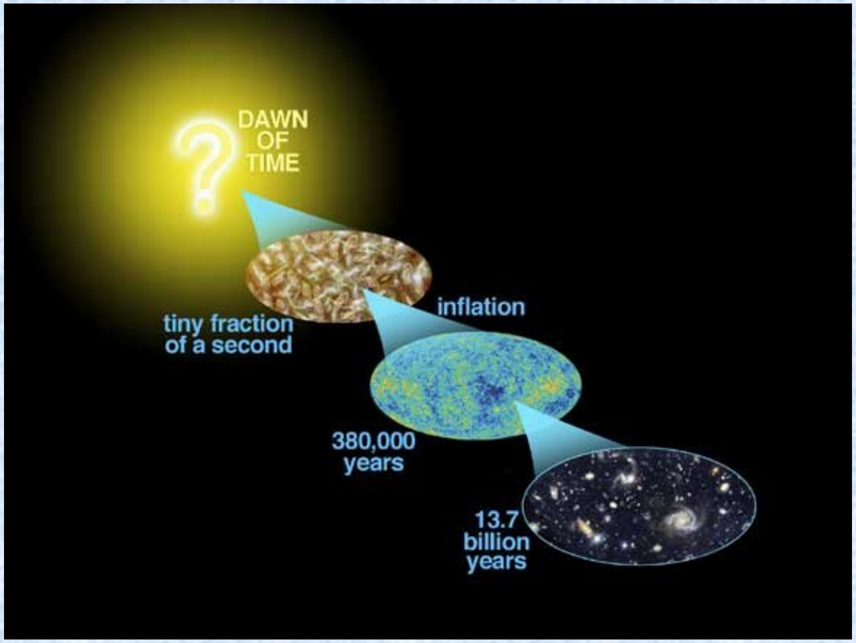
Physics 133: outline. Part 2

- Friedman-Lemaitre-Robertson-Walker Universe
  - Robertson-Walker metric
  - Cosmic Dynamics
  - Special cases and observables
  - Cosmography
    - Dark matter
    - Dark energy



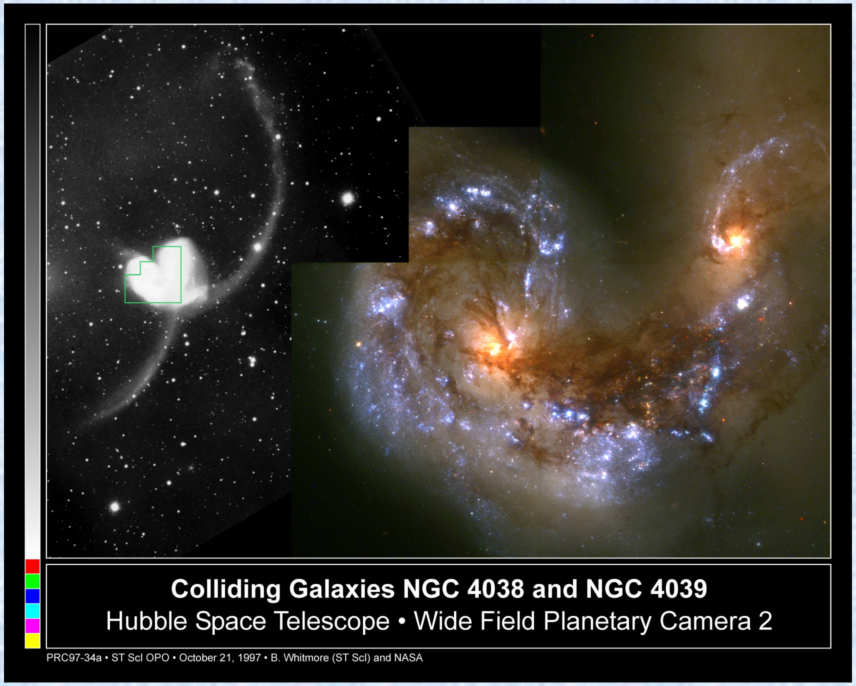
Physics 133: outline. Part 3

- The early universe:
  - Thermodynamics of the early Universe
  - Matter vs. antimatter
  - Bing bang nucleosynthesis
- Inflation
  - Problems of classic Big Bang
  - The inflationary solution



Physics 133: outline. Part 4

- The content of the universe:
  - The formation of structure
  - Galaxies
  - Clusters of galaxies
  - Supermassive Black holes



Units in astronomy. Length:

- Astronomical Unit (AU) = average distance Sun – Earth. ~1.5e11 m. Too small
- parsec (pc) -> kiloparsec (kpc), megaparsec Mpc (Mpc), Gigaparsec (Gpc)
  - 1pc = Distance at which 1 Astronomical Unit subtends an angle of 1 arcsecond (3.086e16 m)
- Examples:
  - Distance between stars in the solar neighborhood: pc
  - Size of a galaxy like the Milky Way: kpc
  - Distance between galaxies or size of clusters: Mpc
  - Distance of the most distant objects known: Gpc

Units in astronomy. Mass, Luminosity and Time:

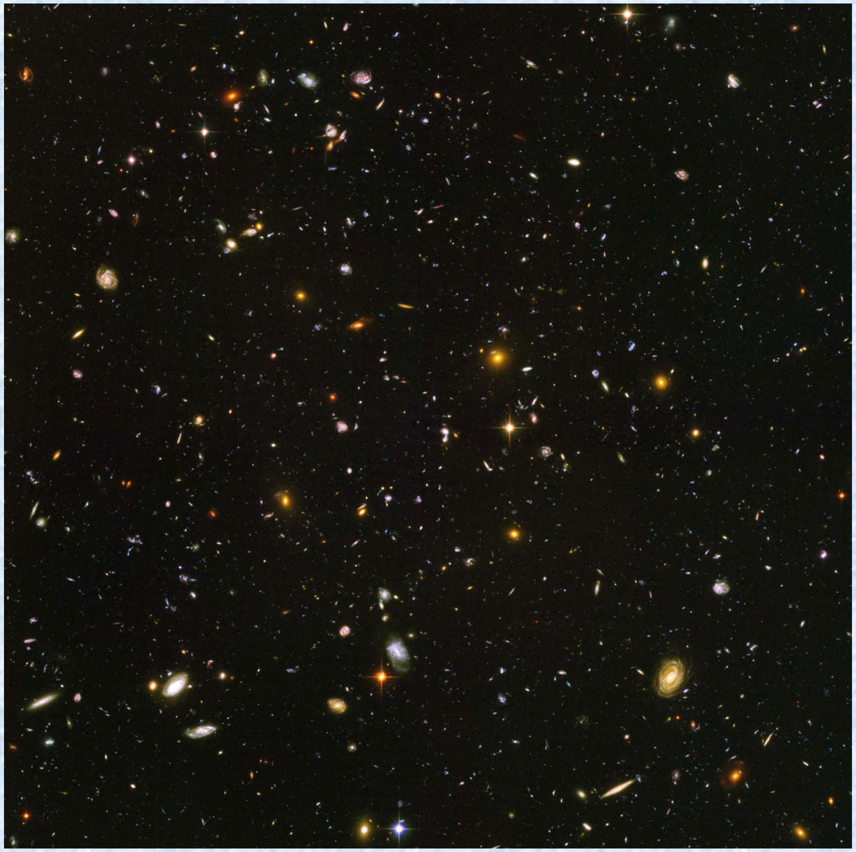
- **M. Solar mass: 1.98e30 Kg**
  - **A large galaxy is typically $10^{11\text{-}12}$ solar masses**
  - **A cluster is typically $10^{14\text{-}15}$ solar masses**
- **L. Solar luminosity: 3.8e26 watt**
  - **A large galaxy is typically $10^{10\text{-}11}$ solar luminosities (what does this mean in terms of mass to light ratio?)**
- **T. Period of Earth's orbit (yr): $\sim\pi\ 10^7$ s**
  - **Typically times are measured in Gyrs. The age of the Earth is 4.6 Gyr, the age of the Universe is 13.7 Gyr.**

Units in astronomy. Units from microscopic physics

- E. Energy: eV = 1.6e-19 J
  - Mass of the electron = 0.511 MeV
  - Mass of the proton = 938 MeV
- L. Angstrom: Å = 10e-8 m
- Planck units (combining fundamental constants):
  - $l_P=\sqrt{(G\ hbar / c^3)}$ = 1.6e-35 m
  - $M_P=\sqrt{(hbar\ c /G)}$ = 2.2e-8 kg
  - $t_P=\sqrt{(G\ hbar/c^5)}$ = 5.4e-44 s
  - (similary one can define Planck's energy and Temperature)

Olbers' paradox. The night sky

- The night sky is dark!!
- This apparently superficial statement (formulated by Heinrich Olbers in the early 1800s) has very profound consequences and is one of strongest pieces of evidence in favor of the big bang

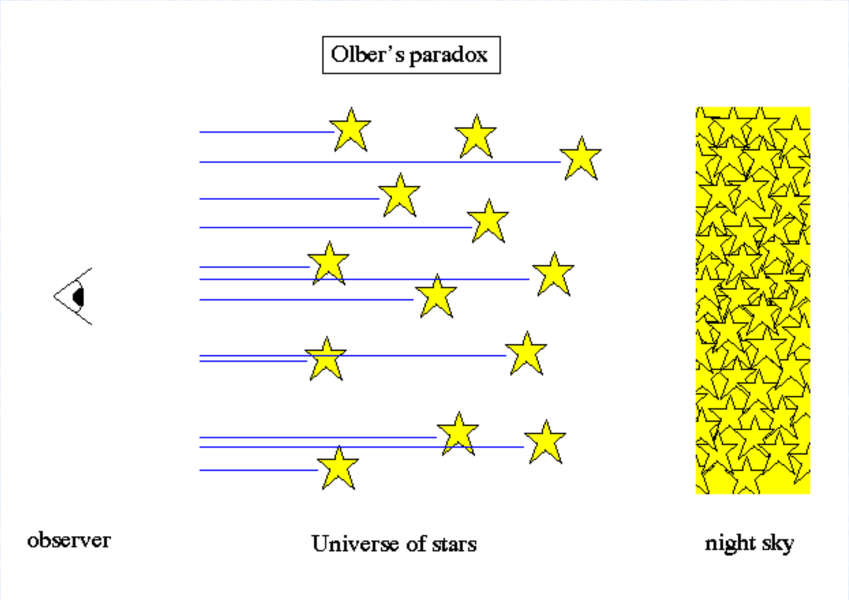


Olbers' paradox. A step back..

- Newton's model of the universe was:
- Eternal
- Infinite (otherwise it would collapse gravitationally)
- Flat Space
- Time independent of space

Olbers' s paradox. What does the sky look like in Newton' s model?

- For every line of sight sooner or later you find a star
- Surface brightness is independent of distance for a Euclidean flat space (draw on the blackboard)
- This would mean that the sky should have the same surface brightness of the sun, your average Joe star, e.g. the Sun...
- [Blackboard]

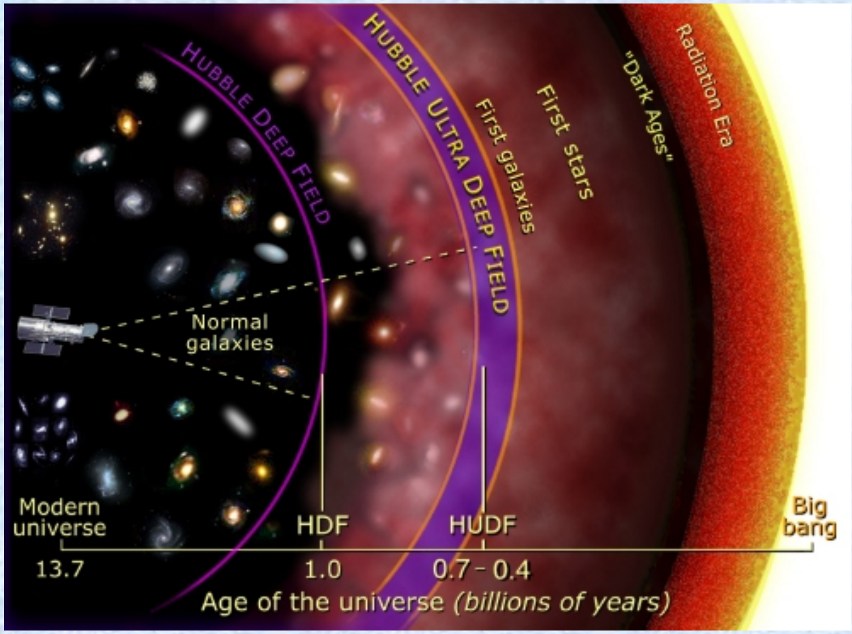


Olbers' paradox. Olbers' solution.

- Olbers postulated that the Universe was filled with an absorbing medium, like fog
- However, if light is absorbed it would heat up the medium, which would re-radiate, producing light albeit at different wavelengths, so this doesn't work!

Olbers' paradox.
The Big-Bang's solution

- In the Big Bang model the Universe is finite in TIME (13.7 billion years)
- This means that we can only see as far away as light has had time to travel
- Furthermore stars were not always shining (the sun for example is 4.5 Gyrs old).
- More later..



Olbers' paradox. Summary

- The night sky is dark
- This implies that the emission of starlight in the universe must be finite, in space, time or both.
- This is fundamental test for any cosmological model
- The Big-bang explains Olbers' paradox with the finiteness of the lifetime of the Universe and hence of its stars:
- The universe is NOT eternal in the past! The universe evolves!

The End

See you on Wednesday!